Coastal vulnerability assessment: a case study in Kien Giang, western part of the Mekong River Delta in Vietnam

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Abstract

Climate change, particularly sea-level rise, threatens low-lying coastal systems, such as small islands on coral atolls, and deltas where millions of people are living. The Mekong River Delta is considered especially at risk. Although most of the delta is only a few metres above sea level, there have been few assessments of vulnerability at local scale. The aim of this thesis is to provide quantitative and qualitative information to guide the process of adaptation and provide visualisations that will enhance local authority's decision making to adapt to climate change, particularly sea-level rise. It focuses on the seven coastal districts within Kien Giang province in the western, micro-tidal section of the delta. A framework is adopted that integrates biophysical effects and socioeconomic stressors for the case study area and consists of three main components of vulnerability: exposure, sensitivity, and adaptive capacity.

The analytical hierarchical process (AHP) method of multi-criteria decision making was integrated directly into a geographic information system (GIS) to derive a composite vulnerability index that indicated areas or hotspots most likely to be vulnerable to sea-level rise. The hierarchical structure comprised three components: exposure, sensitivity and adaptive capacity (level 1); and eight sub-components (level 2): seawater incursion, flood risk, shoreline change, population characteristics, landuse, as well as socioeconomic, infrastructure, and technological capability. The Digital Shoreline Analysis System (DSAS) tool was used to calculate rates of shoreline change along the Kien Giang coast over time in order to derive the shoreline change sub-component that contributed to the exposure component. Beyond this, a further 22 variables (level 3) and 24 sub-variables (level 4) related to vulnerability were also mapped. Based on the weights of variables derived from AHP pair-wise comparisons, a final map was generated to visualise areas reported into five categories of relative vulnerability; very low, low, moderate, high to very high vulnerability.

Several regional patterns emerged. Relatively high exposure to seawater incursion, flood risk, and moderate loss of mangroves characterised the coastal fringe of each district. Those areas

found to be most sensitive tended to have moderate population density, generally with a large rural population and high proportions of ethnic households with limited availability of agricultural land. Many aspects of adaptive capacity could only be represented at district scale, with the least adaptable areas consisting of large proportions of poor households, low income, and moderate densities of transport, irrigation, and drainage systems. Finally, most coastal districts were determined to be of moderate to relatively high vulnerability, with scattered hotspots along the Kien Giang coast, which coincided with settlement areas.

The results obtained, enable identification and prioritisation of the areas, or hotspots most likely to be vulnerable, for which site-specific assessments might further assist the local authorities and communities in better coastal management and conservation. However, the limitations of data accessible at an entire district can influence the outcome. Social vulnerability remains a challenge because it is changing over time and space.

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List of Abbreviations and Acronyms

IPCC	The Intergovernmental Panel on Climate Change
SRES	Special Report Emissions Scenarios
CM-IPCC	IPCC Common Methodology (1991)
TAR-IPCC	IPCC Third Assessment Report (2001)
AR4-IPCC	IPCC Fourth Assessment Report (2007)
AR5-IPCC	IPCC Fifth Assessment Report (2014)
E	Exposure component
S	Sensitivity component
PI	Potential impacts
A	Adaptive capacity component
V	Vulnerability
MRC	Mekong River Commission
MRD	The Mekong River Delta in Vietnam
KGI	Kien Giang province
HTI	Ha Tien district
KL	Kien Luong district
HD	Hon Dat district
RGI	Rach Gia district
CT	Chau Thanh district
ABI	An Bien district
AMI	An Minh district
FAO	Food and Agriculture Organisation of the United Nations
UNESCO	Educational, Scientific and Cultural Organisation of the United Nations
MONRE	Ministry of Natural resources and Environment of Vietnam
ASS	Acid sulphate soils
Ppt	Parts per thousand, ‰

LU	Landuse
SXN	Agricultural production land
LNP	Forestry land
CDG	Specially used land
OTC	Homestead land
SRTM	Shuttle Radar Transfer Mission
DEM	Digital Elevation Model
MSL	Mean Sea Level
Ka BP	Kilo-annum (as in thousand years) before present
GIZ	German Society for International Cooperation
IMHEN	Vietnam Institute of Meteorology, Hydrology, and Environment
SIWRP	The Southern Institute for water resources planning of Vietnam
GSO	General Statistics Office Of Vietnam
MARD	Ministry of Agriculture and Rural Development of Vietnam
DARD	Department of Agriculture and Rural Development
Sub-FIPI	The Southern Sub- Institute of Forest Inventory and Planning
MOT	Ministry of Transport of Vietnam
ICOE	The Institute of Coastal and Offshore Engineering
MOC	Ministry of Construction of Vietnam
NASA	The National Aeronautics and Space Administration of the United States
USGS	The United States Geological Survey
DSAS	Digital Shoreline Analysis System
EPR	The end point rate, m/year
NSM	The net shoreline movement, m
LRR	The linear regression rate
GIS	Geographic information systems
MCDM	Multi-criteria decision making

AHP	The analytical hierarchy process
A	The pair-wise comparison matrix of order n (n by n matrices)
w	The vector weights (or priorities)
λ_{max}	The largest eigenvalue of the matrix *A*
CI	The consistency index
RI	The random consistency index
n	Numbers of variables
CR	The consistency ratio
MB	ModelBuilder
SI	Seawater incursion sub-component
Si	Seawater incursion variable, ppt
St	Soil type variable
FR	Flood risk sub-component
Fd	Flood depth variable, m
El	Elevation variable, m above MSL
SC	Shoreline change sub-component
Sd	Shoreline displacement variable
Al	Coastal adjacent landuse variable
LU	Landuse sub-component
SF	Societal factors sub-component
Pd	Population density variable, inhabitants/ km^2
Ru	Rural people variable, %
Et	Ethnic minorities group variable, %
Fe	Female people variable, %
SO	Socioeconomic sub-component
In	Income variable, US$/capita/yr
Ed	Education variable
Ps	Pupils per primary and secondary school sub-variable
Pt	Pupils per teacher at primary and secondary school sub-variable
Kk	Kids per kindergarten sub-variable

Kt	Kids per teacher at kindergarten sub-variable
He	Health variable
Ht	Inhabitants per health establishment sub-variable
Hs	Inhabitants per health staff sub-variable
Po	Poverty ratio variable, %
TE	Technological sub-component
Id	Irrigation and drainage variable
Ca	Canal capability sub-variable
Se	Sea dyke capability sub-variable
Ri	River density sub-variable
Re	River embankment capability sub-variable
Sg	Sluice gate capability sub-variable
Ey	Electricity variable
Pl	Voltage power line density sub-variable
Ts	Transformer station density sub-variable
IN	Infrastructure sub-component
Ho	Households having solid houses variable, %
Rd	Road capability variable
Te	Communication access variable

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Chapter One

Introduction

1.1 Impacts of climate change, particularly sea-level rise

Coastal systems are increasingly threatened by potential impacts as a result of climate change, as indicated by successive assessments by the Intergovernmental Panel on Climate Change (IPCC). The most widespread risks foreshadowed for coasts are accelerated coastal saline incursion into coastal waterways and water tables, increased inundation of low-lying areas, and shoreline erosion (Abuodha and Woodroffe, 2006b; Nicholls, 2007; Nicholls and Tol, 2006; Nicholls et al., 2008; Nicholls et al., 2007). Vulnerability of coastal areas to sea-level rise is a function of global environmental changes and socioeconomic development (AR5-IPCC, 2014; David et al., 2008). Additionally, a large proportion of the population lives along the coast, and there is widespread migration towards coasts (Nicholls et al., 2007).

Low-lying areas, particularly coastal systems, small islands, coral atolls, and deltas, are most at risk to sea-level rise. The Mekong River Delta in the south of Vietnam is considered in global analyses to be one of three deltas, comprising Nile, Ganges Brahmaputra, and Mekong, which are extremely vulnerable (Nicholls et al., 2007; The-First-Scenarios-VN, 2009) (see Figure 1.1a). Shuttle Radar Transfer Mission (SRTM) data indicate that the Mekong River Delta (MRD) is especially low-lying, with more than 70% of the delta plain less than 4 m above mean sea level (MSL) (Woodroffe et al., 2006). It is vulnerable to flood risk, seawater incursion, and shoreline change, exacerbated as a consequence of sea-level rise. Having the second highest ecological diversity (with the highest occurring in the Amazon), the MRD is home to nearly 18 million people (GSO, 2012); it comprises 13 provinces, seven of which are coastal provinces. The staple food of the Vietnamese people is rice, from 51.3% (GSO, 2000) to 55.6% (GSO, 2012) of which is produced in the MRD. There is an urgent need to assess the vulnerability of the MRD to impacts of climate change, particularly sea-level rise, due to this socioeconomic and ecological importance.

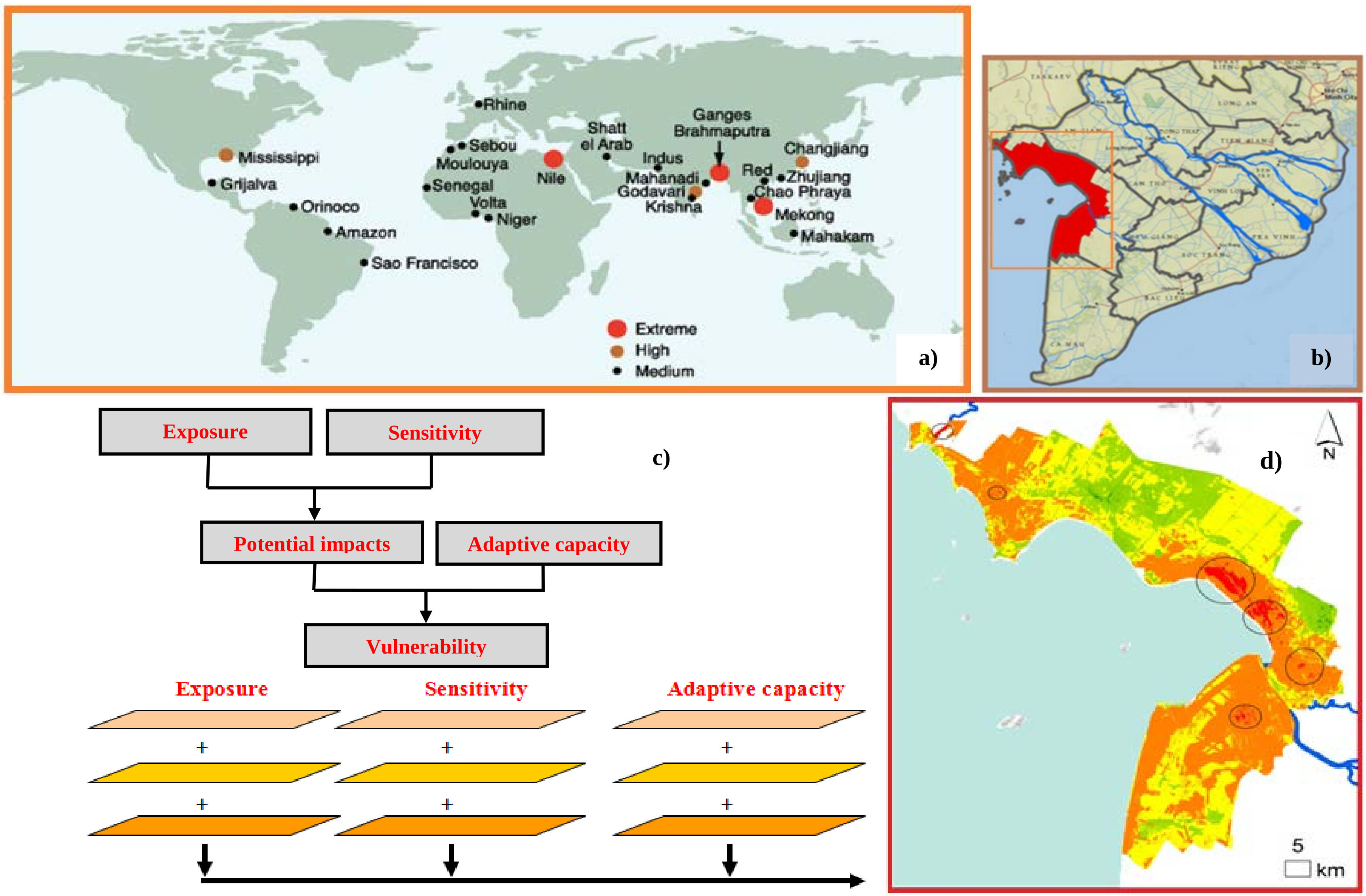


Figure 1.1 Diagram of conceptualisation of the vulnerability: scale-based approaches for the Mekong River Delta a) at global scale; b) at regional scale (as an entire delta), and at local scale (as the study area) indicated by red colour; c) an adopted framework for assessing the vulnerability; and d) mapping of the vulnerability levels for the study area as developed in this thesis (after Figure 6.14d).

A review of recent literature reveals that, despite the threat of sea-level rise to low-lying areas, especially deltas, there have been few assessments of vulnerability at local scale (see a summary of Appendix 1 presented in chapter 2, sub-section 2.6); instead most are focused on global, national, and regional scales. This is believed to be the first study in Vietnam to attempt to combine aspects of the physical nature of the coast and human pressures into an index that captures the vulnerability of specific study sites at the local scale (see Figure 1.1b).

To fully define vulnerability, it is good practice to specify: 1) the entity that is vulnerable; 2) the stimulus to which it is vulnerable; and 3) the preference criteria to evaluate the outcome of the interaction between the entity and the stimulus (Ionescu et al., 2009). There is ongoing debate in the literature on the value of quantitative versus qualitative approaches (e.g., from strictly quantitative to quantitative and qualitative analyses, or a relative measure rather than something that can be expressed in absolute terms) to vulnerability assessment at different scales. Several authors have argued that vulnerability is a relative measure rather than something that can be expressed in absolute terms (Rothman and Robinson, 1997; Downing et al., 2001; Fussell and Klein, 2006). The purpose of vulnerability assessment is increasingly recognised as not only about producing reliable quantitative information and visualisation but also capturing qualitative information and contributing to deliberative decision making (Lorenzoni et al., 2000; Kasperson and Kasperson, 2001; Liverman, 2001; Luers et al., 2003; Eakin and Luers, 2006). However, a number of terms used in this thesis, such as "exposure", "sensitivity", "potential impacts", "adaptive capacity" and "vulnerability" have been used in differing ways in relevant literature. This necessitates clear definition of terminology used here. Figure 1.1c illustrates a framework that will be adopted in this thesis for vulnerability assessment, comprising three key components.

- *"Exposure"* refers to the nature and amount to which the system is exposed to climate change phenomena.
- Whereas *"sensitivity"* reflects the system's potential to be affected (adversely or beneficially) by such changes.
- And *"adaptive capacity"* describes the system's ability to change (autonomously or according to planned measures) in such a way as to maintain (totally or at least partially) its main functions in the face of external changes.

1.2. The coastal district scale

In Vietnam, more attention has generally been placed on responses to natural disasters and climate change mitigation rather than climate change adaptation (APN, 2007). There have been few assessments related to climate change in the MRD, with less effort directed to the western part than the eastern part of the delta. This is thought to be the first study to construct a coastal vulnerability index, comprising the three components: exposure, sensitivity, and adaptive capacity, and to quantify and visualise areas vulnerable to potential impacts of sea-level rise. Seven coastal districts along the Kien Giang coast have been considered in this case study to demonstrate their vulnerability. The study area has a coastline that is over 200 km in length, comprising thin mangrove fringes, located far from the mouths of the main rivers that experience only small influences from the Bassac River. It contains a high population density, and is undergoing conversion from intensive traditional agriculture to fishery activities, tourism and other service industries.

1.3 Research statement

An assessment of vulnerability to climate change is the process of identifying, quantifying, and prioritising the vulnerabilities in a system. Importantly, vulnerability assessments also seek to highlight capacities. Vulnerability assessments are designed as decision support tools for a wide range of stakeholders. It is important to identify objectives early in this process as they help determine the level of detail required in the analysis and the data and products that might be needed. Also, objectives deeply influence the scope and methodology of assessments. Unfortunately, data availability can be a limiting factor in the study scope. In some cases, necessary data may be in multiple databases or in different formats and may require significant effort to merge the information into a usable format. The framework around which this thesis is designed is outlined in Figure 1.2, and comprises the research objectives, scope, methods, processing of results, discussion, and recommendations for further vulnerability assessments.

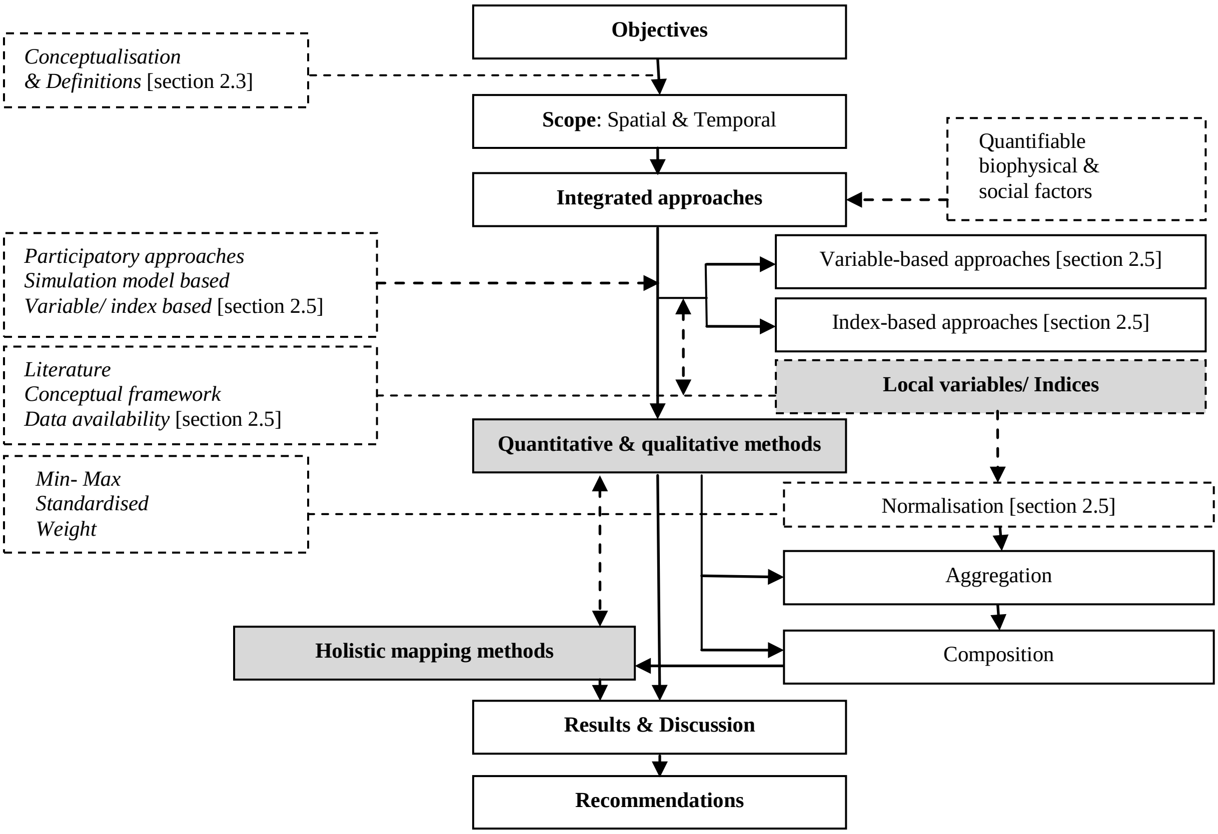


Figure 1.2 Framework indicating the design of this thesis.

1.3.1 Aims and objectives

The overall aim of this thesis is to identify and prioritise the areas in Kien Giang most likely to be vulnerable to adverse effects of climate change, particularly sea-level rise. After reviewing the literature, it was determined that a multi-criteria decision making (MCDM) approach, visualised using geographical information systems (GIS), was most appropriate for site-specific assessments to assist the local authorities and communities with coastal management and conservation. The specific stages of this thesis are as follows:

- Set up a framework that integrates the effects of biophysical and socioeconomic stressors with regards to three main components of vulnerability: exposure, sensitivity, and adaptive capacity at a local scale; and determine variables within the hierarchical structure.
- Examine pair-wise comparisons of variables by applying the analytical hierarchy process tool (AHP), and one MCDM technique for the assessment, and coupled with GIS in order to obtain the outcome.
- Evaluate the outcomes obtained from scale-based approaches.
- Make recommendations based on the lessons learnt from the case study assessment.

1.3.2 Thesis structure

The thesis consists of seven chapters (see Figure 1.3).

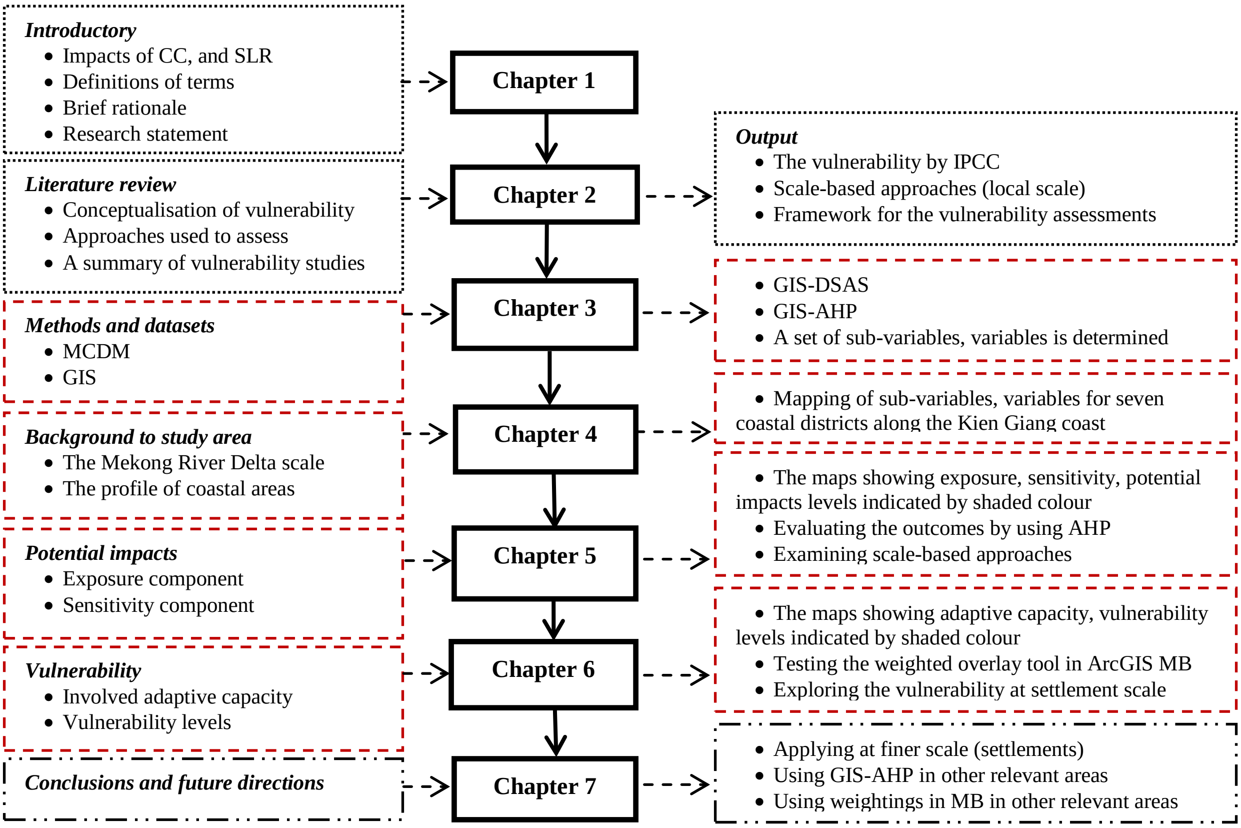


Figure 1.3 A diagram of the thesis structure.

Chapter 1 outlines the research objectives for the study.

Chapter 2 comprises a literature review of coastal vulnerability studies and describes approaches that have been used to assess vulnerability of coasts to the impacts of climate change. This chapter provides a brief summary of the concept of vulnerability, and reviews the development of vulnerability indices to assess coastal vulnerability, and approaches to holistic scale-based vulnerability mapping, using case studies of selected areas at local scales.

Chapter 3 describes the methods used for the site-specific vulnerability assessments. This chapter outlines the conceptual framework for assessments. Multi-criteria and holistic mapping approaches are described that can be used to develop a final composite vulnerability index, comprising three key components: exposure, sensitivity, and adaptive capacity. The results obtained enable identification and prioritisation of the areas most likely to be vulnerable.

Chapter 4 provides background to the seven coastal districts along the Kien Giang coast, a western part of the Mekong River Delta in Vietnam, which are used as case studies in this assessment.

Chapter 5 describes the exposure and sensitivity, and their combination into potential impacts for the study area using ArcGIS Spatial Analyst tools and the AHP tool. Six variables were used in three sub-components to derive the exposure component, while eleven sub-variables were combined into seven variables to derive two sub-components to indicate the sensitivity component. The exposure and sensitivity components were aggregated to indicate potential impacts. AHP is based on subjective judgments, therefore, the priorities of variables requires consideration. In addition, scale-based approaches are also demonstrated.

Chapter 6 describes the adaptive capacity and the overall vulnerability of the study area. Thirteen sub-variables were combined into nine variables to derive three sub-components that represent adaptive capacity. Finally, exposure, sensitivity and adaptive capacity were aggregated to derive a visual representation of the vulnerability of areas. The influence of the relative weightings assigned was examined using the weighted overlay tool in ArcGIS ModelBuider (MB) to test the vulnerability outcomes. A preliminary examination of vulnerability assessment at the settlement scale was also undertaken.

Finally, chapter 7 outlines the key contributions of this study, and identifies future directions for further coastal vulnerability studies.

Chapter Two

Literature review

2.1 Aims of this Chapter

This chapter reviews the literature related to coastal vulnerability and describes approaches that have been used to assess vulnerability of coasts to the impacts of climate change. The following specific topics are discussed in this chapter:

1. The conceptualisation of vulnerability.
2. Approaches and methodologies used to assess vulnerability of coasts to the impacts of climate change.
3. The development of vulnerability indices to assess coastal vulnerability to impacts of climate change, particularly sea-level rise, and approaches to holistic vulnerability mapping with case studies of several areas at local scale.

2.2 Introduction

Sea-level rise associated with climate change is globally considered to be a serious threat, particularly for low-lying and densely populated areas (Bigano et al., 2008; Bindoff et al., 2007). The coast appears to be one of the most vulnerable areas to potential impacts of climate change, particularly because of anticipated future sea-level rise.

In fact, the coastal zone is an important natural resource system, which provides space, as well as living and non-living resources for human activities. Being easily accessible, the coastal zone has been inhabited by people from the early days of civilisation. Past fluctuations of sea levels have been significant factors in the evolution of cultures on a historical time scale (Emery and Aubrey, 1991). Civilisations have founded or expanded as relative sea levels have shifted. The coastal zone is currently a focal point in many national economies with a large number of social and economic activities concentrated in this area.

The importance of the coastal zone will further increase in future, due to the ever-increasing number of people who live there. Adger et al. (2005) indicate that 1.2 billion people, which accounts for 23% of the world's population, now live within 100 km of the coast, and about

50% of the world's population are likely to do so by 2030. While living near the coast is advantageous, it also exposes the inhabitants to an increasing number of detrimental impacts of climate change, with elevated water levels becoming more frequent and severe due to intensively aggregated human activities. There is a need, therefore, to assess coastal vulnerability to impacts of climate change. Methodologies for assessing vulnerability, as widely suggested by the IPCC since the CM-IPCC (1991), needs to consider both biophysical and social aspects, and their mutual interaction to adequately set up relevant adaptation policies for sustainable development.

2.3 The conceptualisation of vulnerability

The initial scientific use of "*vulnerability*" has its roots in geography and natural hazards research, but now this term is a central concept in a variety of research contexts related to natural impacts, such as salinity incursion, drought, bushfire, flooding and inundation, erosion and sedimentation, as well as social effects, such as poverty, famine, and landuse change (Füssel, 2007). Adger (1999) and O'Brien and Leichenko (2001) indicate that vulnerability is not an outcome, but rather a state or condition of being, and a very dynamic one at that, moderated by existing inequities in resource distribution and access, the control individuals can exert over choices and opportunities, and historical patterns of social domination and marginalisation. A brief review of general definitions of vulnerability is given below.

White (1974), about 40 years ago, indicated that "*vulnerability is the degree to which a system, sub-system, or component is likely to experience harm due to exposure to a hazard, either a perturbation or stress*". Later, Timmermann (1981) hypothesised that "*vulnerability is a term of such broad use as to be almost useless for careful description at the present, except as a rhetorical indicator of areas of greatest concern*". Liverman (1990) noted that vulnerability "*has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk*". Other concepts such as exposure, sensitivity, coping capacity, criticality, and robustness could have easily been added to this list (Füssel, 2007). It is apparent that there is no single optimal definition of vulnerability that would fit all assessment contexts. It is important to note that the diversity of definitions can be considered as a primary consequence of the term "*vulnerability*" being used in different policy contexts, referring to different systems exposed to different impacts.

Accordingly several authors have emphasised that the term "*vulnerability*" can only be considered meaningfully with reference to a specific vulnerable situation (Brooks, 2003; Downing and Patwardhan, 2004; Füssel, 2007; Hinkel and Klein, 2007; Luers et al., 2003; Metzger et al., 2005). The following four fundamental dimensions can be used to describe a *vulnerable situation*:

- The *system* that is subject to analysis, such as an integrated human-environment system, a population group, an economic sector, a geographical region, or a natural system.
- The valued *attributes of concern*, which might include for example human lives and health, the existence, income and cultural identity of a community, and the biodiversity, carbon sequestration potential and timber productivity of a forest ecosystem.
- The *hazard*, which refers to a potentially damaging influence on the system.
- A *temporal reference*, which refers to the point in time or time period of interest, (e.g., current vs. future vs. dynamic) (Füssel, 2007).

A clear description of the vulnerable situation is an important first step to avoid confusion concerning vulnerability. On the other hand, different classifications of vulnerability by scientists from different disciplines or with varying perceptions produce different interpretations of the term "*vulnerability*".

Several researchers distinguish bio-geophysical or natural vulnerability from social or socioeconomic vulnerability, (e.g., biophysical vs. social), even though there is little agreement on the meaning of these terms (Adger, 1999; Brooks, 2003; Cutter, 1996; Cutter et al., 2003; Klein and Nicholls, 1999; McLaughlin and Cooper, 2010; McLaughlin et al., 2002; Soares et al., 2012). Other classifications have been suggested; for example, the United Nations (2004) suggest including physical, economic, social, and environmental factors; Moss et al. (2001) suggest including physical-environmental, socioeconomic, and external assistance dimensions; and Fekete et al. (2009) suggest including ecological, social, economic, political and technological aspects.

In general, vulnerability approaches to biophysical conditions are largely based on the natural hazards approach and focus on the distribution of hazardous conditions, human occupancy within hazardous areas, and the degree of loss related to a specific hazardous event (Cutter, 1996; Dow, 1992). The focus is therefore upon the degree of risk and exposure to hazard, which determines the level of vulnerability, and issues such as magnitude, duration, and

impact of the climatic event. These approaches are also known as risk-hazard approaches (Eakin and Luers, 2006; Turner et al., 2003) or impact-driven studies (Ford et al., 2010). Based on these approaches, vulnerability is regarded as an "end-point", (i.e., the outcome of climate change impacts minus adaptation) as its main purpose is generally to provide an understanding of climate change impacts and inform decision-making regarding the costs of adaptation or the costs of mitigation (O'Brien et al., 2007). However, although capable of providing an overall understanding of the physical processes generating exposure, this perspective is limited as it excludes the social, economic, political and cultural factors that need to be addressed in the estimation of vulnerability (Cardona, 2004). From a social perspective, vulnerability is conceived as a socially constructed phenomenon resulting from particular social, political, historical and economic processes and structures that influence social systems, (i.e., individuals, communities, groups) which can lead them to vulnerable conditions (Adger, 1999; Brooks, 2003; Cutter, 1996; Liverman, 1990).

Integrated approaches to vulnerability, also known as synthetic or hybrid approaches, aim to address both the biophysical and social dimensions of vulnerability (Eakin and Luers, 2006; Fussel and Klein, 2006). The process of conceptual integration is pursued by merging concepts from different views on vulnerability (Newell et al., 2005). However, the integration of different conceptual backgrounds (e.g., biophysical and social perspectives) can be problematic, as it requires working with and combining different ways of framing and performing the analysis of vulnerability. The current paradigm in the analysis of climate change vulnerability combines the two conventional perspectives on vulnerability, (i.e., biophysical and social systems), and is perceived to provide a more comprehensive understanding of the multiplicity of processes and dynamics affecting vulnerability of the coupled system (i.e., biophysical and social systems) to climate change (Soares et al., 2012). This is particularly important in the context of policy-driven assessments aiming to provide measures to inform adaptation policy towards reducing vulnerability to climate change (Fussel and Klein, 2006). It provides an extensive conceptual and analytical platform by allowing the integration and application of different conceptual backgrounds as well as a range of methods and tools which have the potential to complement each other and improve the information provided (Mastrandrea et al., 2010).

Numerous researchers distinguish an internal and an external aspect to vulnerability to environmental hazards (Blaikie et al., 1994; Bohle, 2001; Chamber, 1983; Chambers, 1989;

Ellis, 2000; Kasperson et al., 2000; Pielke Sr and Bravo de Guenni, 2003; Sanchez-Rodriguez, 2002; Turner et al., 2003; Watson et al., 1996). In terms of the social vulnerability, studies are concentrated on the social dimensions following the tradition of analysis of vulnerability to hazards, such as population, poverty, food insecurity, and as a dimension of entitlements. This is in contrast to the predominant views on vulnerability to the impacts of climate change which emphasise the physical dimensions of the issue (Adger, 1999; Cutter, 1996). Thus, the focus is drawn to social systems and vulnerability is conceived as having two sides: an external side encompassing the perturbations and shocks the system is subjected to, and an internal side that includes the system's own capacity to cope and respond to hazardous events (Chambers, 1989; Chambers, 2006). As a result, issues such as resilience, sensitivity, resistance, and coping capacity are common elements in these types of studies (Dow, 1992). In this perspective, vulnerability is perceived as the "starting-point" of the analysis where it is considered as a dynamic state resulting from social, environmental, political, and economic processes (O'Brien et al., 2007). This perspective is also known as contextual vulnerability (Ford et al., 2010). Cardona (2004) considered that some of the studies using this perspective have only provided a limited understanding of vulnerability by overemphasising the social and political structures and processes generating vulnerability and by neglecting the hazard impact and physical damage from the analysis.

To summarise, in the biophysical view, the analytical focus of vulnerability is on the exposure to climate change and the sensitivity of the subject of analysis to that exposure. Vulnerability is perceived as the "end-point" of the analysis, therefore, is conceptualised and analysed based on these two components; generally, adaptive capacity is not accounted for in this type of analysis. In the social perspective, vulnerability is conceptualised as a pre-existing condition of the unit regarded as a "starting-point" of analysis and, as a result, exposure (to climate change) is considered as an external element in the analysis of vulnerability (Gallopin, 2006). Thus, social vulnerability largely refers to the "sensitivity" and "adaptive capacity" components of the vulnerability framework. In contrast, when vulnerability is examined in integrated approaches, exposure to climate change is addressed as an internal component of the vulnerability of the coupled system (Gallopin, 2006).

There are common issues with natural hazard assessments and climate change vulnerability assessments. Recently, Romieu et al. (2010) attempted to differentiate vulnerability in the

contexts of climate change from use of the same term in respect of natural hazards, exploring beyond formal divergences in terminology. They indicated that this is related to five factors:

- Process, for example climate change is commonly considered a "stress", whereas natural hazards might be considered a "shock". Individual or societal behaviour while facing these different processes is associated with different institutional, social, and psychological mechanisms (Turner et al., 2003).
- Scale-dependence, including both temporal, (e.g., static vs. dynamic) and spatial scales, (e.g., local vs. global) (Birkmann and Von Teichman, 2009).
- Function (e.g., different institutions).
- Assessment approach (e.g., statistical).
- Levels of uncertainty, and efforts to synthesise gaps and common issues between vulnerability in the contexts of climate change and natural hazards (see Table 2.1).

Table 2.1 Synthesis of gaps and common issues between vulnerability in the contexts of climate change and natural hazard (derived from Romieu et al., 2010).

Issues	Natural hazard	Climate change
Gaps/ differences		
Objective	Identify risk reduction measures: reduce probability of damage	Develop strategies to manage: adaptation relevance & strategies
Process	Natural hazards as "*shock*"	Progressive & irreversible-"*stress*"
Time scale	Event-scale (before/during/after), discrete events, static processes	Long-term and progressive viewpoint (e.g., 2100) discrete and continuous, dynamic processes
Spatial scale	From a local consideration to a global one	From a global awareness to a local need
Functional scale	Often lies within responsibility of Interior, Defence or Development Ministries	Mainly Environment Ministries and Meteorological Services
Simplified formulation	Risk = Hazard x Vulnerability	Vulnerability = (Exposure + Sensitivity) - Adaptation = Impacts – Adaptation
Vulnerability assessment	Step within risk assessment Risk is associated with a notion of probability of occurrence at any time	End in itself Prospective scenarios until a given time
Level of uncertainty	Low to medium	Medium to very high
Common issues	Define a focus, wider than physical environment itself Find a convergence between ''*impact-based*'' & ''*human-based*'' approaches Take into account dynamics & interactions of the socio-environmental system	

According to Soares et al. (2012), vulnerability assessments are considered "second generation" as compared to climate impact assessments, further addressing relevant non-climatic drivers (e.g., economic, demographic), and the adaptive capacity of the system under analysis (Fussel and Klein, 2006). This resulted in the appearance of new vulnerability-driven methodologies characterised by "bottom-up" approaches (e.g., study-site to globe scale) more aligned with social and integrated perspectives on vulnerability. In analytical terms, a focus on current climate variability alongside adaptation and non-climatic factors or drivers marks the shift from climate impact assessment to vulnerability assessments (Fussel and Klein, 2006). This shift is also associated with new approaches to stakeholder involvement, more sophisticated socioeconomic scenarios, and the consideration of adaptation measures, decision-support tools and enhancement of adaptive capacity as ways of reducing vulnerability to climate change (UNFCCC, 2005; Eakin and Luers, 2006; Mahapatra et al., 2015).

The conventional concept of vulnerability, since IPCC SAR (1995), identifies three key components: exposure, sensitivity, and adaptive capacity IPCC TAR (2001). In this thesis, the definition of vulnerability proposed by ICCC AR5 (2014) was used. The glossaries of the IPCC TAR, AR4, and especially AR5 define "*contextual vulnerability (starting-point vulnerability)*" as *"a present inability to cope with external pressures or changes, such as changing climate conditions; it is a characteristic of social and ecological systems generated by multiple factors and processes"*, whereas "*outcome vulnerability (end-point vulnerability)"* defines vulnerability as *"the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place define the levels of vulnerability"*. According to these reports, "*vulnerability"* is considered as a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (AR4-IPCC, 2007). Moreover, vulnerability index refers to "*a metric characterising the vulnerability of a system, which is typically derived by combining, with or without weighting, several indicators assumed to represent vulnerability*" (AR5-IPCC, 2014).

Climate change refers to any change in climate for extended periods, typically decades or longer, whether due to natural variability or as a result of human activity (AR4-IPCC, 2007).

A useful shorthand definition is that the vulnerability to climate change is a "measure of possible future harm" (Hinkel, 2011b).

- "*Exposure*" refers to the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.
- Whereas, "*sensitivity*" refers to the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).
- The combination of exposure and sensitivity defines the degree of the potential impacts of climate change to a system.
- Furthermore, "*adaptive capacity*" refers to the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. Measuring the adaptive capacity of a system enables policy makers to adopt suitable strategies in order to enhance the adaptive capacity or resilience of this system to the impacts of climate change.
- A combination of the potential impact and the adaptive capacities involved defines the vulnerability of a system. A system is anticipated to be vulnerable if it is exposed to climate change impacts, if it is sensitive to those impacts, and if it has a low capacity to cope with those impacts.

Limitations of these definitions have been described by many researchers, who have indicated that they are not accurately defined, that there is considerable overlap between the concepts of sensitivity and adaptive capacity; the concepts are not easily separated, since future sensitivity depends on current adaptive capacities and measures (Brooks et al., 2005; Vincent, 2004), and lack of transparency as to how the defining concepts are combined or that they are not operational concepts (Patt et al., 2008). These definitions have been widely adopted as an appropriate starting point to explore possibilities for vulnerability assessment. Making a theoretical concept operational consists of providing a method (an operation) for mapping it to observable concepts; and that method is then called the operational definition (Bernard, 2000; Copi and Cohen, 2005). Measurement, therefore, is based on notions of comparative or quantitative concepts, that is concepts that can take on different values. These concepts will be called variables (Bernard, 2000). It is worth noting that comparability is key to the notion

of vulnerability (Ionescu et al., 2009). On the other hand, Hinkel (2011a) argued that it is more accurate to speak about making the concept operational or practical instead of measuring it, since vulnerability is a theoretical concept provided by the IPCC (Brooks et al., 2005; Vincent, 2004).

To deal with those limitations, an extended definition of vulnerability and related components, which is developed by European Environment Agency, is adopted in this study. Figure 2.1 shows a flow chart covering three key components for climate change vulnerability assessment.

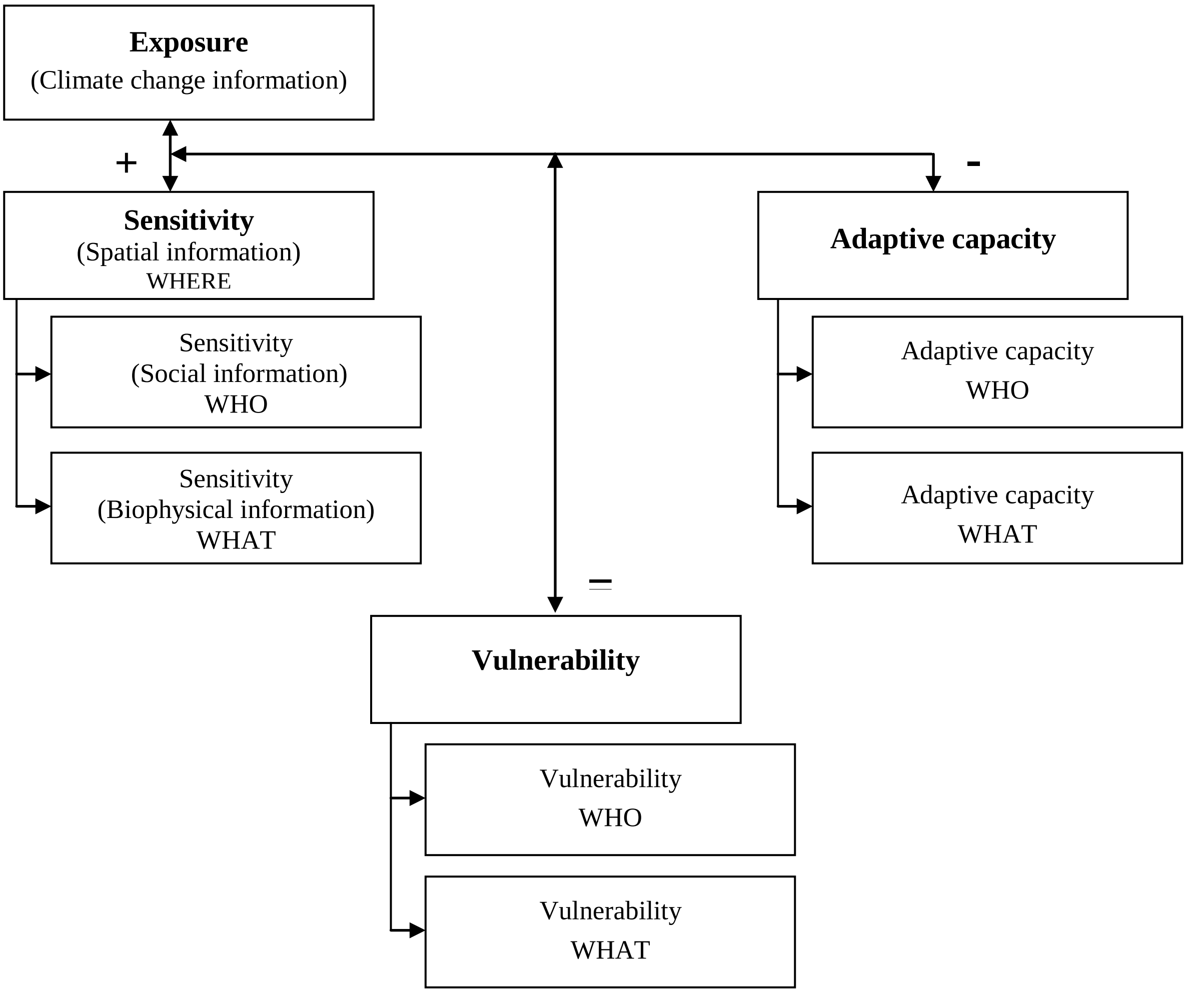


Figure 2.1 Flow chart for combining three key components of assessing climate change vulnerability, (modified from Schauser et al., 2010).

In Figure 2.1, the differentiation between spatial, (e.g., topography), biophysical, (e.g., landuse in general) and social, (e.g., population density) sensitivity components allows a stepwise grouping of:

- Exposure with spatial sensitivity to indicate primarily *WHERE* the potential impacts will be (e.g., the area most likely to be affected by climate change).

- The primary information *(WHERE)* with the social information to indicate *WHO* is sensitive and could be affected (e.g., how population density is affected or groups of the population, such as the elderly or another group could be the most sensitive), whereas, the primary information *(WHERE)* with the biophysical information to indicate *WHAT* is sensitive and could be affected (e.g., which landuse is most likely to be affected by climate change).
- The *WHO* and *WHAT* information with appropriate adaptive capacity information.

Not all combinations are similarly important for all threats. For some threats (e.g., heat) the "*What (is sensitive)*" information is of little interest, except it influences the "*Who (is sensitive)*" information. The relations between *the who* and *the what* are not yet integrated in any variable, therefore, the vulnerability of people and landuse should be dealt with as two separate strands, two different metrics according to the different damage types. It can be seen that the framework developed by European Environment Agency (EEA, 2010; ETC/ACC, 2010) can not simultaneously deal with all limitations; however, it allows identification of cross-space dimensions *where* the potential impacts will be, and *who* and *what* is sensitive and could be affected regarding social, and biophysical factors, and then *who* and *what* information with appropriate adaptive capacity information.

In summary, a vulnerability assessment in the context of climate change needs to define dimensions as clearly as possible. These include:

- Location (or space) of analysis, (e.g., geographical region).
- The system of analysis, (e.g., natural system, and human system).
- The valued attributes of concern, (e.g., income, poverty, education, and health).
- The hazard/ the potential impact, (e.g., flood risk, erosion, and saltwater incursion).
- A temporal reference, (e.g., current, future, and dynamic) with regard to the three components: exposure, sensitivity, and adaptive capacity.

2.4 Approaches used to assess coastal vulnerability

A common methodology for vulnerability assessment was developed by the IPCC in 1991 (CM-IPCC, 1991). Many approaches for assessing coastal vulnerability to climate change have evolved since, based on that common methodology (Abuodha and Woodroffe, 2006a, 2010; Harvey and Woodroffe, 2008; McFadden, 2007; Mcleod et al., 2010). Table 2.2 presents numerous methods for assessing coastal vulnerability to climate change.

Table 2.2 Methods used for assessing coastal vulnerability to climate change.

No.	Methods	Application
1	Common methodology (CM-IPCC, 1991)	Applied to coastal countries and includes 7 steps: delineate the case study area; inventory study area characteristics; classify the relevant socioeconomic development factors; assess the physical changes; frame response strategies; assess the vulnerability profile; classify future requirements.
2	Synthesis and Upscaling of sea-level rise Vulnerability Assessment Studies (SURVAS, 2004)	Deploys activities: reviewing potential impacts of human induced sea-level rise at the national, sub-national scales; holding several workshops under the guidance of leading coastal vulnerability experts to focus on the tools available for assessing the physical susceptibility and socioeconomic vulnerability; directly contributed to the DINAS-COAST project which developed the DIVA tool.
3	Dynamic and interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to sea-level rise project (DIVA-COAST) and Dynamic & Interactive Vulnerability Assessment (DIVA) Tool	The first European methodology since 2004, integrating information on physical, ecological & socioeconomic characteristics that enables analysis of a range of mitigation and adaptation scenarios; it is based on decomposition of the world's shoreline into a series of 1-dimensional coastal segments and does not therefore capture the multidimensional complexity of extensive low-lying areas such as deltas (David et al., 2008; Hinkel and Klein, 2007; Vafeidis et al., 2004; Woodroffe, 2010).
4	Simulator of CLIMate Change Risks and Adaptation Initiatives (SimCLIM)	An open framework software system, originally developed by IGCI (2005), now maintained and distributed by (Warrick, 2009a). The system can be applied from global to local scales: assessing coastal flood risk from tropical cyclones and river flooding, effects of rainfall change, the risks of climate variability and change in domestic water supply tank systems (ADB, 2005; Warrick, 2007, 2009b; Warrick et al., 2005), links directly to other models such as hydrological models and DSSAT crop models (Warrick and Cox, 2007).
5	Community Vulnerability Assessment Tool (CVAT; Flax et al., 2002)	Developed by the Coastal Services Centre of National Oceanographic and Atmospheric Administration, CVAT supports the linking of environmental, social & economic data to build an effective strategy in response to hazards, both at macro & micro levels based on systematic evaluation of vulnerability. CVAT consists of 7 steps: Hazard identification and prioritisation; hazard analysis; critical facilities analysis; social analysis; economic analysis; environmental analysis; and mitigation opportunities analysis. It was conducted in some counties and islands of US to identify and understand its hazard risks and vulnerabilities. The Risk and Vulnerability Assessment Tool (RVAT) is an extension of the methodology in CVAT, and supports of communities to identify their risks and vulnerabilities to coastal storms to create effective hazard mitigation strategies and reduce storm impacts (Russell, 2003).
6.1	Coastal Vulnerability Indices such as coastal vulnerability index (CVI)	Developed by Gornitz et al. (1994), CVI includes 8 physical parameters to assess the vulnerability of a coastal area to anticipated sea-level rise: relief, rock type, landform, vertical (tectonic movement, shoreline displacement, tidal range, and wave height.
6.2	Coastal social vulnerability index (CSoVi)	Boruff et al. (2005) have suggested a hybrid approach that integrates a socio vulnerability index (SoVI) with socioeconomic variables developed by Cutter et al. (2003) into a CVI to produce the overall coastal social vulnerability index in their assessments of the coastal vulnerability of US counties. CSoVI additionally includes parameters, namely poverty, population, development, ethnicity, age, and urbanisation.
6.3	Place vulnerability index (PVI)	Particularly, Boruff and his colleagues (2005) applied the hazard of place model of vulnerability (Cutter, 1996) to derive the place vulnerability index (PVI) for each of the US counties by adding CVI and CSoVI scores and then classifying PVI scores into low, medium and high classes. Analysis of Variance (ANOVA) identified significant differences (at 95% confidence level) for each of these indices in different coasts. These differences were brought out by the socioeconomic data considered inclusively.

The majority of coastal hazard studies have focused on physical factors associated with coastal vulnerability, such as geo-physical dynamics (e.g., geo-morphological processes), or physical impacts (e.g., sea-level rise, flooding and inundation) rather than socioeconomic factors of coastal vulnerability, such as poverty (Abuodha and Woodroffe, 2006a; Eakin and Luers, 2006; Nicholls et al., 2008). Harvey and Woodroffe (2008) also indicate that the concept of coastal vulnerability developed from IPCC needs to be expanded from biophysical impact reduction to vulnerability reduction or resilience enhancement. Several approaches to evaluate coastal vulnerabilities in Australia were summarised by Harvey and Woodroffe (2008) who remarked that there has been little consistency or uniformity in the way in which Australian researchers have assessed the vulnerability of the Australian coast to the impacts of climate change. Kay et al. (1993; 1996), as a result of criticisms of the IPCC CM (1991), proposed four key stages in alternative approaches to assess coastal vulnerabilities. The first stage focused on the biophysical condition of the study area and delineated those areas of potential future coastal hazard. The second stage considered the notion of the susceptibility to stress, shock and damage caused by climate change while recognising the importance of resilience of the natural coastal system. The third stage focused on the inter-relationship between the condition of the study area and connected systems; and the final stage considered the possible policy options and plans determined by governments to reduce coastal vulnerabilities.

A number of factors, accordingly, need to be determined in the context of climate change and coastal vulnerability assessment, such as objectives of the research or policy questions addressed, the urgency of the threat, the geographical and temporal scope of the analysis, the reliability of future climate impact projections, the level of previous knowledge, and the availability of data, expertise, and other relevant resources. This is necessary in order to select a proper assessment approach to be used in a specific vulnerable situation, such as location (e.g., regional or local area), or sector (e.g., agricultural sector) (Eakin and Luers, 2006). In this thesis, scale dependence, the level of previous knowledge, and the availability of data, expertise and their links will be shown to be obstacles that should be considered in assessing coastal vulnerability.

Vulnerability is scale-dependent, across both space and time. First, vulnerability is spatially scale-dependent, depending on whether it is national, regional or local. Yoo et al. (2011) claimed that the spatial scale of climate change vulnerability assessments is often either too

broad when focused on the national or regional scale (Bryan et al., 2001; Dawson et al., 2009; Dominguez et al., 2005; Mokrech et al., 2008; Thieler and Hammer-Klose, 1999, 2000a, b) or too narrow when focused on coastal segments (Pendleton et al., 2005; Mahapatra et al., 2015). Abuodha and Woodroffe (2006a) summarise numerous approaches based on segmentation techniques that rank sections of the coastline according to a semi-quantitative assessment of variables. These are useful to determine high priority areas for vulnerability reduction; however, most lack incorporation of socioeconomic aspects of vulnerability. Harvey and Woodroffe (2008) also indicate that awareness in terms of impacts of climate change, particularly sea-level rise, has come from a global or national scale, but there is need for specific impact assessments and adaptation strategies that are local. Torresan et al. (2008) note that a more detailed approach at the local and regional scale requires that coastal systems and dynamics are described in detail and that more complex and data intensive models require site-specific metrics and variables to understand and manage the difficulties of a specific study area and allow identification of more specific vulnerable areas and sectors that could support policy and decision-making in design of comprehensive adaptation strategies. Romieu et al. (2010) also emphasise that local assessments provide more bottom-up and locally contextualised views of vulnerability formation, but are difficult to connect to climate change projections which are not yet available with sufficient resolution for local assessment.

Second, the temporal scale involved in coastal zone processes and dynamics can last from hours to days for storm surges, from days to years for El Niño weather events, and from decades to millennia in the case of regional vertical land movements. As such, the need for adaptation to climate change is evident and this need is greatest in coastal areas and will continue for centuries considering long-term coastal challenges (e.g., sea-level rise). Nicholls et al. (2007) show that when efforts to reduce climate-related risks to coastal systems are reactive and standalone, they are less effective than when they are part of integrated coastal zone management. Integrated coastal zone management is recognised as the most appropriate process to cope with current and long-term coastal challenges such as climate change, particularly sea-level rise (Nicholls and Klein, 2005; Nicholls et al., 2007). Proactive adaptation to climate change aims to reduce a system's vulnerability by minimising risk and/or enhancing the system's resilience. Nicholls and Klein (2005) identify five objectives of proactive adaptation for coastal zones, including:

- Increasing robustness of infrastructural designs and long-term investments.
- Increasing flexibility of vulnerable managed systems.

- Enhancing adaptability of vulnerable natural systems.
- Reversing maladaptive trends.
- Improving societal awareness and preparedness.

Three basic adaptation strategies are often recognised: 1) protect: to reduce the risk of the event by decreasing the probability of its occurrence; 2) accommodate: to increase society's ability to cope with the effects of the event; and 3) retreat: to reduce the risk of the event by limiting its potential effects (Nicholls and Klein, 2005; Smit et al., 2001). For example, protect, accommodate and retreat (planned) responses in terms of sea-level rise for vulnerable coastal areas are presented in Table 2.3.

Table 2.3 Protect, accommodate, and retreat (planned) responses for some landscape components vulnerable sea-level rise.

Component	Protect	Accommodate	Retreat
Built environment	Protect coastal development, (e.g., seawalls, dykes, beach nourishment, sand dunes, surge barriers, and land claim)	Regulate building development and increase awareness of hazards, (e.g., flood hazard maps, and flood warnings)	Establish building setback codes, (e.g., managed realignment, and coastal setbacks)
Crops	Protect agricultural land, (e.g., seawalls, dykes, beach nourishment, sand dunes, surge barriers, and land claim)	Switch to aquaculture or floating agriculture	Relocate agricultural production, (e.g., managed realignment, and coastal setbacks)
Wetlands	Create wetland habitats by land-filling and planting	Strike balance between preservation and development	Allow wetland migration, (e.g., managed realignment, and coastal setbacks)

It is rather difficult to differentiate current and future vulnerability because, as Schauser et al. (2010) point out, there is a lack of data for projections of sensitivity and adaptive capacity. On the one hand, for many socioeconomic sectors, only past data from the last census, that might be 10 or 20 years old, are available. On the other hand, future vulnerability depends on past actions, adaptation and societal adjustments. Most existing variables are somehow measuring current or past vulnerability. Therefore, until these are available, it will be necessary to focus on current (+/- 10 years) vulnerability. In most cases, particularly at the local scale, the future aspects relate primarily to climate projections and may only include population dynamics if projection data is available.

Scenarios prepared by Nakicenovic et al. (2000) in the Special Report on Emissions Scenarios (SRES) provided by IPCC, have been used to predict future societal developments due to the

limitations in future datasets, current methods and understanding. A range of SRES scenarios was developed to represent the range of driving forces, such as demographic development, socioeconomic development, and technological change; emissions in the scenario literature; and alternative modelling approaches. These SRES aim to reflect current understanding and knowledge about future (a period of 1990 up to 2100) emission outcomes and underlying or associated uncertainties. An overview of SRES scenario quantifications adapted from Nakicenovic et al. (2000) is presented in Table 2.4.

Table 2.4 Overview of SRES scenario quantifications, adapted from Nakicenovic et al. (2000).

Set (Scenario)	SRES							Total
Family/ Storyline	A1[1]				A2[2]	B1[3]	B2[4]	4
Group	A1C	A1G	A1T	A1B	A2	B1	B2	7
	A1FI Fossil Intensive		A1T Non fossil energy sources	A1B A balance across all sources	A2	B1	B2	6
Globally harmonised	2	3	6	2	2	7	4	26
Other Scenarios	1	0	2	1	4	2	4	14
Different Models Used	3	3	6	3	5	6	6	6

Note: The scenario is also oriented toward environmental protection and social equity; it focuses on local and regional levels. Six modelling groups develop 40 SRES scenarios, comprising globally harmonised and other scenarios. Each scenario family, two main types of scenarios were developed those with harmonised assumptions about global population, economic growth, and final energy use and those with alternative quantification of the storyline. Together, 26 scenarios were harmonised by adopting common assumptions on global population and gross domestic product (GDP) development. Thus, the harmonised scenarios in each family are not independent of each other. The remaining 14 scenarios adopted alternative interpretations of the four scenario storylines to explore additional scenario uncertainties beyond differences in methodological approaches. They are also related to each other within each family, even though they do not share common assumptions about some of the driving forces.

[1] A1 describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. A1 includes four groups, designated as A1T, A1C, A1G and A1B that explore alternative structures of future energy systems. In the summary for policymakers, the A1C and A1G groups have been combined into one "Fossil intensive" A1FI scenario group whereas the other three scenario families consist of one group each to finally create six scenario groups.

[2] A2 describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

[3] B1 describes a convergent world with the same low population growth as in A1, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

[4] B2 describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in B1 and A1.

In summary, since the CM-IPCC in 1991, several approaches for coastal vulnerability assessment to climate change have been implemented. Selection of appropriate spatial, emphasising locally contextualised views, and temporal scales to dealing with current and long-term impacts to climate change that have been discussed. It seems to lack incorporation of socioeconomic issues into assessment, particularly at local scale.

2.5 The development of vulnerability indices

Several researchers indicate that the analysis of vulnerability often relies on the use and aggregation of indicators (Cutter et al., 2000; Moss et al., 2001; Vincent, 2007; Yohe and Tol, 2002). Indeed, it is necessary to develop vulnerability indices that can help identify vulnerable regions, sectors or population groups, raise awareness, and can be part of a monitoring strategy.

Generally, vulnerability index development involves sequential stages including the selection of indicators, normalisation of indicators to a common scale, and aggregation to a final value.

- First, the goal of indicator selection is to choose proxy variables for the underlying theoretical dimensions of vulnerability comprising physical and social factors related to the components of vulnerability assessments: exposure, sensitivity, and adaptive capacity.
- Second, it is important to note that normalisation of data to a common (comparable) unitless scale and subsequent summation of the normalised data is generally used to overcome issues of incommensurability when combining multiple indicators.
- Finally, the aggregation stage refers to the way it is used to combine transformed, normalised, and weighted indicators into the final index used; common options include multi-criteria analysis (Tate, 2013).

Hinkel (2011a), however, notes two challenges in the development of vulnerability indices. The first challenge lies in the difficulty of exactly defining the vulnerable system. On the one hand, this is due to many assessments being concerned with systems with large system boundaries; for instance, the vulnerability of a whole country (e.g., its regions, economic sectors and social groups) to all climate-related hazards (e.g., both primary and secondary ones) and possibly other hazards. On the other hand, even local assessments targeting individuals or communities need to take into account the wide political, institutional, economic and social context that determines vulnerability, as expressed by the concept of "*contextual vulnerability*" (O'Brien et al., 2007). For instance, "*population density*" is

considered as an indicator for the social vulnerability assessment. Population density in agrarian communities may either increase or decrease vulnerability (Meyer et al., 1998). High population density may result in a dependence on degraded or marginal land for food production. These lands can rapidly become unproductive and therefore increase vulnerability to food insecurity (Reycraft and Bawden, 2000). Conversely, high population density in locations with high quality agricultural land may allow intensified production and investment in infrastructure to increase food supplies (Boserup, 1965). If population density alone is considered as the key vulnerability indicator, the interaction with the environmental system and its capacity for agricultural production could lead to the development of inappropriate policy. Therefore, to gain a more holistic insight requires an understanding of how multiple, often inter-dependent; indicators of vulnerability vary in relation to each other. Vulnerability assessments are therefore highly context specific (Füssel, 2009; Yohe and Tol, 2002).

The second challenge is the forward-looking aspect of vulnerability. As discussed above, vulnerability indices must indicate a possibility, (i.e. some state that might or might not come about in the future (Ionescu et al., 2009; Patt et al., 2008)). The "*usual*" indices, however, indicate a state and not the potentiality of a future state. The UNDP's Human Development Index 2006, for example, indicates the current state of development rather than the possibility of future development. Due to this forward-looking aspect of vulnerability, developing a vulnerability index includes building a predictive model, a task similar to the case of developing a simulation model. In both cases, a function is built that, based on the observed present state, returns information on possible future states. The difference between the two approaches is one of complexity and the treatment of time. In the index-based approach the function (e.g., the index) is, by definition, simple (see above) and time independent (in the sense that it does not contain time as an argument). A vulnerability index does not give us information on when in the future harm will occur. In the simulation-model-based approach, the function (e.g., the simulation model) is complex and time-dependent, in the sense that it is a computer program representing the dynamical system that is iterated over time including feedbacks and non-linearity. It is, thus, important to distinguish between:

- Harm indices, which are indices that evaluate a state of a system based on normative judgments of what constitutes a good or bad state. These indices do not include the forward-looking aspect.

- Vulnerability indices, which are indices of possible future harm. These indices include both the forward-looking aspect as well as the normative aspect of defining harm (Hinkel, 2011a).

Despite those challenges in the development of vulnerability indices, Füssel and Klein (2006) and Eakin and Luers (2006) indicate that vulnerability indices have been applied for many scientific purposes (e.g., for identifying causal processes and explaining attributes of vulnerable systems, for linking system attributes to vulnerability outcomes, and for mapping, ranking and comparing vulnerability across regions), at many scales (from local to global), and with different policy objectives (e.g., more realistic assessment of climate change risks, aiding the allocation of resources across regions, monitoring the progress in reducing vulnerability over time, and identifying suitable entry points for interventions).

Different decision contexts and scales generally require different kinds of information. For example, an index developed to describe household vulnerability to natural hazards in Mozambique may be largely irrelevant in Germany, or outright inapplicable if used in German studies (Vincent, 2007); additionally institutions such as the United Nations Environmental Programme (UNEP, 2006) and the UK's Department of International Development (Thornton et al., 2008) have recently undertaken broad scale (multi-national to continental scale) vulnerability mapping exercises in Africa. Nevertheless, quantifying and communicating the multiple drivers of socio-natural vulnerability is problematic, particularly when seeking to explicitly map vulnerability across broad spatial scales (Eakin and Luers, 2006; Füssel, 2009; Van Velthuizen et al., 2007). It can be clearly seen that there have been implicit uncertainties in these broad scale vulnerability assessments.

There are three broad approaches for developing vulnerability indices, according to Harvey et al. (2009) and Hinkel (2011a); Most vulnerability methodologies make use of a combination of two; All three of the following approaches that were used in this thesis.

- First, theory-driven, also known as deductive approaches, based on existing scientific knowledge in the form of conceptual frameworks, theories or models about the system considered to identify relevant variables, and determine their relationships, and generate a list of components (Adger and Vincent, 2005; Moss et al., 2001; Schröter, 2004; Schröter et al., 2005; Yohe et al., 2006).

- Second, data-driven, also known as inductive approaches, these select vulnerability variables based on their statistical relationship with observed vulnerability outcomes (e.g., mortality due to natural hazards) (Briguglio, 1995; Brooks et al., 2005; Dilley et al., 2005; Eriksen and Kelly, 2007; Peduzzi et al., 2002; Tol and Yohe, 2007).
- Third, the normative approach, based on subjective individual or collective expert opinion; this has been widely applied for the development of variables for various purposes (Kienberger et al., 2009). The most prominent example is the selection of variable components for the Human Development Indicator (HDI) (Schauser et al., 2010).

In order to make theoretical concepts operational in the context of climate change and vulnerability assessment, there also have been three approaches used for a great diversity of different systems, as well as spatial and temporal scales; these are: 1) participatory; 2) simulation-model-based; and 3) indicator-based approaches. In relation to this study, indicator-based approaches are reviewed in terms of their usage and limitations in the context of climate change and vulnerability assessment. Moreover, they have been used to develop a final composite/summary coastal vulnerability index, comprising the three variables of exposure, sensitivity, and adaptive capacity, respectively. A vulnerability index generally aims to simplify a number of complex and interacting parameters, represented by diverse data types, to a form that is more easily understood and has much greater utility as a management tool.

In fact, the indicator-based approach is divided into two different types. These are index- and variable-based approaches, although a sharp distinction is not always evident. A comprehensible explanation of the adopted approaches is essential to support the proper uses. Ramieri et al. (2011) have attempted to distinguish the two types. On the one hand, index-based approaches express coastal vulnerability by a one dimensional, and generally unitless, risk or vulnerability index. These approaches are not immediately transparent since the final index does not enable the understanding of assumptions and aggregations that led to its calculation. On the other hand, variable-based approaches express the vulnerability of the coast by a set of fairly independent variables. In many cases, variables are combined into a final composite index that characterises key coastal issues, such as coastal drivers, risk, hazard, exposure, sensitivity, impacts, adaptive capacity, and damage. Moreover, these approaches allow the evaluation of different aspects related to coastal vulnerability to produce evaluated variables corresponding at those steps within a completely consistent assessment context.

According to Fisher (1922), the use of indices as policy tools started in 1920. Gallopin (1997) considered that an indicator is an utility from observable variables, called indicating variables or theoretical variables. Indices or variables are a kind of measure - they are generally sets of information used to determine the status quo or changes of a characteristic of a system (Sullivan, 2002). Variables should be measurable, accessible, transferable, easy to be applied in practice, and not redundant (Birkmann, 2006; Lane et al., 1999). Depending on the context and the purpose of the envisaged vulnerability assessment, these variables may be of quantitative character. But they may also embrace qualitative criteria or broader assessment approaches to allow for the integration of aspects, such as the institutional or cultural vulnerability (Birkmann, 2006).

Several researchers (Birkmann, 2006; Hinkel, 2011a; Kienberger et al., 2009) adopt three steps in the development of vulnerability indices. Several researchers indicate that the variable- and index-based approaches could be considered as appropriate methodologies only at local scales. They also argue that vulnerability is a context-specific rather than a generic condition. They conclude that indexes of vulnerability assessments cannot be meaningful when applied to large-scale systems (e.g., comparing countries), and so should focus on smaller scales of analysis because of several reasons.

- The first step is the definition of what is to be indicated. In the case of climate change vulnerability indices, this would be the vulnerability of a system to climate change. A wide range of different systems (e.g., individuals, households, communities, ecosystems, regions, economic sectors and countries) are considered. Often these systems can be conceptualised as natural systems (Judge et al., 2003) and integrated with social systems (Birkmann and Fernando, 2008; Boruff et al., 2005), because vulnerability is determined by the interaction of bio-geophysical (or natural environment) and social/ or socioeconomic (or human) sub-systems. Defining the system needs to include defining the system's boundaries. Therefore, systems of analysis at local scales can be narrowly defined (Barnett et al., 2008; Hinkel, 2011a).
- The second step is the selection of the indicating variables, and it consists of defining the domain of the index function, and typically require large investments in data harvesting or collection and analysis (Villa and McLeod, 2002).
- The third step is aggregation of the indicating variables. This consists of defining the indicator function itself, involving some aggregation of multiple sub-indicators to produce a

single index. Aggregation can hide deficiencies in data, and so the mathematics of index development is very important (Bossel 1999).

Additionally, a common approach to holistic vulnerability mapping is to aggregate (i.e., where the same units are used), or to composite (i.e., where different units are used) (Abson et al., 2012; Schauser et al., 2010), capturing the multiple aspects of biophysical and social vulnerability and adaptive capacity into a single index, or small number of spatially explicit vulnerability indices, termed a vulnerability "*score*", reducing the amount and complexity of information that must be communicated, and acting as powerful visual tools to identify those areas most vulnerable to climate change effects. The study by Preston et al. (2008) on vulnerability variables for the Sydney Coastal Councils Group region can be identified as an example of good practice (see Appendix 1); indicating that it is often necessary to integrate datasets from many different sources that vary in format, scale and by their methods of acquisition due to the strong socio-economic component of vulnerability. Indeed, an integrated quantitative model that represents all the linkages and relationships between such data, combining them in a meaningful way, is strongly recommended.

The complex structure of vulnerability assessment frameworks is often described by hierarchical aggregation (Hiete and Merz, 2009; Schröter et al., 2005), and aggregated vulnerability indices are computed using the mathematics of index construction (Moss et al., 2001; Schmidtlein et al., 2008). However, the combination of multiple variables of aspects of vulnerability into aggregated vulnerability indices must overcome the incommensurability of the units in which the individual indicators are measured (Sullivan and Meigh, 2005). Before aggregating, indicating variables must be normalised to create a common measurement unit. Common normalisation methods include min- max, standardisation, and ranking methods (Schauser et al., 2010). Further discussion of those methods will be presented in chapter 3.

Weighting methods, also known as ranking methods, express the contribution and relative importance of the individual variables in the system. Using weighting methods can be considered as a supporting tool for a more objective (Wang et al., 2011) and consistent decision process (Saaty, 1980; Saaty, 1994). This helps avoid over-estimation of the contribution or importance of variables in terms of vulnerability (Yoo and Kim, 2008), and can identify more accurately the most vulnerable areas on the map (Kubal et al., 2009; Wang et al., 2011). However, there have not been many studies that used weighting methods in their

studies. This is because of lack of comprehensive understanding of the theoretical vulnerability framework (Hiete and Merz, 2009) and a lack of knowledge about weighting methods which are often considered to be complicated. In fact, weighting methods used in most studies are based on expert opinions, or stakeholder involvements (qualitative data), rather than scientific results (quantitative and qualitative data) (Schauser et al., 2010). The analytical hierarchy process (AHP) is one multi-criteria analysis method that has been used successfully in recent studies (Schauser et al., 2010). The AHP was originally developed by Saaty (1980) and has been refined since then, based on mathematics and psychology (a semi-quantitative approach). It is a structured technique for organising and analysing complex decisions. As such, AHP is considered a useful tool for multi-criteria assessment when coupled with computing weights of individual variables in the analyses. AHP and weightings will be further described in chapter 3.

Geographical information systems (GIS) have been used as a visualisation tool for integration of data and the creation of indices that express their combined effect (Bryan et al., 2001; Harvey et al., 1999; Schleupner, 2009; Sharples, 2006; Tate et al., 2011; Thumerer et al., 2000; Wilkinson, 1996; Woodroffe, 2010; Woodroffe et al., 2007; Zeng et al., 2006). GIS tool and its application will be further described in chapter 3.

2.6 Case studies on the development of vulnerability indices

Some case studies involved development of vulnerability variables/ indices in the contexts of climate change and coastal vulnerability assessment, and these are reviewed to find appropriate studies that can form the basis for the research to be conducted in following chapters. There is a focus on studies relevant to coastal areas at local scales, and studies of regions similar to the Mekong River Delta in Vietnam (the MRD). Details of case studies, vulnerability indices, particularly social vulnerability indices including variables used to assess climate change vulnerability, are summarised in Appendix 1. The review specifically focuses on studies that use a set of variables as determinants categorised into three main components of vulnerability: exposure, sensitivity, and adaptive capacity. To date, however, there seems to have been no convincing framework or methodology on how to quantify and compare vulnerability to climate change at spatial-dependent scales (e.g., regions, coastal areas, urban areas) using selected variables/ indicators regarding the three main components of vulnerability aggregated or combined into a composite vulnerability index. A few good examples of a consistent methodological approach have been found (Kleinosky et al., 2006;

Preston et al., 2008; Reid, 2008; Reid et al., 2009; Schröter, 2004; Schröter et al., 2005; Yoo et al., 2011; Yusuf and Francisco, 2009).

In Vietnam, recently, more attention has been placed on response to natural disasters and climate change mitigation rather than climate change adaptation activities (APN, 2007). Moreover, there have been several assessments related to climate change, mainly undertaken in the eastern part of the MRD. On the other hand, these studies have focused on assessing the biophysical processes at different spatial scales (focusing on the whole delta rather than regions within it), examining variables closely related to climate change, particularly sea-level rise, and their impact on features of landscape and the response of Asian mega-deltas, including the MRD (Woodroffe et al., 2006). These studies have included hydrological and morphological processes at the mouth of the Mekong River (Mikhailov and Arakelyants, 2010), transport of sediments, soils and materials (Brinkman et al., 1993; Ta et al., 2002a), projecting scenarios of climate change and sea-level rise (The-First-Scenarios-VN, 2009; The-Second-Scenarios-VN, 2011), simulating inundation maps (Reid, 2008; Wassmann et al., 2004), or assessing flood risk (Dinh et al., 2012; Huong and Pathirana, 2013), water quality analysis (Nguyen, A. D. et al., 2008), landuse planning (Nguyen, 2006), change to forest wetlands (Le and Wyseure, 2007), mangrove forests (Phan and Hoang, 1993; Phan and Populus, 2007; UNEP, 2004a), coral reefs (UNEP, 2004b), seagrasses (UNEP, 2004c), and agriculture - aquaculture systems (Le, 2010; Nguyen and Nguyen, 1998; Wassmann et al., 2004). These have been biophysical rather than assessing social vulnerability, or integrated vulnerability, such as reducing the vulnerability of water resources, food security and the environment to climate change impacts (Mainuddin et al., 2010); assessing the impacts of climate change on sectorial effects (Mackey and Russell, 2011), and indicating local perception, impacts and adaptation of agrarian communities in the coastal provinces of the Mekong (Nguyen et al., 2012). To the author's knowledge, to date there are no studies constructing a coastal vulnerability index, comprising three components: exposure, sensitivity, and adaptive capacity, to quantify and visualise areas vulnerable to impacts of climate change across the MRD at regional and especially local scales.

It can be seen from a summary in Appendix 1 that there is little consistency between approaches that have incorporated social variables into coastal vulnerability indices. Moreover, there have been only four out of a total of 53 case studies (accounts for 7.55%) summarised, which can form the basis for case studies in the MRD. These include:

1) A case study by Mackey and Russell (2011), which assessed the impacts of climate change, based on climate hazards, including sea-level rise, saline incursion, flood, and storm surge, and crossed four sectorial effects, comprising socioeconomic, agriculture and livelihoods, urban settlements and transport, energy and industry for the western part of the MRD, including two provinces: Kien Giang and Ca Mau. They adopted a standard comparative vulnerability and risk assessment methodology and framework to identify the comparative vulnerability and adaptive capacity of natural and human systems, among particularly vulnerable geographic hotspots (a district boundary).

2) Yusuf and Francisco (2009) conducted assessments for sub-national areas, regions, provinces, and districts for South East Asia, in which climatic hazard maps for five climate-related risks, tropical cyclones, floods, landslides, droughts, and sea-level rise, were generated. Population density was used as the proxy for human sensitivity to climate hazard exposure. The extent of protected areas was the proxy indicator for ecological sensitivity of the respective areas. An index of adaptive capacity is also created, as a function of socioeconomic factors, technology, and infrastructure. The socioeconomic variables comprise the Human Development Index (income, literacy, and life expectancy), poverty, and inequality.

3) Preston et al. (2008) conducted an assessment, and mapping of climate change vulnerability throughout the Sydney Coastal Councils Group region, which incorporated five areas of potential climate change impacts, such as extreme heat and human health effects, sea-level rise and coastal hazards, extreme rainfall and urban storm water management, bushfire, and natural eco-systems and assets.

4) Yoo et al. (2011) developed a method for local vulnerability assessment with application to coastal cities. They suggest a framework that corresponds to the second stage of an alternative method proposed by Kay et al. (1993; 1996) for the assessment of climate change on a local scale by incorporating statistical data, and expert opinions into GIS.

Additionally, a summary from Appendix 1 indicates a set of variables as determinants categorised into three components of vulnerability: exposure, sensitivity, and adaptive capacity that could be used for the study-sites assessment. These include:

- Exposure which refers to how the system is exposed to climate change, that is determined by a set of conditions and resources termed the determinants of exposure which consist of biophysical hazards/ or threats due to climate change, (e.g., sea-level rise and

coastal hazards, extreme rainfall and urban storm water management, extreme heat and human health effects).

- Sensitivity reflects the system's potential to be affected by changes, that is represented by a diversity of indicators generally categorised into two main sub-components: human/ or population sensitivity, accounted for 75.5% cases, (e.g., population density, gender, race and ethnicity) and landuse sensitivity factors, accounted for 47.2%, (e.g., agriculture landuse, protected land area).
- Adaptive capacity describes the system's ability to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences that is represented by a range of information and datasets. These include: 1) socioeconomic indicators, accounted for 34%, (e.g., poverty, income, education, health care services); 2) technology indicators, accounted for 13.2%, (e.g., availability of irrigation, electricity coverage); 3) infrastructure, accounted for 22.6%, (e.g., road density, access to information (radio, internet), and intervention tools (early warning system)); and 4) institutional capacity, accounted for 18.9%, (e.g., awareness, governance, policy foundation). About a third of studies examined were conducted at local scale (e.g., at city, county, and district level), and only one of these was undertaken in a delta.

Generally determining sensitivity and adaptive capacity components are not easily differentiated and separated in many cases; this may be because future sensitivity depends on current adaptive capacities and measures. To sum up, Tables 2.5 and 2.6 summarise the physical and social vulnerability ranges used by several researchers, respectively. Of which, dark shading vulnerability ranges by different researchers were used to assess in this thesis that will be discussed in chapters 5, and 6.

Table 2.5 Physical vulnerability ranges used by different researchers.

Variable	Rank					References
	Very low	Low	Moderate	High	Very high	
Relief, m	≥ 30.1	20.1- 30.0	10.1- 20.0	5.1- 10.0	0-5.0	Gornitz (1991)
Sea-level rise, mm/year	≤ -1.1 < 1	-1.0- 0.99 1 - 2	1.0- 2.0 2 - 5	2.1- 4.0 5 - 7	≥ 4.1 7 – ≥ 9	Gornitz (1991) Özyurt and Ergin (2010)
Tidal range (mean), m	≤ 0.99 < 0.5	1.0- 1.9 0.5- 2	2.0- 4.0 2- 4	4.1- 6.0 4- 6	≥ 6.1 > 6	Gornitz (1991) Özyurt and Ergin (2010)
Wave height (max), m	0- 2.9	3.0 - 4.9	5.0- 5.9	6.0- 6.9	≥ 7.0	Gornitz (1991)
Flood depth, m	< 0.5	0.5 – 1.0 0 - 1	1.0 – 1.5 1 - 3	1.5 – 2.0 3 - 6	2.0 – ≥ 2.5 > 6	Kafle et al. (2007) Bormudoi et al. (2008)

	< 0.8	0.8 – 1.2	1.2 – 2	2 – 4	> 4	Le et al. (2009)
	≤ 1	2	3	4 - 5	> 5	Özyurt and Ergin (2010)
	< 0.5	0.5 – 1.2	1.2 – 2.0	2.0 – 3.0	> 3.0	Dang et al. (2011)
	< 0.25	0.25 – 0.5	0.5 - 1	1 – 1.5	> 1.5	Mackey and Russell (2011)
	0 – 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0	Dinh et al. (2012); Tingsanchali and Karim (2005)
	≤ 0.5	>0.5- ≤1.0	>1.0- ≤1.5	> 1.5- ≤ 2	> 2	Balica et al. (2013)
Salinity, ppt	< 1	1 - < 2.5	2.5 – 3	3 - 4	> 4	Grattan et al. (2002)
	< 1	1 - < 4	4	> 4		Mackey and Russell (2011)
		< 4	4	> 4		Hoang et al. (2012)
		< 4	4 - 8	> 8		Le (2003)
Shoreline displacement, m/year	≥ 2.1	1.0 – 2.0	-1.0 – 1.0	-1.1 - -2.0	≤ -2.0	Gornitz and Kanciruk (1989)
	≥ 2.1	1.0 – 2.0	-1.0 – 1.0	-1.1 - -2.0	< -2.0	Gornitz (1991)
	> 2.0	1.0 – 2.0	-1.0 – 1.0	-1.1 - -2.0	< -2.0	Gornitz et al. (1994)
		> - 5.0	-15.0 - -5.0	- 30.0 - -15.0	< -30.0	Pham et al. (2005)
	> 15.0	5.0 – 15.0	-5.0 – 5.0	-15.0 - -5.0	< -15.0	Dwarakish et al. (2009)
	> 2.0	1.0 – 2.0	-1.0 – 1.0	-1.0 - -2.0	< -2.0	Pendleton et al. (2010)
	> 2.0	1.0 – 1.9	-0.9 – 0.9	-1.0 - -1.9	< -2.0	Abuodha and Woodroffe (2010)
	0.3- 0.5	0 – 0.3	-1- 0	-1.0 - -2.0	-2.0 - -4.0	Nguyen (2012)

Table 2.6 Social vulnerability ranges used by different researchers.

Variable	Rank					References
	Very low	Low	Moderate	High	Very high	
Population density, inhabitants/ km^2		1-750	750 - 1 500	1 500 - 2 250		Kafle et al. (2007)
		< 500	500 - 1 000	> 1 000		Dang et al. (2011)
		66 - 168	196 - 333	339- 2 190		Mackey and Russell (2011), whereas those in Kien Giang [268]
	< 250	250 - 500	500 - 1 000	1 000 - 2 500	> 2 500	Average in other regions in Vietnam [260]
Landuse patterns	Water	Minimal use, nature conservation, potential agricultural land	Livestock grazing, irrigated horticulture, woodland	Residential	Transport & Communication	Preston et al. (2008)
	Protected area	Unclaimed	Settlement	Industrial	Agricultural	Özyurt and Ergin (2010)
	Rocky cliffs	Scrub	Beach, sand dunes, forest, rough	Agricultural land, Tee boxes, fairways, amenity grass	Urban, residential, car parks, greens	McLaughlin and Cooper (2010)
	Forest, sea (Limited used)	Agricultural land (Low-impact used)	Living and tourism (Middle-impact used)	Industry and transport (High-impact used)		Liu (1996) and Huang et al. (2012)
		The bare land	Water/wetland, grassland	Forest, farmland	Built-up	Yin et al. (2012)
Local income level, mil.VND/capita/yr		> 6.0 million VND (US$ 375)/capita/yr	2.4 – 6.0 million VND (US$ 150 - 375)/capita/yr	< 2.4 million VND (US$ 150)/capita/yr		Dang et al. (2011)

2.7 Chapter Summary

The coast supports millions of people and has recently been considered as one of the most vulnerable areas to the impacts of climate change, particularly sea-level rise. Accordingly, there is an urgent need to undertake actions to respond to those threats that are becoming more severe.

Despite a diversity of different conceptualisations of vulnerability, the definitions and concepts of vulnerability and other related concepts provided by IPCC are considered as a starting point to explore possibilities for vulnerability assessment. Concepts of vulnerability are distinguished into two types, comprising space (i.e., internal vs. external), and factors, (i.e., biophysical vs. social). With regard to the biophysical view, vulnerability is the "end-point" of the analysis, and is conceptualised and analysed based on two components: exposure and sensitivity, and generally adaptive capacity is not accounted for in analyses. In contrast, vulnerability in the social perspective is conceptualised as a pre-existing condition of the unit regarded as a "starting-point" of analysis. Integrated approaches to vulnerability aim to address both the biophysical and social dimensions of vulnerability.

In addition, several researchers indicate that vulnerability assessments have been considered as "second generation" assessments that address relevant non-climatic drivers (i.e., economic, demographic), and the adaptive capacity of the system under analysis. This resulted in the appearance of new vulnerability driven methodologies characterised by "bottom-up" approaches, and more aligned with social and integrated perspectives on vulnerability. Currently, coastal vulnerability assessments are mainly focused on biophysical factors rather than socioeconomic effects. On the other hand, those attempts at coastal vulnerability assessment to the impacts of climate change are either too broad, (i.e., national or regional) or too narrow, (i.e., segment), and lack of consistency.

Generally there have been three methodological approaches, termed participatory, simulation-model-based and indicator-based approaches, used to make theoretical concepts operational in the context of climate change and vulnerability assessment for a great diversity of different systems, as well as spatial and temporal scales. Until now, there seems to have been no convincing framework or methodology focused on how to quantify and compare vulnerability to climate change at spatially-dependent scales using selected indicator variables, with respect to the three main components of vulnerability, and aggregated or combined into a composite

vulnerability index. Specifically, indicator-based or multi-criteria approaches, and holistic vulnerability mapping appear the best techniques to apply to the case study-site. There are four suitable case studies that can form the basis for research to be conducted in following chapters. Furthermore, a diversity of variables categorised into three components of vulnerability, exposure, sensitivity, and adaptive capacity in those vulnerability assessments, was indicated that could be considered for case study-sites (see Appendix 1). Approaches and methods used in the study area will be further discussed in chapter 3, while the background to the study area will be presented in chapter 4.

Chapter Three

Methods and datasets

3.1 Aims of this chapter

The aim of this chapter is to present methods and tools used in this study for assessing vulnerability in a way that integrates physical and social factors with respect to impacts of climate change, particularly sea-level rise. Multi-criteria and holistic mapping approaches were used to develop a final composite vulnerability index comprising three key components: exposure, sensitivity, and adaptive capacity. This was used to identify and visualise the areas most likely to be vulnerable in the seven coastal districts along the Kien Giang coast, in the western part of the Mekong River Delta in Vietnam (the MRD).

The chapter is structured as follows. Section 3.2 introduces the approach and the vulnerability indices. Section 3.3 outlines the conceptual framework for assessments. Geographic information systems (GIS) used for the assessment are described in section 3.4. Sub-section 3.4.2.1 presents tools, the Spatial Analyst Tools in particular, run in ArcGIS 10, that were used to generate and aggregate the various thematic layers based on attributes, in order to identify, and visualise the most likely hotspots vulnerable to the impacts of sea-level rise. Sub-section 3.4.2.2 presents the Digital Shoreline Analysis System (DSAS) extension tool, used to analyse shoreline change, respectively. Sub-section 3.4.2.3 outlines the analytical hierarchy process (AHP) extension tool, the multi-criteria decision making (MCDM) tool, used to obtain an overall aggregated ranking of the performance of the alternatives as to how it contributes to vulnerability. Variables, research information and datasets for the study area are described in section 3.5. A summary of this chapter is presented in section 3.6.

3.2 Introduction

The use of indices in vulnerability assessments, as outlined in the previous chapter, can help prioritise vulnerable regions, sectors or population groups, raise awareness, and be part of a monitoring strategy. Until now, there has been no consistent framework or methodology for developing vulnerability indices to quantify and compare vulnerability to climate change at spatially-dependent scales, and that addresses the three main components of vulnerability. A

consistent methodology is needed for study-site vulnerability assessment, in particular for coastal areas.

Numerous researchers indicate that the analysis of vulnerability often relies on the aggregation of variables (Cutter et al., 2000; Moss et al., 2001; Vincent, 2007; Yohe and Tol, 2002), and may be governed by local circumstances (Soares et al., 2012). Vulnerability assessment that couples biophysical and social factors seems to be more complex because the composite vulnerability index combines sets of different variables as determinants of the three main components: exposure, sensitivity, and adaptive capacity, but the data is rarely available in appropriate formats or at suitable scales. In such a situation, confusion can arise if a logical, well-structured decision-making process is not followed. Multi-criteria approaches can be useful techniques to provide "*a framework, which can handle different views on the identification of the elements of a complex decision problem, organise the elements into a hierarchical structure, and study the relationships among components of the problem*" (Boroushaki and Malczewski, 2010).

The two focus approaches to vulnerability assessment in this study, MCDM and GIS, can benefit from each other (Feizizadeh and Blaschke, 2013; Gorsevski et al., 2012; Greene et al., 2011; Phua and Minowa, 2005; Thill, 1999). MCDM provides a rich collection of techniques and procedures for structuring decision problems, and designing, evaluating and prioritising alternative decisions, whereas GIS provides a powerful platform for organisation of layers (thematic maps) in a variety of formats (e.g., raster or vector data) and plays a role in performing logical and mathematical analyses during vulnerability assessment. Indeed, GIS is often recognised "*as a decision support system involving the integration of spatially referenced data in a problem solving environment*" (Cowen, 1988).

Spatial decision problems generally involve a set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria. The alternatives are evaluated by a number of individuals (e.g., participants, decision-makers, managers, stakeholders, interest groups). The individuals are characterised by unique perceptions with respect to the relative importance of criteria on the basis of which the alternatives are evaluated. As such, AHP is one of the MCDM methods that has recently been incorporated into GIS to address decision problems with a spatial component.

3.3 Conceptual framework

A conceptual framework for the assessment was set up, following that used by the Intergovernmental Panel on Climate Change (IPCC), and adopted by the European Environment Agency (EEA, 2010; ETC/ACC, 2010). This comprises three interacting components: exposure, sensitivity, and adaptive capacity. It has been adapted for sub-national scale assessments in terms of climate-change vulnerability by Yusuf and Francisco (2009), as part of the Economy and Environment Program for Southeast Asia, which included Kien Giang province, Vietnam. This framework can be structured hierarchically, assigning correlations of variables representing physical and social factors into the three components of vulnerability. The hierarchical structure will be further discussed in section 3.4.1. The conceptual diagram for the assessment is presented in Figure 3.1.

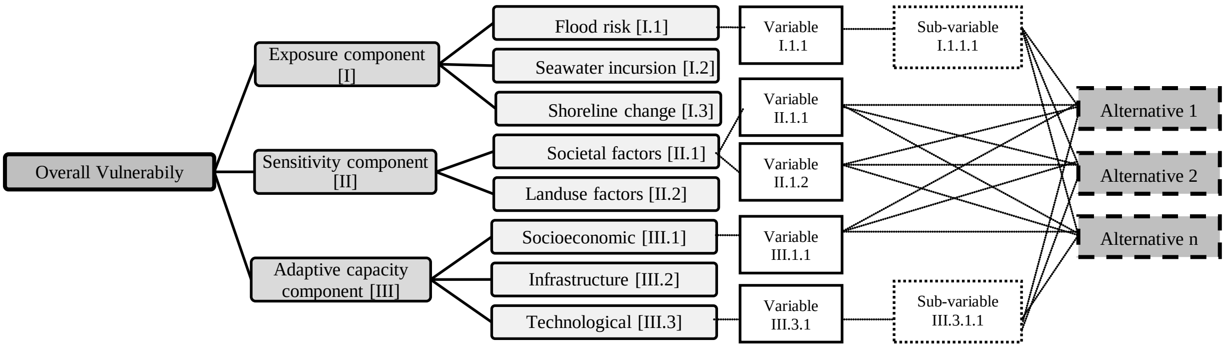


Figure 3.1 Conceptual framework for coastal vulnerability assessment of the study area (modified from EEA, 2010; ETC/ACC, 2010; Saaty, 1980; Yusuf and Francisco, 2009).

Note: An overall aggregated ranking of the alternatives intended to identify hotpots in the study region, and visualise those areas appearing most vulnerable.

Several case studies of coastal assessments have defined sub-components, and variables. The exposure component is generally assessed by using information and datasets from historical records of climate-related hazards that consider past exposure to climate risks as the best available proxy for future climate risks (Yusuf and Francisco, 2009). As seen in Figure 3.1, the exposure component for this study was represented by three sub-components: flood risk, seawater incursion, and shoreline change; these were assigned as measures of the system's exposure to sea-level rise effects. Other exposure factors such as storm-surges, drought, bushfire, and landslide were considered lesser threats and were not included for the study area.

In terms of the sensitivity component, spatial information was used to indicate "*What*" is sensitive with regard to biophysical information and could be affected (i.e., which landuse is most likely to be affected by sea-level rise), whereas the spatial information relating to social factors was also used to indicate "*Who*" is sensitive and could be affected (i.e., characteristics, such as density, of the population that is affected) (EEA, 2010; ETC/ACC, 2010). Therefore, sensitivity was represented by two key factors: societal sensitivity and landuse sensitivity factors.

In addition, sub-components of the adaptive capacity component were represented by socioeconomic, technological, and infrastructure sub-components (Yusuf and Francisco, 2009). Institutional capability (e.g., public awareness, policy foundation, and governance) was not considered as part of the adaptive capacity component, because of data limitations (see Appendix 1). Moreover, several variables such as debt, literacy, gini coefficient (proposed by Gini as a measure of inequality of income or wealth), number of civil society organisations (farmer groups, cooperatives), number of government employees, government budget for investment in social services and infrastructure measuring the adaptive capacity have not taken into account into this study because of several reasons. First, these variables are available only at large scale (obtained from the statistics data at entire provincial or district levels that are not suitable for the study). Therefore, the mappable results have been influenced markedly to scale-based input data (see Figure 5.12 and Appendix 17 for evaluation of scale-based input data (e.g., population density at different scales) in order to represent sensitivity for the study area). Second, several authors have claimed that a more detailed approach at the local and regional scale requires that coastal systems and dynamics are described in detail and using more complex and data intensive models (Torresan et al., 2008; Romieu et al., 2010). Last but not least, social vulnerability is changeable, unpredicted over time that closely refers to the two components sensitivity and adaptive capacity, in terms of measuring the vulnerability. The recent study by Mahapatra et al. (2015) also indicates that the social factors should be incorporated for coastal vulnerability index assessment.

Combining the exposure, sensitivity, and adaptive capacity components, hotspots most likely vulnerable in the assessment with regard to the importance of evaluation variables have been indicated. Moreover, Appendix 1 summarises a range of variables representing vulnerability that have been considered for the assessment.

3.4 Tools for evaluation of coastal vulnerability

Multi-criteria decision making methods have been used to analyse spatially explicit problems using GIS for at least 20 years. However, MCDM techniques have rarely been integrated directly into GIS in previous analyses because of the variety and complexity of the MCDM methods (Greene et al., 2011). Recently it has become easier to combine the two with AHP available as an extension to ArcGIS, as has been undertaken in this vulnerability assessment.

Once variables for the assessment had been selected, GIS and its geo-processing tools (e.g., Spatial Analyst tools, and extension tools) were used to capture attributes related to these selected variables from a diversity of sources (e.g., from satellite images, statistical data from reports or surveys, GPS), and in different formats (e.g., raster, or vector). These were analysed with regard to their relative weights or priorities assigned in terms of their contribution or importance to the impacts of climate change. Variables were related to the three key components: exposure, sensitivity, and adaptive capacity in a hierarchical structure. This comprised pair-wise comparisons of variables within MCDM. The final stage involved construction of an overall aggregated ranking of the alternatives intended to identify hotpots in the study region, and visualise those areas appearing most vulnerable.

3.4.1 Application of Multiple Criteria Decision Making methods

In this study, AHP, originally developed by Thomas Saaty (1980), was the Multiple Criteria Decision Making (MCDM) method used to estimate, compute, then derive relative weights of the contributing variables used as indicators of potential impacts of sea-level rise. It involved components (or criteria) and attributes to visualise the areas (alternatives) most likely to be vulnerable through pair-wise comparisons using a hierarchical structure.

Since it is known from psychological studies (Miller, 1956; Saaty, 1977) that an individual cannot simultaneously compare many elements at a time (usually no more than 7 ± 2 elements), an approach is needed that reflects, and communicates complex comparisons in terms of simple numbers, or descriptive or normative statements, that can condense the enormous complexity of real problems into a manageable amount of meaningful information. AHP provides the opportunity to do this. It is an intuitive and relatively easy method for formulating, and analysing decisions (Harker, 1989); a tool to permit explicit exhibition of appraisement criteria and also a multi-attribute decision method, which refers to a quantitative technique (DeSteiguer et al., 2003); and it can be integrated with qualitative data (Lee et al.,

2001; Stephen and Downing, 2001). The application of AHP can handle complicated geographical situations, where different weights are assigned (Mahapatra et al., 2015).

The value of AHP has been increasingly recognised in developed and developing countries around the world, particularly since 2005 (Sipahi and Timor, 2010). For example, in China nearly a hundred universities around offer courses in AHP, and numerous doctoral students choose AHP as the subject of their research and dissertations. Over 900 papers have been published on AHP applications in China, and there is at least one Chinese scholarly journal devoted exclusively to AHP (Sun, 2005). AHP has been used in the analysis of a wide range of topics (such as: establishing payment standards for surgical specialists, strategic technology road-mapping, infrastructure reconstruction in devastated countries, economic stabilisation in Latvia, portfolio selection in the banking sector, wildfire management to help mitigate global warming, and rural micro-projects in Nepal in the 2005, 2007, 2009). Several researchers have used the AHP tool in a range of fields, such as impacts of climate change on transportation sectors (Berrittella et al., 2007), eco-environmental quality assessment (Zhang and Cai, 2012), site allocation (Chen, 2006; Şener et al., 2011), mining (Huang, S. B. et al., 2012), vulnerability of catchments (Chang and Chao, 2012; Kienberger et al., 2009), flood risk assessment in the context of climate change (Chen et al., 2011; Nguyen, D. M. et al., 2011; Qiang et al., 2013; Wu et al., 2011), landslides (Hasekioğulları and Ercanoglu, 2012; Yoshimatsu and Abe, 2006), forests and bushfire (Laxmi-Kant et al., 2012; Sharma et al., 2012), land-use suitability in coastal areas (Bagheri et al., 2013) or for resource planning (Nyeko, 2012), risk assessment of coastal erosion in deltas (Li et al., 2010), the physical vulnerability of coastal areas at regional scales (Le Cozannet et al., 2013), and coastal beach exploitation (Tian et al., 2013), or for coastal vulnerability assessment (Duriyapong and Nakhapakorn, 2011; Lin and Lee, 2012; Mahapatra et al., 2015).

Further details about procedure, involving the following three key steps of AHP, can be found in Saaty's papers (1977, 1980, 1987, 1990, 2003), Harker and Vargas (1987), and Malczewski (1999).

- **Decomposition into a hierarchical structure comprising components, sub-components, variables, and sub-variables**. Decomposition into a hierarchy has often been based on previous studies and empirical experiences.

In its most typical form, a hierarchy is often structured from the top (i.e., objectives from the managerial standpoint) through the immediate levels (i.e., components, sub-components, variables, and sub-variables chosen as reference to evaluate one product, process or condition to that subsequent levels depend on), and on to the lowest level (i.e., which is a list of alternatives referring to the objects, cases (study areas) that will be compared and ranked to achieve the objective) (see Figure 3.3).

The objective of this study has already been defined, and the problem has been hierarchically structured with components, sub-components, variables, sub-variables broken down into each level of the problem, with layer-by-layer dominant relationships from top (i.e., assigning as the objective) to bottom (i.e., assigning as the alternatives).

- **Comparative judgments, defining, and executing data collection to obtain pair-wise comparisons within the hierarchical structure.** The comparison uses pair-wise matrices in which the decision-makers fill each upper diagonal element with a value obtained from the fundamental rule scale for pair-wise judgments following Saaty (1980). In the construction of pair-wise comparison matrix, each factor is rated against every other by assigning a relative dominant value between 1 and 9 (see Table 3.1). The lower triangular portion of the square matrix is completed with reciprocal values to those in the upper triangular portion; The variables are compared pair-wise with respect to their impacts on an element above them in the hierarchy to determine their relative importance, while the alternatives are compared pair-wise with respect to each evaluation variable to determine the relative ranking of the alternatives.

- Finally, **synthesis of priorities (determination of mean weights of each component); constructing an overall ranking of the alternatives and simultaneously testing consistency.** Assessment of matrix consistency employing consistency measures proposed by Saaty (1977). Computation of the weighted scoring index to compare the overall performance of the alternatives in order to answer the initial goal of the procedure (see Equations 3.2 to 3.10; Tables 3.2, and 3.3).

Table 3.1 The fundamental AHP scale for pair-wise comparisons by Saaty (1980).

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment moderately favours one element over another
5	Strong importance	Experience and judgment strongly favours one element over another
7	Very strong importance	One element is favoured very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation

Note: Values of 2, 4, 6, and 8 can be used to express intermediate values. Values of 1.1, 1.2, 1.3, etc can be used for elements that are very close in importance.

Example of AHP applied to coastal vulnerability assessment index

In the study by Preston et al. (2008), a climate change induced sea-level rise index is constructed comprising three key components: exposure [E], sensitivity [S], and adaptive capacity [A]. [E] was judged to have a particularly high influence on vulnerability [V] because of the fact that the existence of coastal impacts presupposes proximity to the coastline, and was assigned a weight of 2. [S] was assigned a common weight of 1, while [A] was judged to have a low influence on [V], and was assigned a weight of 0.5, due to the fact that:

- The [A] does not necessarily contribute to effective adaptation.
- The [A] can never eliminate all vulnerability.
- Responsibility for management of some risks may be beyond the household, local authorities or community levels.
- The [A] of some systems (e.g., natural ecosystems) is quite limited.

The way that AHP works is demonstrated below using an example from the Preston et al. (2008). Once the hierarchy has been structured, starting with level 1 (assinging three components), and proceeding to level 0 (see Figure 3.1) and pair-wise comparison matrix, determining which of each pair-wise variable was more important with respect to impacts of sea-level rise, is presented in Eq 3.1.

- The value of “1.6” implies that [E] is roughly equal importance to [S] (see Table 3.1), comparing [E] to [S].
- Similarly, the value of “8” implies that [E] is extremely important compared to [A], comparing [E] to [A].

- In addition, the value of "2.55" indicates that [S] is moderately important compared to [A], comparing [S] to [A].
- A reciprocal matrix was obtained when the lower triangular portion of the matrix was completed with the reciprocal values of those used in the upper triangular portion.

For computing the priorities of the elements, a judgmental matrix (*A*) is assumed as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1k} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2k} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & a_{ij} & \cdots \\ a_{k1} & a_{k2} & \cdots & \cdots & a_{kk} \end{bmatrix} \quad or \quad \begin{vmatrix} \mathbf{1} & 1.6 & 8 \\ 1/_{1.6} & \mathbf{1} & 2.55 \\ 1/_{8} & 1/_{2.55} & \mathbf{1} \end{vmatrix} \qquad \textbf{Eq 3.1}$$

Where, *A* = positive pair-wise comparison matrix of order k (k by k matrices); a_{ij} represents the pair-wise comparison rating between the element i and element j. The entries a_{ij} are governed by the following rules: $a_{ij} > 0$; the matrix has reciprocal properties, which are $a_{ij}=1/a_{ji}$ with every i, j ($\forall i, j \in k$), and $a_{ii}=1$ with $\forall i, \in k$.

Each column of the pair-wise comparison matrix is normalised by Eq 3.2, and relative weights (w_i) of each component are normalised and computed by averaging across the rows by Eq 3.3 as follows:

$$a_{ij}^{*} = \frac{a_{ij}}{\sum_{i=1}^{k} a_{ij}} \qquad \forall i, j \in k \qquad \textbf{Eq 3.2}$$

and

$$w_i = \frac{\sum_{j=1}^{k} a_{ij}^{*}}{k} \qquad \forall i, j \in k \quad or \quad w_i = \begin{pmatrix} 0.5996 \\ 0.3038 \\ 0.0962 \end{pmatrix} \qquad \textbf{Eq 3.3}$$

Judgment Matrix Consistency Measurement

The normalised eigen vector is also called priority vector. Since it is normalised, the sum of all elements in priority vector is 1. Apart from the relative weight, it is importance of consistency assessment of the judgment matrix due to dealing with human judgement. There is a relationship between the pair-wise comparison matrix (*A*), and the vector weights/ or priorities (w) according to Saaty (1980), as shown in Eq 3.4.

$$Aw = \lambda_{max} \cdot w_i \qquad \textbf{Eq 3.4}$$

$$or\ Aw = \begin{pmatrix} 1 & 1.6 & 8 \\ 1/1.6 & 1 & 2.55 \\ 1/8 & 1/2.55 & 1 \end{pmatrix} \begin{pmatrix} 0.5996 \\ 0.3038 \\ 0.0962 \end{pmatrix} = \begin{pmatrix} 1.8555 \\ 0.9239 \\ 0.2903 \end{pmatrix}$$

The eigen value is obtained from the summation of products between each element of eigen vector and the sum of columns of the reciprocal matrix. λ_{max} is the largest eigen value of the matrix *A*. For the example of Preston et al. (2008), according to Eq 3.4, with n = 3 (the number of comparisons), λ_{max} is obtained from Eq 3.5:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{k} \frac{(Aw)i}{w_i} \qquad \textbf{Eq 3.5}$$

$$\text{or } \lambda_{max} = \frac{1}{3}\left(\frac{1.8555}{0.5996} + \frac{0.9239}{0.3038} + \frac{0.2903}{0.0962}\right) = 3.051$$

Saaty proposed a measure of consistency, called the consistency index (CI) as deviation or degree of consistency that can be obtained from Eq 3.6, and the consistency ratio (CR) can be calculated using Eq 3.7.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \text{or} \quad CI = \frac{3.051 - 3}{3 - 1} = 0.0255 \qquad \textbf{Eq 3.6}$$

and,

$$CR = \frac{CI}{RI} \quad \text{or} \quad CR = \frac{0.0255}{0.52} = 0.049 \qquad \textbf{Eq 3.7}$$

Where, the random consistency index (RI) is obtained from a randomly generated pair-wise comparison matrix. The values of the RI from matrices of order 1 to 15 as proposed by Saaty (1980), are presented in Table 3.2.

Table 3.2 The Random Consistency Index (RI) by Saaty (1980).

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

Note: n: numbers of variables; RI: the random consistency index by Saaty (1980)

In general, a CR of 0.1 or less is considered acceptable. If the value is higher, the judgments may not be reliable and should be elicited again. More recently, Saaty (1994) suggested CR thresholds of 0.05 and 0.08 for 3 by 3 and 4 by 4 matrices, respectively. Considering that the

CR value obtained in this example (0.049; Eq 3.7) is inferior to proposed limits, the consistency of the matrix is accepted and the normalised weights are confirmed as 0.5996 (Exposure), 0.3038 (Sensitivity), and 0.0962 (Adaptive Capacity), as demonstrated by Eq 3.3.

A pair-wise comparisons matrix and derived relative weights of the three components: exposure, sensitivity, and adaptive capacity, measuring the impacts of sea-level rise by using AHP for the example of Preston et al. (2008), is sumarised in Table 3.3.

Table 3.3 Pair-wise comparisons matrix, comprising three components: exposure, sensitivity, and adaptive capacity, and relative weights by AHP, derived for the study of Preston et al. (2008).

CVI	E	S	A	w
E	1	1.6	8	0.5996
S	1/1.6	1	2.55	0.3038
A	1/8	1/2.55	1	0.0962

Note: CI = 0.0255; RI = 0.52; CR = 0.049 (< 0.05: acceptable).

Computing the overall composite weight of each alternative

Once the priorities of components of different levels are accepted, in order to obtain a final ranking of the alternatives a_i, the priorities are aggregated as follows:

$$S\,(a_i) = \sum_k w_k S_k(a_i) \qquad \textbf{Eq 3.8}$$

Where, w_k is the local priority of the component k (level 1) and $S_k(a_i)$ is the priority of attribute (level 2) with respect to component k of the upper level.

Subsequently, the normalized weights of each one of the three components (results from Eq. 3.3) are aggregated to Eq 3.8, in order to obtain the final composite vulnerability index to each alternative, as indicated in Eq 3.9:

V = 0.5996 E + 0.3038 S + 0.0962 A **Eq 3.9**

Similarly, in the example of constructing a climate change vulnerability index (CCVI) of Yusuf and Francisco (2009), for the sub-national areas (regions/districts/provinces) in Southeast Asia, including the Kien Giang province, as mentioned in chapter 2, the three key components: E, S , and A were assigned as of equal importance. Weights of E, S, and A in AHP, therefore, are computed as 0.3333, 0.3333, and 0.3333, respectively, with CR = 0.0000. Table 3.4 summarises the relative weights of components with regard to climate change and

sea-level rise impacts derived from AHP from the assessments conducted by Preston et al. (2008) and Yusuf and Francisco (2009).

Table 3.4 A summary of relative weights used in AHP calculation for the three components: exposure, sensitivity, and adaptive capacity with regards to vulnerability to climate change induced sea-level rise.

References/ Component	Climate related hazards study of Yusuf and Francisco (2009)		Impacts of sea-level rise study of Preston et al. (2008)	
	Original weights	Relative weights, w	Original weights	Relative weights, w
Exposure	1/3	0.3333	2	0.5996
Sensitivity	1/3	0.3333	1	0.3038
Adaptive capacity	1/3	0.3333	0.5	0.0962
The consistency ratio		*0.0000*		*0.0490*

Table 3.4 shows that the results derived from AHP may be different in studies using similar approaches depending on the subjective and objective judgments in the assessment. For instance, Preston et al. (2008) judged the adaptive capacity component to have a low influence on coastal vulnerability in terms of impacts of sea-level rise, assigning it a weight of 0.5, while they judged the exposure component to have a particularly high influence on vulnerability assigning it a weight of 2. On the other hand, Yusuf and Francisco (2009) assessed that the three components exposure, sensitivity, and adaptive capacity were of equal importance with respect to the objective of measuring CCVI, focusing on climate related hazards, and assigned a weight of 1/3 for each component respectively.

In summary, AHP plays an important role because it captures both subjective and objective evaluation measures. The AHP process provides a logical framework to determine the ranking of each alternative towards achieving the objective. Furthermore, the AHP tool provides a useful mechanism for checking the consistency of the judgments measures and alternatives suggested by decision-makers, therefore, reducing the subjective judgments in decision making. The AHP tool will be used to assess the vulnerability of the seven coastal districts along the Kien Giang province to sea-level rise, and results, and discussion will be presented in the following chapters 5, and 6.

3.4.2 Application of Geographic Information Systems

GIS has been considered a powerful platform in terms of assessment, planning, and management of landuse, natural resources, environment and climate change for some time (Hopley et al., 2006; McIntyre, 2007; Preston et al., 2008; Schleupner, 2009; Vafeidis et al.,

2004; Woodroffe et al., 2007). The ArcGIS 10 software application developed by ESRI, was used for this assessment of Kien Giang. Once information and datasets had been obtained from a diversity of sources, various tools, in particular, the Spatial Analyst Tools, were used to generate a series of thematic layers determined from selected variables or sub-variables (see Figure 3.2). These tools will be further explained in sub-section 3.4.2.1.

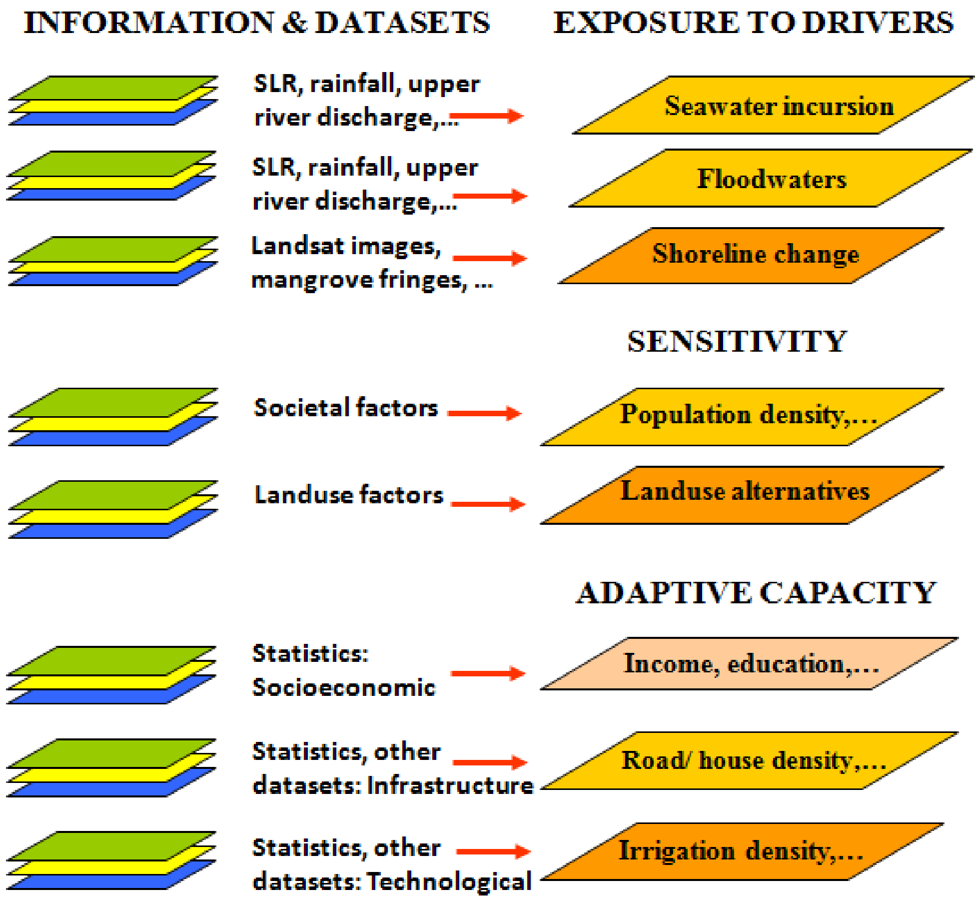


Figure 3.2 Schematic outline of information and datasets input into GIS to generate thematic layers in the coastal vulnerability assessment, comprising of the three components: exposure, sensitivity, and adaptive capacity.

Additionally, two important extension tools:

- The DSAS 4.3 tool (Thieler et al., 2009), an extension to ArcMap 10 developed by the United States Geological Survey (USGS), was used to assess temporal shoreline change (see details in sub-section 3.4.2.2).
- The AHP extension tool developed by the Satecs was used to derive the relative weights of variables by judging their importance, and obtaining an overall aggregated ranking of the alternatives with regard to vulnerability (see details in sub-section 3.4.2.3).

Finally, the areas (or hotpots) most likely to be vulnerable were identified and visualised in the study area, using a series of maps (e.g., thematic sub-components and components). Variables, research information, and datasets for the study area will be further described in section 3.5. Figure 3.3 summarises variables, and sub-variables used in the sub-components, and their hierarchical incorporation into components using the AHP method (of MCDM) in GIS, to obtain a vulnerability levels map for the study area. The hierarchical structure used to map coastal vulnerability in the study area is shown in Figure 3.3. The coastal vulnerability assessment was divided into six levels (see Figure 3.1), whereas background for the study area will be presented in the next chapter, chapter 4.

- Overall vulnerability was assigned as level 0.
- Level 1 consists of the *three components*: exposure, sensitivity, and adaptive capacity.
- Level 2 comprises *eight sub-components*: three geo-physical sub-components: seawater incursion, flood depth, and shoreline change; two social sensitivity sub-components: societal factors, and landuse factors; and, three adaptive capacity sub-components: socioeconomic, technological, and infrastructure conditions.
- Beyond this, a further *twenty-two variables* and *twenty-four sub-variables*, related to vulnerability were also assigned to levels 3, and 4 respectively.
- The mapping was undertaken for *the seven* coastal districts of the Kien Giang coast: Ha Tien, Kien Luong, Hon Dat, Rach Gia, Chau Thanh, An Bien, and An Minh, related to alternatives was assigned to the lowest level.

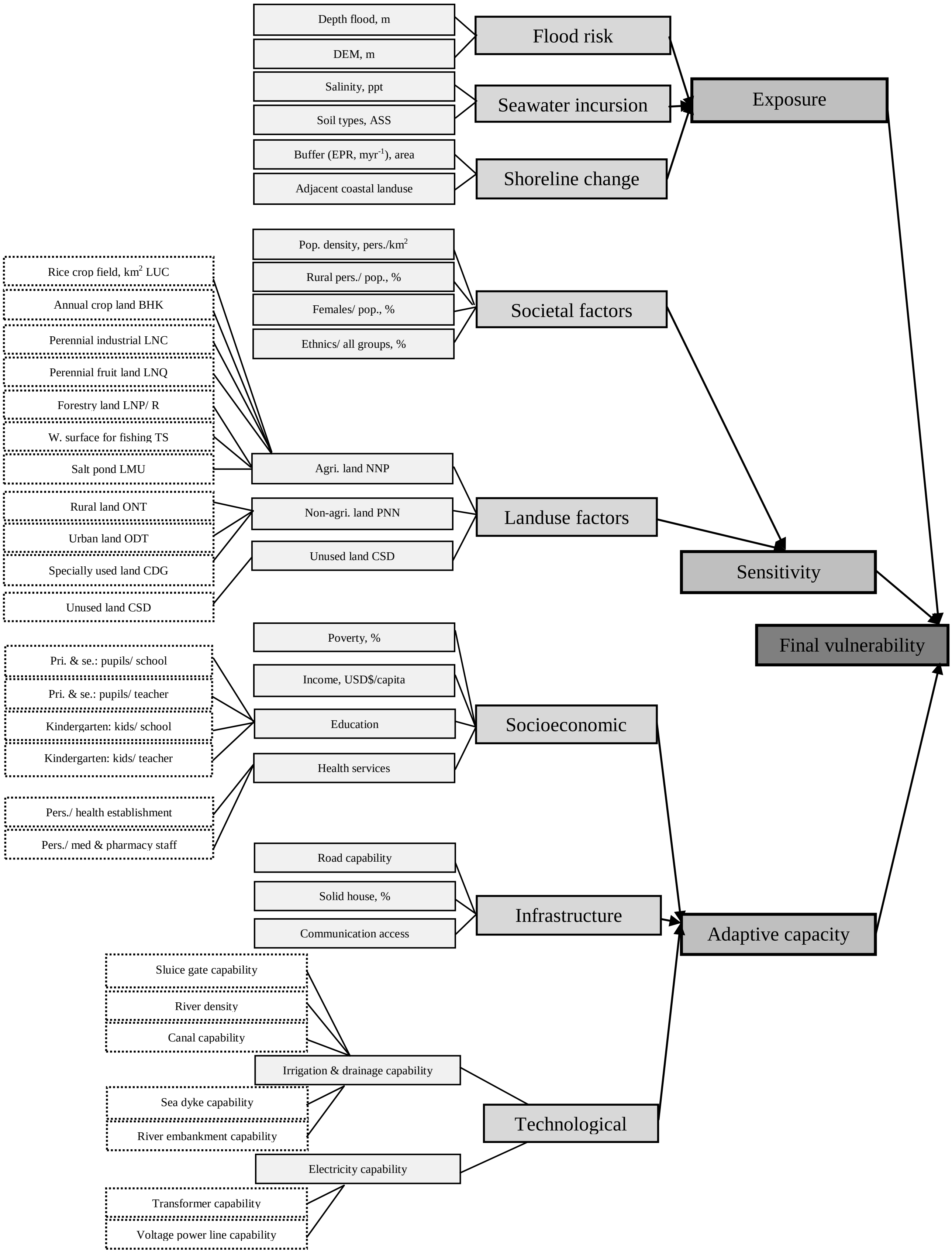
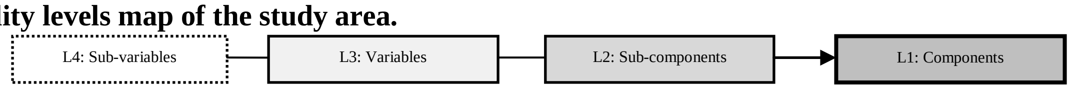


Figure 3.3 Variables and sub-variables used in the sub-components and their hierarchical incorporation into components using the AHP method (of MCDM) in GIS, to obtain a vulnerability levels map of the study area.



3.4.2.1 The Spatial Analyst Tools

The diversity of data sources, formats, and spatial scales from which information was derived for the study area necessitated conversion to a common spatial reference before they could be integrated. A spatially homogenous scale of the 30 m resolution (cell-size of 30 m) raster data was used over the seven coastal districts along the Kien Giang coast. This represented the highest resolution at which the majority of datasets were available for the region, corresponding with 30x30 m, and 60x60 m in area of each cell-size of Landsat images downloaded freely from databases of the United States Geological Survey (USGS) and the Global Land Cover Facility, Maryland (GLCF). A digital elevation model (DEM), with the 15 m resolution (15x15 m in area of each cell-size), was obtained from the database of the National research program of science and technology (KHCN-BDKH/11-15; code BDKH.08), undertaken by Tran et al. (2013). Other datasets were processed to match this spatial reference using one of the following methods:

- **For vector/polygon data:** vector polygon data were converted to the 30 m resolution raster by using The Conversion Tools in the ArcToolbox.
- **For vector/polyline and point data:** the Kernel density tool in the Spatial Analyst Tools was used in the environment settings with the 30 m resolution of raster analysis.
- **For grid raster data:** data were converted to integer raster data by using the Math tool in the Spatial Analyst Tools in the environment settings with the 30 m resolution of raster analysis.

Data conversion introduced uncertainty into the variables. However, the implications of data heterogeneities for vulnerability estimates were judged to be negligible for several reasons.

- All variables were converted to a qualitative ranking and maps represent relative vulnerability, as opposed to absolute measures of consequence or impact. Once data layers were converted to a common spatial reference, data were assigned a qualitative ranking from 1 to 9, with 1 representing low exposure, low sensitivity or high adaptive capacity, and 9 representing high exposure, and sensitivity or low adaptive capacity. In most instances, scoring was accomplished by using the Manual classification method to reclassify data to a classification range, based on its specific contribution to sea-level rise effects. In some instances, the Jenks's Natural Breaks algorithm (Jenks) was used to reclassify data to assign the scores from 1 to 9 (see Table 3.14). One the one hand, a method of Manual data classification refers to seek to partition data into classes according to natural groups in the data distribution. One the other hand, Natural Breaks occur in the histogram at the low points

of valleys. Breaks are assigned in the order of the size of the valleys, with the largest valley being assigned the first natural break.

- It is import to identify the functional relationship between the variables and vulnerability (the correlation structure). Two types of functional relationship are possible: vulnerability increases as the value of the variables increases (or decreases in the case of adaptive capacity). For instance, presumably a system is likely to be significantly vulnerable if it is highly exposed to climate change impacts, if it is highly sensitive to those impacts, and if it has a low capacity to cope with those impacts. Therefore, the exposure, and sensitivity have proportional relationships regarding their contributions to vulnerability, whereas adaptive capacity has inversely proportional relationships to vulnerability. These functional relationships should be taken into account in aggregation of the variables to avoid misleading inferences. Accordingly, variables were converted to a quantitative scale and the functional relationship normalised between the variables and vulnerability to a standard spatial reference prior to their integration. Normalisation of individual variables, therefore, provides a linear transformation that preserves the ranking, and the correlation structure of the original data, and allows for variables with different scales to be integrated (Tran et al., 2010).

- Vulnerability for the study area was assessed through the aggregation of three maps representing separately the different components of vulnerability: exposure, sensitivity, and adaptive capacity. Integration of variables for each component of vulnerability was achieved by using AHP to calculate the relative weights of all variables. Different sub-components, and the three components were weighted in the calculation of vulnerability, in regard to their relative importance. For example, in some instances, the climate conditions to which an area is exposed may be a secondary consideration, with respect to vulnerability in comparison to the sensitivity of the people or infrastructure. Similarly, capacity to adapt does not necessarily mean that vulnerability does not exist, particularly for those areas routinely exposed to unavoidable hazards. Finally, the aggregation of the three component layers was accomplished by summing the relative weights from the three vulnerability layers, with the result again being re-scored to a scale/ranking from 1 to 5, with 1 representing very low exposure, very low sensitivity or very high adaptive capacity and 5 representing very high exposure, very high sensitivity or very low adaptive capacity. The application of AHP to study area will be further discussed in sub-section 3.4.2.3.

3.4.2.2 The Digital Shoreline Analysis System extension tool

The DSAS 4.3 tool (Thieler et al., 2009), an extension to ArcGIS 10 developed by the United States Geological Survey (USGS), was used to determine past rates of shoreline change (e.g., erosion) over a period of time in the seven coastal districts along the Kien Giang coast. Figure 3.4 shows the DSAS icon run in the ArcMap environment.

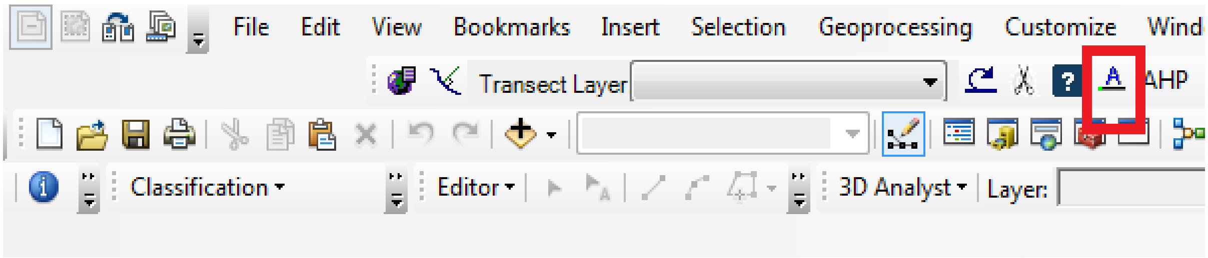


Figure 3.4 The DSAS icon run in the ArcMap environment.

Landsat images downloaded from the database of the USGS, and the GLCF, over the 40-year period along the Kien Giang coast, were geo-referenced and rectified, and then digitised to create a single shoreline position (e.g., format shapefiles as polylines) in each specific year. Details of these images will be presented in sub-section 3.5.2.3.

The initial preparation step is taken to reference all shorelines to the same features (e.g., water/vegetation indicators selected). Each shoreline represents a specific position at a particular time period, and must be assigned to that date in the shoreline feature-class attribute table (Thieler et al., 2009). The baseline is constructed by the user and serves as the starting point for all transects cast by the DSAS application. A baseline is defined and transects are cast, with change determined in position at which transects intersect shorelines. Transects were placed perpendicular to the shorelines and a baseline along the Kien Giang coast to calculate EPR and NSM. These results were derived to evaluate the areas of shoreline change and their trends (e.g., erosion, stability, and accretion) for the study area. DSAS uses a measurement baseline method to calculate rate of change statistics for a time series of shorelines. The process of historical shoreline interpretation is presented in Figure 3.5.

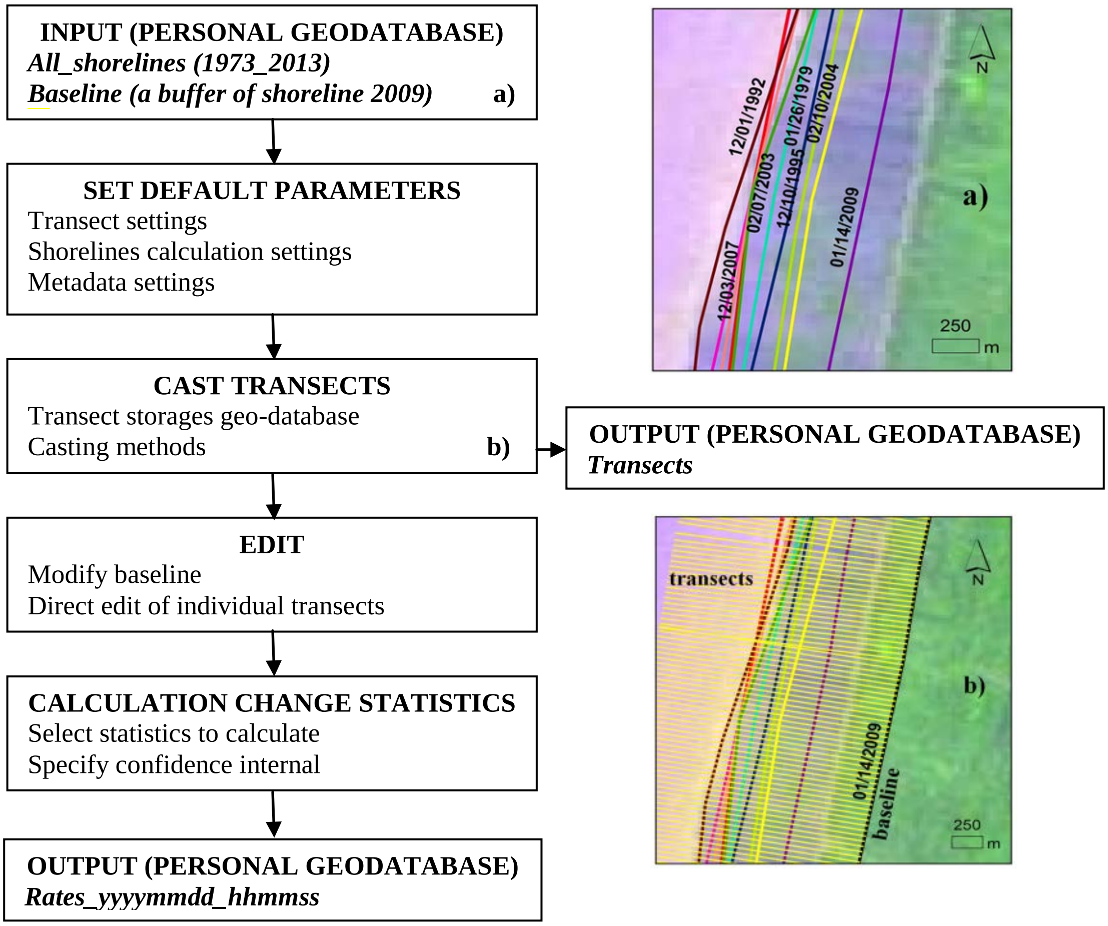


Figure 3.5 Diagram illustrating the steps to establish transects locations and compute change rate statistics by using DSAS, (derived from Thieler et al., 2009).

Three statistical methods were used to calculate the rate of shoreline change based on distances between positions from 1973 to 2013; these include the end point rate (EPR), the net shoreline movement (NSM) and the linear regression rate (LRR):

- **The end point rate** was calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. The major advantages of the EPR are the ease of computation and minimal requirement of only two shoreline dates.

EPR (m/ year) = distance/ (time between the oldest and youngest shorelines).

- **The net shoreline movement** was used to calculate a distance, not a rate. The NSM is associated with the dates of only two shorelines. It reports the distance between the oldest and youngest shorelines for each transect. This represents the total distance between the oldest and youngest shorelines.

NSM (m) = distance between the oldest and the youngest shorelines.

- **A linear regression rate of change statistic** was determined by fitting a least squared regression line to all shoreline points for each individual transect. The linear regression rate is the slope of the line.

There are a number of uncertainty sources that may affect historical shoreline mapping and change rates (Cenci et al., 2013; Fletcher et al., 2003; Morton et al., 2004; Thieler et al., 2009). In this study, seasonal error, digitising error, pixel error, and geometric or rectification error were considered as sources of uncertainty. These errors were assumed to be uncorrelated and random, and quantified by calculating the square root of the sum of the squares of all uncertainty factors (Fletcher et al., 2003). The positional errors for each period can be incorporated into an error for each transect. The value can be annualised to provide an estimation for the shoreline change rate at any given transect (Morton et al., 2004).

Results, and discussion using the DSAS tool for coastal vulnerability assessment along the Kien Giang coast are presented in chapter 5 (sub-section 5.3.3).

3.4.2.3 The Analytical Hierarchy Process extension tool

The AHP extension tool, developed freely for non-commercial use only by the Satecs, is run in the ArcMap environment as shown in Figure 3.6. AHP enables all variables, which are considered relevant for making a decision related to the objective to be compared against each other in a pair-wise comparison matrix, expressing the relative preference among the variables. Input requirements are the classified raster datasets. ArcMap performs a raster operation and calculates the weighted sum of the previously defined variable rasters. The number of variables, which can be used for the analysis, is limited to 20 and a minimum of two rasters is required.

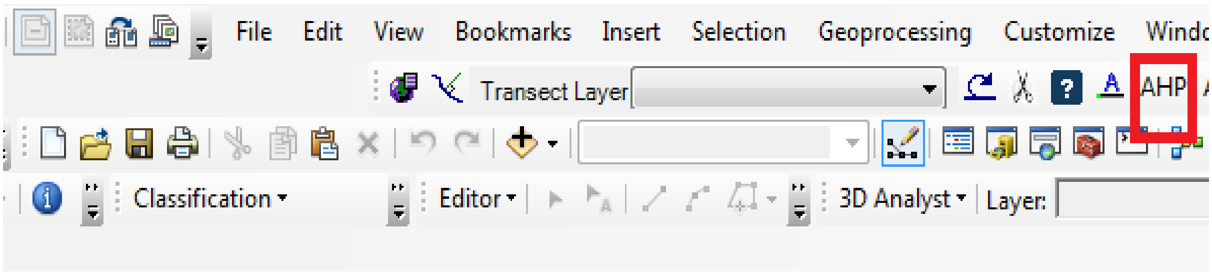


Figure 3.6 The AHP icon run in the ArcMap environment.

All variables were converted to classified integer raster datasets, prior to using AHP, to estimate the overall priorities or relative weights for the study area. The range of classified

variables used is summarised in Table 3.5. Results and discussion using the AHP tool for coastal vulnerability assessment along the coastal districts in Kien Giang are presented in chapters 5, and 6.

3.5 Variables, research information and datasets for the study area

Since vulnerability is multi-dimensional, dynamic in time, scale-dependent and site-specific, different variables were selected according to the scale of the analysis, and the available data from a range of sources, such as field observations, or statistical results. The first important step in indicator-based approaches for vulnerability assessment, as outlined in the literature review in the previous chapter, is to select the variables. Therefore, it is essential to identify the criteria for the selection of key variables involving components, sub-components, variables or sub-variables, which can be used for a specific study area. The aim is to compile a list of proxies using the following criteria. First, the sub-variables, variables, sub-components, and components must describe the local physical and social factors as determinants contributing to or influencing vulnerability of a specific system. Second, the data must be available, accessible, reliable, and reducible for each component. Finally, variables need to be independent, measurable, and relevant to collection.

3.5.1 Variables for coastal study-site vulnerability assessment

As summarised in sub-section 3.4.2.1, in order to construct a composite index of vulnerability for the study area (assigning the objective of measuring vulnerability as level 0), data were needed at several levels. This included *3 components*: exposure, sensitivity, and adaptive capacity (level 1); *8 sub-components*: 3 geo-physical sub-components: seawater incursion, flood depth, and shoreline change, and 5 social sub-components: societal sensitivity, landuse sensitivity, and three adaptive capacity sub-components: socioeconomic, infrastructure, and technological (level 2); beyond which a further *22 variables* (level 3) and *24 sub-variables* (level 4) were assigned according to specific relationships between the variables and vulnerability (see Figure 3.3). In fact, variables were, obtained from a diverse array of sources, including data on current and future scenarios, and in different formats. Table 3.5 presents the selected variables for the assessment of the study area. In addition, the spatial extent or resolution of the original dataset appears in parentheses following the variable.

Table 3.5 Datasets acquired used in this assessment.

Exposure Component	Sensitivity Component	Adaptive Capacity Component
1. Elevation (raster 15m)	*Societal factors* (statistical data district)	*Socioeconomic capability*
2. Flood depth for 3 scenarios: baseline (in 2000), in 2030, and in 2050 (raster 15m and 30m)	1. Population density (statistical data district/ convert / raster 30m)	1. Income (district survey/ convert/ raster 30m)
3. Shoreline displacement (buffer 1km/ raster 30m and 60m)	2. Rural people (statistical data district/ convert / raster 30m)	2. Poverty ratio (statistical data district/ convert / raster 30m)
4. Adjacent coastal landuse (convert/ raster 30m)	3. Female people (statistical data district/ convert / raster 30m)	3. Education (statistical data district/ convert/ raster 30m)
5. Seawater incursion for 3 maps/scenarios: in 2010, in 2030, and in 2050 (raster 15m and 30m)	4. Ethnicity (district survey/ convert/ raster 30m)	3.1 Kids per kindergarten school (statistical data district/ convert/ raster 30m)
6. Soil types (convert/ raster 30m)	*Landuse factors* (convert / raster 30m)	3.2 Kids per kindergarten teacher (statistical data district/ convert/ raster 30m)
	5. Agricultural land (convert / raster 30m)	3.3 Pupils per primary and secondary school (statistical data district/ convert/ raster 30m)
	5.1 Rice cropland (convert / raster 30m)	3.4 Pupils per primary and secondary teacher (statistical data district/ convert/ raster 30m)
	5.2 Annual planted land (convert / raster 30m)	4. Health services (statistical data district/ convert/ raster 30m)
	5.3 Perennial cropland (convert / raster 30m)	4.1 Inhabitants per health establishment (statistical data district/ convert/ raster 30m)
	5.4 Forest land (convert / raster 30m)	4.2 Inhabitants per health staff (statistical data district/ convert/ raster 30m)
	5.5 Fishery land (convert / raster 30m)	*Infrastructure capability*
	6. Non-agricultural land (convert / raster 30m)	5. Houses (Households having solid houses) (statistical data district/ convert/ raster 30m)
	6.1 Special landuse (convert / raster 30m)	6. Communication access (Fixed-line telephone subscribers) (statistical data district/ convert/ raster 30m)
	6.2 Urban residential area (convert / raster 30m)	7. Road capability (a Kernel function radius 5km/ raster 30m)
	6.3 Rural residential area (convert / raster 30m)	*Technological capability*
	7. Unused land (convert / raster 30m)	8. Irrigation and drainage capability (raster 30m)
		8.1 Sluice gate capability (raster 30m)
		8.2 Canal capability (raster 30m)
		8.3 River density (raster 30m)
		8.4 River embankment capability (raster 30m)
		8.5 Sea dyke capability (raster 30m)
		9. Electricity capability (raster 30m)
		9.1 Transformer capability (raster 30m)
		9.2 Voltage power line capability (raster 30m)

As seen in Table 3.5, the coarsest resolution of rasters used for the study area is 60 m, derived from the Landsat images of 60x60 m in area of each cell-size. The sources of datasets for each component, and explanations of variables will be given in the following sub-sections. However, in the case of sub-components related to societal sensitivity, socioeconomic and infrastructure adaptive capacity, statistical data are only accessible at the spatial extent of the district, which imposes some further limitations.

3.5.2 Research information and datasets for the study area

Research information and primary and secondary datasets will be outlined in the following sub-sections to clarify selected variables and accessible data sources respectively for the study area. An explanation of the proxies selected for variables for the study area is presented in Tables 3.6, 3.8, and 3.9, with respect to the three key components: exposure, sensitivity, and adaptive capacity, respectively.

3.5.2.1 Explanations of variables and main sources

For the study area, flooding and inundation can result from three main types of floods. These are river floods, coastal floods, and urban floods. Three proxies, as seen in Table 3.6, would be appropriate to describe exposure to the flood risk sub-component: depth, duration, and flow velocity (Nguyen, D. M. et al., 2011). In fact, there is insufficient data for each of these for the study area. However, Dinh et al. (2012) indicate that the depth of flood proxy is considered the most important of these. Therefore, flood depth was chosen as a proxy of flood impacts for the study area.

Table 3.6 Variables and proxies for the exposure component of the assessment.

Sub-component	Variable	Proxy	Sources
Flood	Depth	A range of flood depth, m Area of inundation	IMHEN (2010a); Mackey and Russell (2011); Mainuddin et al. (2010); Tran et al. (2013)
	Duration		Not available - NA
	Velocity		NA
	DEM	Elevation, m (a MSL)	Tran et al. (2013)
Seawater incursion	Salinity	A range of salinity incursion, ppt Area of incursion	Mackey and Russell (2011); Le and Le (2013)
	Soil types	ASS classified by FAO	MONRE, undated and modified by the author, 2013
Shoreline change	End point rate	A rate of shoreline displacement, m/year; Buffer 1km	Landsat images &DSAS
	Adjacent coastal landuse	LULC, however focused on forests tolerant to brackish conditions	MARD, 2010 and modified by the author, 2013

Three scenarios of flood depth for the study area were obtained (with the necessary permissions) from models built as part of relevant projects (IMHEN, 2010a; Mackey and Russell, 2011; Mainuddin et al., 2010; Tran, H. T. et al., 2013). These include:

- A baseline scenario represented by extreme historical flood depth that was observed in the year 2000.
- Scenario Flood 1 (F1) projected future events for 15 cm sea-level rise under an A2 emissions scenario through upstream discharge through Kratie station in Cambodia from June to November (in high-flow season) by the year 2030.
- Scenario Flood 2 (F2) projected future events for 30 cm sea-level rise by the year 2050 (see a summary of these scenarios in Table 3.7).

In addition, an elevation proxy, derived from the DEM was considered as another proxy for the flood risk sub-component (Kuenzer et al., 2013). The DEM was obtained from the project, undertaken by Tran et al. (2013), and will be described in sub-section 3.5.2.2.

Additionally, three simulated scenarios of salinity incursion were obtained for the seawater incursion sub-component from a collaborative project between Sinclair Knight Merz (SKM), the Vietnam Institute of Meteorology, Hydrology, and Environment (IMHEN), and the Kien Giang Peoples Committee, undertaken by Mackey and Russell (2011). Together, three maps of maximum seawater incursion in specific years were used for the analysis obtained from a national research program of science and technology (KHCN-BDKH/11-15, code BDKH.05) on the causes of seawater incursion and solutions for the MRD, undertaken in the context of climate change by Le and Le (2013). As part of that project, salinity was recorded from 32 permanent stations distributed along the MRD coast and some mobile stations to generate maximum seawater incursion maps for many years. These include:

- A baseline scenario represented by extreme historical drought and seawater incursion that was observed in the year 1998.
- A projected future scenario Drought 1 (D1), representing seawater incursion together with upstream discharge through Kratie station in May (the lowest flow month during low-flow season), in association with 15 cm sea-level rise by the year 2030.
- A similar projected future scenario Drought 2 (D2), with 30 cm sea-level rise by the year 2050.
- Maps of maximum seawater incursion in 1998, 2010, and 2011 obtained from salinity data records (see a summary of these scenarios in Table 3.7).

Soil types provide an indication of susceptibility to salinisation, and maps soil types, as a suitable proxy, were obtained from the Ministry of Natural Resources and Environment of Vietnam (MONRE). These were undated, and have been modified by the author in 2013 (see chapter 4, Appendix 3c). There are three naturally dominant soil types in the MRD comprising alluvial soils found along the Mekong and Bassac Rivers; saline soils distributed along coastal areas; and acid sulphate soils (ASS) where soils or sediments containing iron sulphides, the most common being pyrite (FeS_2), are distributed on both sides of the Mekong and Bassac Rivers. These main soil types were classified by FAO (see Table 3.14) and it will be discussed in the following section of next chapter (see sub-section 4.4.2.4).

Table 3.7 A summary of maps/ scenarios of flood depth, and seawater incursion used in assessments for study area.

No	Sub-component	Abbreviation	Explanation	Source
1	*Flood risk*			IMHEN (2010a); Mackey and Russell (2011); Mainuddin et al. (2010); Tran et al. (2013)
1.1		Baseline (in 2000)	Simulated extreme historical flood depth that occurred in September 2000, m	
1.2		F1 (by 2030)	Projected simulation of flood depth of 15 cm sea-level rise in an A2 emissions scenario by 2030, m	
1.3		F2 (by 2050)	Projected simulation of flood depth of 30 cm sea-level rise in an A2 emissions scenario by 2050, m	
2	*Seawater incursion*			
2.1		Baseline (in 1998)	Simulated extreme historical drought and salinity incursion that occurred in 1998, ppt	Mackey and Russell (2011)
2.2		D1 (by 2030)	Projected simulation of salinity incursion of 15cm sea-level rise by May 2030, ppt	
2.3		D2 (by 2050)	Projected simulation of salinity incursion of 30cm sea-level rise by May 2050, ppt	
2.4		Max 1998	Collect salinity data from stations to map a maximum seawater incursion in 1998, ppt	Le and Le (2013)
2.5		Max 2010	Collect salinity data from stations to map a maximum seawater incursion in 2010, ppt	
2.6		Max 2011	Collect salinity data from stations to map a maximum seawater incursion in 2011, ppt	

The end point rates (EPRs) from the DSAS analysis, were assigned as one of proxies of the shoreline change, in terms of proxies for the shoreline change sub-component (see sub-section 3.4.2.2). Ten Landsat images were used to compute and interpret the shoreline change for the duration of 40 years for the study area, the details of which will be presented in sub-section

3.5.2.2. Additionally, the adjacent coastal landuse, focusing on area of mangrove forests along the Kien Giang coast was chosen as the other proxy that was obtained from the GIS database of Ministry of Agriculture and Rural Development of Vietnam (MARD, dated 2010), and then modified by the author in 2013 (see chapter 4, Appendix 9a.2c). The effectiveness of mangrove forest coverage to protect the coastline naturally will be further discussed in the next chapter, sub-section 4.5.3.3.

Table 3.8 Variables and proxies for the sensitivity component of the assessment.

Sub-component	Variable	Proxy	Source/ Tool
Societal factors	Population density	Persons/ km^2	KGI statistics 2012
	Rural population	Percentages of rural persons living in rural areas (i.e., Rural population vs. Urban population vs. Total population)	KGI statistics
	Gender	Percentages of females living in an area (i.e., Female vs. Male vs. Total population)	KGI statistics
	Ethnicity	Percentages of ethnic minorities population (i.e., non-Kinh (minority people) vs. Kinh (majority people) vs. Total population)	KGI surveys 2011
Landuse factors	Agriculture land	Agricultural, aquacultural and forest land, land for salt production pond, etc	MONRE dated 2008, modified by the author in 2013
	Non-agriculture land	Urban and rural settlement, and public infrastructure: roads, bridges, airport, hospitals, offices, cemetery, water bodies, etc	
	Unused land	Bare-land, conservative land	

Information on population characteristics is important in terms of sensitivity, as seen in Table 3.8, and proxies of societal sensitivity factors have been chosen in the sub-component of sensitivity (Samson et al., 2011). The assumption here is that regions that are relatively less inhabited will be less vulnerable compared to regions with high population densities, given the same degree of exposure to climate hazards. The proxies of societal sensitivity factors such as rural population, (i.e., rural vs. urban vs. total population), gender of population (i.e., female vs. male vs. total population), and ethnicity, (i.e., non-Kinh vs. Kinh vs. total population) will be described in the following sections. Variables related to population density, rural population, gender, ethnics were obtained from the statistical yearbook of the Kien Giang statistical office (2012) and surveys of the Kien Giang district in 2011 (see chapter 4, Appendix 9c). In terms of the landuse sensitivity sub-component, landuse categories (i.e., agriculture land vs. non- agriculture land vs. unused land) (Nguyen et al., 2012; Samson et al., 2011) were classified by MONRE to be used as proxies of this sub-

component. The landuse map was derived from the GIS database of MONRE dated 2008, and was then modified by the author in 2013 (see chapter 4, Appendix 9a.2).

Table 3.9 Variables and proxies for the adaptive capacity component of the assessment.

Sub-component	Variable	Proxy	Source/ Tool
Socioeconomic	Income	Annual average income per capita	KGI surveys
	Poverty ratio	Percentage of poverty per household	KGI statistics
	Education system	Contribution of education with regard to: - Numbers of kids per kindergarten school - Numbers of kids per teacher at kindergarten school - Numbers of pupils per primary and secondary school - Numbers of pupils per teacher at primary and secondary school	KGI statistics
	Health service	Contribution of health services with regard to: - Numbers of inhabitants per medical and pharmacy staff - Numbers of inhabitants per health establishment	KGI statistics
Infrastructure	Communication access	Numbers of inhabitants having per fixed-line telephones subscriber registered under users addresses	KGI statistics
	Road capability	Road capability (a Kernel function, radius 5 km) with regard to: - National or highway road level - Provincial road level - District road level and others	Tran et al. (2013)
	Houses	Percentage of households having (fully and partly) solid houses	KGI statistics
Technological	Irrigation and drainage capability	Irrigation and drainage capability with regard to: - Sluice capability - Canal capability - River density - River embankment capability - Sea dyke capability	SIWRP GIS database, dated 2010
	Electricity capability	Electricity capability with regard to: - Transformer capability - Voltage power line capability	Tran et al. (2013)

As seen in Table 3.9, there were several proxies for the three sub-components of variables for the adaptive capacity component. First, the socioeconomic sub-component, as used here, comprised variables of income, poverty ratio, education, and health services. Second, infrastructure sub-component variables consisted of types of houses (e.g., solid houses), communication access (e.g., fixed-line telephone subscribers), and road capability. Third, technological sub-component variables refer to irrigation and drainage and electricity capabilities. Accordingly, variables related to income, poverty ratio, education, health

services, communication access, solid houses were obtained from the statistical yearbook of the Kien Giang statistical office (2012) and the Kien Giang's district surveys in 2011 (see chapter 4, Appendices 9d.1, and 9d.2). Road, and electricity network data were obtained from the database of the project undertaken by Tran et al. (2013) (see Appendices 9d.2, and 9d.3, respectively), while the irrigation and drainage network data were obtained from the Southern Institute for water resources planning of Vietnam (SIWRP) GIS database dated 2010 (see Appendix 9d.3). Explanations are given in Table 3.10. All these variables or proxies are further described in the next chapter, chapter 4.

Table 3.10 Explanations of proxies of variables for the assessment.

No.	Name	Explanation	References/ Notes
	Exposure		
	Flood		
1	Flood depth	The depth (m) of flood events	Tingsanchali and Karim (2005), Van et al. (2013), and Appendices 8c
2	DEM	Elevation	Figure 4.4
	Seawater incursion		
3	Salinity	Salinity (ppt) that affects the productivity/ yield of paddy crops and the fishery sector.	Le (2003), and Appendices 8d
4	Soils types	Different soil types as classified by FAO	Appendix 3c
	Shoreline change		
5	End point rates	m/ year	Thieler et al. (2009)
6	The adjacent coastal landuse	Landuse, focused on land for mangroves fringes tolerant to brackish water (i.e., along the coast or seawater intruded areas)	
	Sensitivity		
	Societal factors		
7	Population density	Higher population density seems to be more vulnerable to impacts of sea-level rise. Local population density is slightly higher than the national density.	Appendix 9c
8	Rural people	Based on statistical data, there are about 70% of people living in rural areas in Vietnam where they can get fewer opportunities to increase their standard of living or infrastructure. Their livelihoods depend on natural resources, activities such as agriculture, fisheries, etc. As such, they are likely to be vulnerable groups to impacts of sea-level rise.	Appendix 9c
9	Female people	Men and women will be faced with different vulnerabilities to climate change impacts due to existing inequalities such as, their role and position in society, access to resources and power relations that may affect the ability to respond to the effects of climate change. In fact, there exits inequalities in Vietnam that females, particularly rural females have lesser roles and positions, and fewer opportunities in society and their family. Females are likely to be a group vulnerable to potential impacts of sea-level rise.	Appendix 9c
10	Ethnic minorities groups	The major ethnic group is "Kinh/Vietnamese" whilst remaining groups are the minority groups. They are "Hoa/Chinese", "Cham", and "Khmer/Cambodian". There exists a strong correlation between ethnicity and poverty in the study area which	Appendix 9c

		is related to the percentage of non-Kinh groups in the local population.	
	Landuse factor		
11	Landuse	Landuse is classified by MONRE. These include 3 main landuse categories: agriculture land, non agriculture land, and unused land.	Appendix 4
	Adaptive capacity		
	Socioeconomic		
12	Income	Income is calculated as the total amount of money received, including salaries, revenues from agriculture, forestry, aquaculture, industry, construction, trade, services, etc. High income is presumed to indicate a higher capacity to invest in facilities to respond to sea-level rise.	Appendix 9d.1
13	Poverty ratio	The new poverty thresholds, used to decide eligibility for social welfare benefits, have now been set at VND 400 000 (US$ 20.5) per person per month for rural households; and VND 500 000 ($25.6) per person per month for urban households. Regions with households below this standard are considered poor. (The government has changed poverty standards that will apply for the coming five years, from 2011 to 2015). The poorest people are least able to survive the impacts of climate change induced sea-level rise.	Appendix 9d.1
14	Education system	The education system of the study area includes kindergartens, and primary and secondary level. Children aged 5 and under attend kindergartens, while children aged 6 and older attend primary and secondary schools.	Appendix 9d.1
15	Health services	Health services include medical and pharmacy staff, and establishments.	Appendix 9d.1
	Infrastructure		
16	Communication access	Communication access is indicated by the number of inhabitant sharing a fixed-line telephone subscriber registered under users address.	Appendix 9d.2
17	Road	Roads include three main levels: national or highway roads, provincial roads, and district roads	Appendix 9d.2
18	Solid houses	Indicated by the number of dwellings with the pier, the outer wall and the roof made of solid materials such as concrete, bricks or tiles. Those can be permanent/ fully solid house with a longevity greater than or equal to fifty years; or partly solid house with reduced longevity. Percentage of households having solid houses.	Appendix 9d.2
	Technological		
19	Irrigation and drainage capability	Irrigation and drainage capability comprises availability of sluices, canals, rivers, river embankments, and sea dykes.	Appendix 9d.3
20	Electricity capability	Electricity capability comprises availability of transformer, and voltage power line.	Appendix 9d.3

Most of these datasets were collected while undertaking three periods of fieldwork: from 30 of November 2011 to 10 February of 2012, from 12 October of 2012 to 3 March of 2013, and from 18 to 26 of January 2015 in the seven coastal districts along the Kien Giang coast.

3.5.2.2 Administrative boundaries and the Digital Elevation Model for the study area

Maps used in this study include the Kien Giang administrative boundaries map in 2011 at a scale of 1: 75 0000, UTM/WGS 84 datum, zone 48N, national meridian 1050, and coordinate

and elevation system VN2000, and includes a sub-map C-48-70. The DEM used was obtained from the research (KHCN-BDKH/11-15; code BĐKH.08), undertaken by Tran et al. (2013), and has the 15 m resolution (cell-size of 15 m) raster for the seven coastal districts in Kien Giang with average ranges of elevation from 0.3 - 0.5 m (the south-western part) and 0.8 - 1.2 m (the north-eastern part). Elevations are given above mean sea level (MSL) - compared with the average water level in the national standard of Vietnam in Hon Dau, Hai Phong.

3.5.2.3 Landsat Satellite images

Landsat satellite images are useful for mapping natural resources and have been widely used to detect erosion and accretion along the coast (Alhin and Niemeyer, 2009; Ekercin, 2007; Hereher, 2011; Nguyen, L. D. et al., 2011). The third generation of Landsat satellites has recently been launched. Landsat images used for the study area, with scene size of 185x185 km, have been downloaded from the database of the USGS (http://earthexplorer.usgs.gov; http://glovis.usgs.gov/) and from the GLCF (http://landcover.org/data/). Table 3.11 presents resolutions of a set of Landsat images. These datasets have the following characteristics:

- Corner lower right latitude: 9°11'52"N.
- Corner upper left longitude: 105°12'28"E.
- Zone number: 48N.
- Map projection: UTM.
- Datum: WGS84.

Table 3.11 Resolution of Landsat MSS, TM, ETM$^+$, and OLI_TIRS images.

Landsat images	Sensor	Band#s	Spectral range μm	Pixel resolution m
L 1-4	MSS multi-spectral	1,2,3,4	0.5 - 1.1	60x60
L 4-5	TM multi-spectral	1,2,3,4,5,7	0.45 - 2.35	30x30
L 4-5	TM thermal	6	10.40 - 12.50	120x120
L 7	ETM$^+$ multi-spectral	1,2,3,4,5,7	0.450 - 2.35	30x30
L 7	ETM$^+$ thermal	6.1, 6.2	10.40 - 12.50	60x60
Panchromatic	ETM$^+$ thermal	8	0.52 - 0.90	15x15
L8	OLI_TIRS	8		30x30

Note: The Multispectral Scanner (MSS), the Thematic Mapper (Postma), the Enhanced Thematic Mapper Plus (ETM$^+$), and the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) Landsat images.

Each shoreline vector required specific attributes that are presented in Table 3.12, whereas the baseline attribute field requirements that are presented in Table 3.13.

Table 3.12 Shoreline attribute table requirements for DSAS analysis, (derived from Thieler et al., 2009).

Field name	Data type	Origin	Requirement
OBJECTIVE	Objective ID	Auto-generated	Required
SHAPE	Geometry	Auto-generated	Required
SHAPE_Length	Double	Auto-generated	Required
Date	Text (Length = 10 or 22)	User-created	Required
Uncertainty	Any numeric field	User-created	Optional

Table 3.13 Baseline attribute field requirements for DSAS analysis, (derived from Thieler et al., 2009).

Field name	Data type	Origin	Requirement
OBJECTIVE	Objective ID	Auto-generated	Required
SHAPE	Geometry	Auto-generated	Required
SHAPE_Length	Double	Auto-generated	Required
ID	Long integer	User-created	Required
Group	Long integer	User-created	Optional
OFFshore	Short integer	User-created	Optional
CastDir	Short integer	User-created	Optional

A summary of the classification of variables in terms of vulnerability and potential impacts of sea-level rise for this study is presented in Table 3.14. Variables were classified into 5 categories: very low, low, moderate, high, very high, with regard to vulnerability and potential impacts of sea-level rise for the study area. The Manual and Jenks classification methods (Jenks) were used to classify the ranges of several of these variables. Particularly, Jenks, based on natural break classification, recently have been used for several researchers (Ahmed, 2014; Berry and BenDor, 2015; Chen et al., 2013; Luan et al., 2011; Sambah and Miura, 2013; Szlafsztein and Sterr, 2007). Jenks, in this analysis, were used in classification in order to represent sub-components, three key components, and the final vulnerability outcome.

Table 3.14 The range of variables and their classification in terms of vulnerability selected for use in this assessment.

No	Component/ sub-component/ Variable	Ranking: Very low	Low	Moderate	High	Very high	References
E	**Exposure**						
E1	*Flood risk*		Jenks was used to classify the range				
	Flood depth, m	0 – 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0	Dinh et al. (2012); Tingsanchali and Karim (2005) and Van et al. (2013)
	DEM, m above MSL	> 2	1.2 - 2	1.2 - 1	1 – 0.8 & 0.8 – 0.5	< 0.3 & 0.5 – 0.3	Study area
E2	*Seawater incursion*		Jenks was used to classify the range				
	Salinity, ppt		< 4	4 - 8	> 8		Le (2003)
	Soil types	Water bodies, Alluvial soils	Acrisols/ Gray soils	PASS	AASS	Saline soils	Study area
E3	*Shoreline change*		Jenks was used to classify the range				
	Shoreline displacement, m/yr	> 15.0	5.0 – 15.0	-5.0 – 5.0	-15.0 - -5.0	< -15.0	Dwarakish et al. (2009)
	Adjacent coastal landuse	Mangrove fringes	Man-made infrastructure	Fishery farming	Agriculture	Built-up	Study area

S	**Sensitivity**					
S1	*Societal factors*	Jenks was used to classify the range				
	Pop. density					Study area/ statistics
	Rural pop, %					Study area/ statistics
	Female pop, %					Study area/ statistics
	Ethnic groups, %					Study area/ statistics
S2	Landuse patterns	The bare land	Water/ wetland, grassland	Forest, farmland	Built-up	Yin et al. (2012)
A	**Adaptive capacity**					
A1	*Socioeconomic*	Jenks was used to classify the range				
	Income					Study area/ statistics
	Poverty ratio					Study area/ statistics
	Health (include: health establishment, health staff)	Jenks was used to classify the range				Study area/ statistics
	Education (include: kids per school, per teacher; pupils per school, per teacher)	Jenks was used to classify the range				Study area/ statistics
A2	*Infrastructure*	Jenks was used to classify the range				
	Road capability	Jenks was used to classify the range				Study area/ buffer
	Houses (% households having solid houses)					Study area/ statistics
	Communication access (Numbers of inhabitants sharing a fixed-line telephone subscriber)					Study area/ statistics
A3	*Technological*	Jenks was used to classify the range				
	Irrigation and drainage capability (include: capabilities of river, canal, sluice gate, sea-dyke, river embankment)	Jenks was used to classify the range				Study area/ buffer
	Electricity capability (include: transformer, voltage power line)	Jenks was used to classify the range				Study area/ buffer

3.6 Chapter summary

In this chapter, the conceptual framework is described which was developed to undertake this coastal vulnerability assessment. It consists of a hierarchical structure, comprising a set of 24 sub-variables and 22 variables categorised into 8 sub-components of the 3 key components of vulnerability: exposure, sensitivity and adaptive capacity.

GIS was utilised to allocate relative weights to the selected variables, analysed using the AHP tool (a type of MCDM), as determinants of biophysical and social factors in terms of climate change vulnerability. These were aggregated for the three key components: exposure, sensitivity, and adaptive capacity, to compute a final vulnerability index for the study area. As a result, hotpots, comprising areas most likely to be vulnerable to the impacts of climate change, were identified and visualised. AHP and GIS are two distinctive approaches, enabling integration of MCDM assessments into GIS improving the spatial capabilities and the analytical power and its use in decision making. The next chapter describes background to the study area, followed by chapters 5 and 6, which present the results and discussion of the analysis.

Chapter Four

Background to study area

4.1 Aims of this chapter

The aim of this chapter is to provide an overview of the Kien Giang (KGI) coast, along the western part of the Mekong River Delta in Vietnam (MRD) as background to site-specific vulnerability assessments. Seven coastal districts along the KGI coast comprise the case study area.

The chapter is structured as follows. Section 4.2 presents a brief introduction to the MRD as vulnerability-driven methodologies characterised by "top-down" approaches (i.e., from global, national to regional spatial approaches), whereas an emphasis on site-specific assessments in KGI, characterised by "bottom-up" approaches (i.e., local to regional scale). An overview of the MRD is described in section 4.3. The natural and social conditions of the MRD in the context of climate change, particularly sea-level rise, are presented in sub-sections 4.3.1, and 4.3.2. Section 4.4 provides a profile of the case study area. Section 4.5 presents a summary of this chapter.

4.2 Introduction

Damage including loss of life, crop failures, and other critical ecosystem vulnerabilities worldwide will be exacerbated by climate change and sea-level rise, especially in Asia and Pacific areas (Burke et al., 2002; Harvey, 2006; Harvey and Mimura, 2006; Mimura, 2006; Nunn and Kumar, 2006). With many low-lying areas, a long and narrow coastline, high population density, and rapid economic growth, Vietnam is considered to be one of the countries likely to be most affected by global climate change and particularly sea-level rise (Carew-Reid, 2008). The MRD has been suggested to be the most vulnerable region within the country to the impacts of sea-level rise (The-First-Scenarios-VN, 2009) because it has about 730 km of coastline, comprising seven coastal provinces (www.mekongdelta.com.vn) with densely populated deltaic lowlands. Of these, coastal provinces, Kien Giang and Ca Mau along the margin of the western part of the delta (from Ca Mau cape to Ha Tien) are predicted to be the places at particular risk from sea-level rise by the end of this century within seven

coastal areas along the Vietnam coast (The-Second-Scenarios-VN, 2011). This thesis aims to reassess the view that the coastal areas along the Kien Giang coast are most vulnerability to the effects of sea-level rise.

4.3 The Mekong River Delta in Vietnam

The MRD is in the most downstream part of the Mekong River Basin, largely south of the Vietnam - Cambodia border. It lies between the South China Sea to the east, the so-called east sea; the Gulf of Thailand in the west, the so-called west sea; and Vam Co Dong River and Ho Chi Minh City in the northeast (see Figure 4.1). The MRD is also called, as "Cuu Long River Delta" which means "Nine Dragon River Delta" in the Vietnamese language, and comprises Can Tho city and 12 administrative provinces. It is the home for about 17.4 million people (GSO, 2012), making up 23% of Vietnam's population.

Figure 4.1 Location of the MRD, showing the study area shaped red.

The MRD is defined by the confluence of the Mekong River and the Tonle Sap in Cambodia (Nguyen et al., 2000). The delta starts in Cambodia but over 80% of area is in southwest Vietnam (accounting for 12% of area of Vietnam) (MRC, 2010b; Nguyen et al., 2000). The MRD plays crucial roles in developing the socioeconomic profile of Vietnam as well as

providing food security, employing over 80% of local rural labour-force, according to numerous reports by MRC. However, local people are still considered some of the poorest in the world (Stewart, 2008).

4.3.1 Natural conditions of the MRD

Generally, the MRD is tide-dominated (Reineck and Singh, 1980) as denoted by the triangular classification of deltaic depositional systems in terms of being defined by the end-members of fluvial supply, tidal and wave dominance (Galloway, 1975; Hori and Saito, 2007). However, the Mekong Delta initially evolved as a strictly tide-dominated delta, but changed into a mixed wave- and tide-dominated delta since 3ka BP (Nguyen et al., 2000; Tanabe et al., 2003a). Annually, mean water discharge of the river is 470 km^3/year (Lu and Siew, 2005; MRC, 2010a), and floodwaters deposit fertile sediments from the upper basin on fields and wetlands in Cambodia and Vietnam that account for approximate 160 million tonnes/year (Milliman and Ren, 1995; Milliman and Syvitski, 1992; Ta et al., 2002a). The massive sediment supply to the coast has resulted in an extensive delta plain with an area of 50 000 km^2 (Hori, 2000). This productive area has been called a massive “rice bowl” for Vietnam.

4.3.1.1 Topography

The MRD is a very low-lying plain. The majority of its elevation is under 5 m above MSL, according to the SRTM digital elevation data available as 3 arc second (~90 m resolution) DEMs, originally produced by NASA, and currently distributed free of charge by the USGS. The only high ground comprises some 200 - 270 m high hills and mountains in the northern delta, bordering Cambodia. Along the Cambodian border, the terrain varies from 2.0 - 4.0 m, and gradually lowers into the central plains, and then into tidal flats and coastal areas respectively. Consequently, the MRD is particularly vulnerable to flooding by river waters from upstream and high tidal waters from seaward.

4.3.1.2 Geology, landform, soil, and surface morphology

An early account of the geology of the Mekong Delta was provided by Gagliano and McIntire (1968). Recently, a series of boreholes sunk into the deltaic sediments have expanded our understanding of the deltaic geology (Nguyen et al., 2000; Ta et al., 2001b; Ta et al., 2005; Ta et al., 2002a, b). The oldest sediments, which are linked to the modern delta body, accumulated in the early to mid-Holocene, at 8ka BP (Tamura et al., 2009), and preceding the mid Holocene sea level high stand in the region. The modern Mekong Delta started to form 6

- 7 ka BP (Nguyen et al., 2000; Ta et al., 2001b; Ta et al., 2002a, b). In this phase the coastline was located in modern southern Cambodia (Nguyen et al., 2000; Tamura et al., 2009) and is generally referred to as marking the most landward margin of the delta body (Woodroffe et al., 2006). Peat horizons and pollen records in the mid-Holocene indicated that the coastal zone was occupied by a broad mangrove swamp (Penny, 2006, 2008; Tamura et al., 2009). The increasing influence of waves and the formation of beach ridges after 3 ka BP (Nguyen et al., 2000; Tanabe et al., 2003a) are associated with the extensive seaward progradation of the delta together with a large sediment discharge (Ta et al., 2002a). Ta et al. (2005) also indicate that morphological differences in the delta are related both to past variations in the coastal environment and the rate of delta progradation, as it has transitioned from a tidally-dominated estuary to one characterised by shore-parallel beach ridges reflecting wave conditions in the east sea.

Several landform units of the delta were formed based on processes of accretion and erosion under different environmental conditions. Each landform unit has different hydrographic and pedological conditions and, therefore, each forms a distinct agro-ecological environment. According to Nguyen (1993), the MRD is mainly divided into five landform units, and various sub-units respectively, comprising:

- *Old alluvial terrace unit* occupies small areas in the northeast of the delta, along the Cambodia-Vietnam border.
- *Floodplain unit* consists of two sub-units: high floodplain comprises natural levee, sand bar, back swamp, closed and opened floodplain, located in the northwest of the delta with the greatest inundation depth in the flood season, and tide affected floodplain comprises natural levee, back swamp, broad depression floodplain, which occupies the center of the delta. It is strongly influenced by the daily tides of the Mekong and Bassac Rivers.
- *Coastal complex unit* runs along the coasts of the east sea and the west sea, consisting of four sub-units: sandy beach ridge, coastal flat, inter ridge, and mangrove swamp.
- *Broad depression unit* occupies a large area in the south of the delta, consisting of two sub-units: broad depression and peat depression.
- *Hills and mountains* consist of large and small separate ranges in the west of the delta (see Appendix 2).

The distribution of soil types is generally related to land formation. Holocene sediments beneath the delta are predominantly composed of silt, clay, and sand (Nguyen et al., 2000).

Hashimoto (2001) also indicates that sediment consists of typically organic rich mud and peat formed from local vegetation in the areas quite far from the main river which are not drained by channels. In fact, there are many different classifications of soil types, depending on specific purposes. The soil classification by FAO/UNESCO was used in this thesis. The FAO/UNESCO soil classification is an international classification system in accordance with Soil Taxanomy standards, which is based on soil property quantification and soil classification diagnostic signals derived soil groupings that have been commonly used in Vietnam since 1975 (see Appendix 3a). According to the soil classification by FAO/UNESCO, there are three major soil types that are significantly affected by agricultural, and aquacultural activities in the MRD (see Appendix 3b). These include the:

- *Alluvial soil group* (shown in the purple colour in Appendix 3b). This group can be found along the banks of the Mekong and Bassac Rivers, in floodplain units, and account for 28.9% of the delta which is agriculturally productive. The group is slightly acidic, with pH values of 4.5 - 6.5, and is the most suitable for the cultivation of rice. However, the area of this soil group is annually affected by flood and land erosion.
- *Saline soil group* (shown in the yellow and blue colour). This group can be found along the MRD coast, in coastal complex units that stretch from Go Cong (Tien Giang) to Ha Tien (Kien Giang). The soil has a salinity of about 3 ppt and pH value of 4.0, and account for about 21.4% of the delta. A large area of mangrove forests occupies this group.
- *Acid sulphate soils (ASS) group* (shown in the red and green colour). This group is distributed on both sides of the Mekong and Bassac Rivers and accounts for 28% of the delta. This group has high contents of the ions Fe^{3+}, and SO_4^{2-}; and FeS_2 is formed under oxidising conditions. The group has very high concentrations of sulphide and very low pH values of 2.26 - 3.54, and is generally only suitable for *Melaleuca* planting.

On the basis of morphology, the subaerial MRD plain can be classified into two parts:

- *An upper (inner) delta plain* dominated by fluvial processes (Gupta, 2009), which is mainly occupied by floodplain and swamp.
- *A lower (outer) delta plain* mainly influenced by marine processes, which is tide- and wave-dominated (Gupta, 2009); and characterised by a well-developed beach-ridge system that is mainly composed of mangroves, beach ridges (including foreshore), and tidal flats (Gagliano and McIntire, 1968; Nguyen et al., 2000).

Additionally, based on the influence of interaction between river discharge, diverse tidal patterns, and landform, the MRD can be divided into three hydrological regions. These are:

- *The river-flood* areas in the northern plains, including an upper (inner) delta plain, where the impact of the river floods is dominant; this region accounts for 7.5% of area of the MRD.
- *An area with combined river flood-tidal impacts*, bound by the Cai Lon River - Xeo Chit Channel, Lai Hieu Canal - Mang Thit River, and Ben Tre - Cho Gao Canals; this region accounts for about 40% of area of the delta.
- *The coastal regions,* comprising a lower (outer) delta plain with direct influence of the primary tides, and includes the entire coastal region along the east sea and the west sea; this region accounts for about 50% of area of the delta.

4.3.1.3 Network of rivers and canals

The MRD has a tortuous and interlacing network of rivers and canals. The modern MRD system has two major distributary channels, an eastern channel called the Mekong River and a western channel called the Bassac River, which flows into the east sea through seven distributaries (see Figure 4.1). The positions of these distributary channels are estimated to have been relatively stable over 2 - 3 ka BP based on the distribution of the beach ridges, which indicate inter-distributary plains (Ta et al., 2002a). The Mekong River, also known as the Tien River, or in Vietnamese it is called "Sông Tiền", runs through Tan Chau (An Giang), and enters the east sea with five distributaries. Additionally, the shape of the river is becoming complex because of several islands and sandbars in the channel. The Bassac River, also known as the Hau River, and in Vietnamese is called "Sông Hậu", runs through Chau Doc (An Giang). The Bassac River is connected with the Mekong River through Vam Nao passage, and continuously runs parallel with the Mekong River, and enters the east sea with two distributaries. The discharge ratio between the Mekong and the Bassac Rivers during a high water event is approximately 80% and 20%, respectively. The study by IMHEN (2010a) indicates that the discharge through Tan Chau station, where the Mekong River runs through, varies annually with a maximum river flow discharge of about 20 000 m^3/s in September and a minimum flow discharge of 2 000 m^3/s in April. In contrast, the discharge through Chau Doc station, where the Bassac River runs varies annually from a maximum river flow discharge of about 6 000 m^3/s in September to a minimum flow discharge of about 300 m^3/s in April. At the Vam Nao passage, connecting the rivers 20 km downstream of Tan Chau and Chau Doc, the discharge ratio between the two river branches becomes almost equal.

Additionally there is an extensive network of canals that occupies about 9% of the total delta area (Nguyen, 2002); these canals are connected to the east and west seas. The canal network was constructed in the past 300 years, with most parts of the network developed in a little more than a century across the delta (Brocheux, 1995; Miller, 2006; Biggs 2012). The main purpose of the canal network was stimulating typical rice-water agricultural production and water transportation; and was sometimes strategic as in the case of Vinh Te canals, which has influenced their efficacy. The intricate, recently-built canal system, with a density of 8 - 10 m/ ha, comprises 7 000 km of main canals, 4 000 km of secondary on-farm canal systems, and more than 20 000 km of protection dykes to prevent early floods (MARD, 2003). Apart from aiding rice production and water transportation, there are increasingly negative consequences affecting people and environment conditions in the region, such as growing numbers of mosquitoes as a result of high humidity, limitation of land-road routes, flood and seawater incursion (i.e., the fresh-to salt- water gradient apparent in deltas and estuaries).

4.3.1.4 Coastal oceanography

The MRD coast is influenced by tidal dominance along the west sea and mixed wave- and tide- dominance along the east sea. The tide regime in the west sea is diurnal with an amplitude of only 0.5 - 0.8 m (Phan and Hoang, 1993), whereas in the east sea it is more irregular, being semi-diurnal with a mean tidal range of 2.5 - 3.8 m, and mean wave height of 0.9 m (Nguyen et al., 2000; Ta et al., 2001a; Ta et al., 2001b). In the open sea, the wave and wind direction is related to the monsoon season; for the northeast monsoon season wind and wave direction is dominantly within an arc northeast-east-southeast, while for southwest monsoon season they are dominantly within an arc west-southwest (see Appendix 8a). In terms of wind regime, the annual average wind speed is 2.7 m/s in the west sea according to the observational data at the station located in Phu Quoc Island. During the northeast monsoon season the average wind speed is 2 - 3 m/s, with a maximum wind speed of 48 m/s; while the average wind speed is 2 - 5 m/s and the maximum wind speed is 57 m/s during the southwest monsoon season. Based on observational data at the station located in Petro Mining platform Bach Ho, the annual average wind speed is stronger in the east sea, being 6 m/s higher than the west sea. The average wind speed is 6 - 8 m/s, with the maximum of 48 m/s during the northeast monsoon season while the average wind speed is 5 - 6 m/s with a maximum speed of 39 m/s during the southwest monsoon season (IMHEN 2010a,b; ICOE; Le et al., 2011).

Wave regimes are induced by the monsoons and show a seasonal reversal of direction along the front of the delta (Ta et al., 2001a; Wolanski et al., 1996). Incident wave energy is generally highest at the end of the wet season and during the dry season, particularly in the months of November and December. The wave direction, particularly along the east sea, coincides with the southwest monsoon during the wet season, but conditions are far less energetic than the waves associated with the northeast monsoon during the dry season. Strong northeast to east monsoons in the dry season bring large waves exceeding 3 m offshore and 2 m onto the shore in the east coast. For the west coast, strong southwest monsoons can create waves exceeding 3 m offshore that impact are reduced to around 1 m onto the shore.

During the southwest monsoon a great volume of sediment is discharged by high river flows and is transported to the river mouths, which has resulted in the formation of the southeastern coastal plain. That plain includes sandy beach ridges of 3 - 10 m elevation above MSL and separated by inter-ridge swamps of 1.5 - 2.5 m above MSL along the east coast (Ta et al., 2005). During the northeast monsoon, which coincides with a period of low river discharge and sediment supply, the sediment along the coast is reworked by stronger northeasterly waves and currents, and then transported and eventually deposited on shore, particularly in the southern Ca Mau peninsula. This has resulted in the rapid expansion of Ca Mau cape westward. The Ca Mau cape is now dominated by tidal channels, marshes, and extensive mangrove forests. On the western edge of the peninsula, including coastal districts along the southern Kien Giang coast, is a section of coast that is remarkably straight, most likely due to structural control, although this characteristic has been influenced by waves and currents (Ta et al., 2002a).

4.3.1.5 The confounding effects of climate change, particularly sea-level rise

The MRD, being located in a tropical region, is hot and sunny year-round with an average temperature of 28.5^{o}C, humidity of 80%, and mean annual rainfall which is higher in the western coastal areas (2 000 - 2 300 mm) and lower in the central inland areas (1 200 - 1 500 mm). From May to October, the climate is humid with high rainfall, which causes periods of flooding and inundation, while the climate from November to April is drier, with little rainfall, which causes periods of drought or shoreline erosion.

a. Sea-level rise and weather variability

According to observed data by Southern Vietnam meteo-hydrological stations, the annual average temperature has increased by an average of 0.6^{o}C and rainfall has increased by about 9% over the last 50 years in Southern Vietnam. Additionally, data from the tidal gauges along the Vietnam coast showed an increasing rate of the average sea-level rise of 3 mm/ year during the period of 1993 - 2008, while observed data from satellite altimetry indicated an increase in sea level at a rate of 2.9 mm/ year from 1993 to 2010 (IMHEN, 2010b).

In attempts to overcome these threats, the Vietnamese Government (2007) approved the national strategy for natural disaster prevention, response and mitigation by the year 2020 that outlines the strategy for disaster mitigation and management, and focuses on severe phenomena such as floods, storms and droughts. Following this, a national target program to respond to climate change and sea-level rise (2008) has been approved that aims to assess climate change impacts on sectors and regions in specific periods and to develop feasible action plans to effectively respond to climate change in the short-term and long-term to ensure sustainable development of Vietnam, to take opportunities to develop towards a low-carbon economy, and to join the international community's efforts in mitigating climate change and protecting the climatic system. Under the national target program, the first climate change and sea-level rise scenarios for Vietnam (2009) were developed and an update (The-Second-Scenarios-VN) was completed in late 2011. These scenarios of climate change and sea-level rise developed and published in Vietnam were based on the IPCC SRES: low (B1), medium (B2, A1B) and high (A2, A1FI scenarios) (see details in Table 2.4). Of these, B2 was recommended for all ministries, sectors and local authorities to initially assess the impacts of climate change and sea-level rise and then to build action plans on climate change responses. In the same year, the Vietnamese Government also has approved the national strategy for climate change (2011) that outlines the plan to respond to climate change up to 2020 and 2050.

The-Second-Scenarios-VN (2011) indicates the predicted increasing trends in temperature (^{o}C), rainfall (%), and sea-level rise (cm) per year, relative to 1980 - 1999 by 2100, based on the IPCC SRES B2 in 13 provinces in the MRD. The temperature is predicted to increase by 0.6 - 0.7°C in 2030, with a steady increase of 1.0 - 1.4°C by 2050 (see Appendix 7a). The rainfall trend particularly in the MRD by 2100 is projected to increase at a slower rate than has been observed. In particular, observation data indicates a 9% increase in rainfall during

the past 50 years, while projections indicate an increase in rainfall of only 1.2 - 2.3% by 2030, and 2.1 - 4.2% by 2050 (see Appendix 7c). In addition, there is projected to be a significant increase in sea levels, with an average increase of 12 - 14 to 13 - 15 cm by 2030, and 23 - 27 to 25 - 30 cm in 2050 (see Appendix 7e), compared to observation data at Vung Tau station over the past 30 years along the MRD coast (The-First-Scenarios-VN, 2009).

b. The impacts of climate change, particularly sea-level rise

Tropical depressions such as typhoons, which generally develop over the east sea, seldom reach the MRD, but the delta is episodically affected by heavy rain, wind and high ocean waves, which are associated with such storms situated offshore or in central Vietnam during the rainy season. For this reason, storms related to tropical depressions have been excluded from this study and three main physical impacts have been taken into account for the MRD; flooding and inundation in the wet season, seawater incursion in the dry season, and shoreline erosion.

- ***Appearance of high flooding and inundation*** in the MRD during the wet season comprises high flow rate from upstream, and overflow from the border of Vietnam - Cambodia, in combination with high rainfall and high tides from the sea, and the coincidence of these effects during the southwest monsoon, is outlined in Table 4.1. Consequently, flooding and inundation may cover about 32.5 - 45% area of the delta, with a depth from 0.5 - 4.0 m and the period of inundation being 3 - 6 months, particularly in the floodplain unit of the MRD (see section 4.3.1.2).

Table 4.1 The classification of flood in the MRD, (modified after Cantho.cool.ne.jp).

Classification	Generation area	Cause	Main damages
Riverine	Upper main rivers	A rise in river water level	Lives, Houses, Crops, Infrastructure
Inland	Whole area	A rise in river water level	Houses, Hygiene
Urban	City	Asphalting, Downpour	Houses, Hygiene
Tidal	Lower rivers and coast	Flood tide	Crops, Salinisation
Wave	Lower coast	Flood wave	Protective, and specially used forests, Crops, Infrastructure

As seen in Table 4.1, the most dangerous form of the flood for the entire MRD in relation to threats to human life and damage is the riverine flood because of high flow discharge originating from upstream. The river-flood in the MRD annually occurs normally from May to December, but their peaks are usually in September and October. It is noted that river-flood in the MRD can be divided into three periods:

- *Early flood season*, from mid-July to mid-August, when the main rivers flood quickly and rise strongly (2 - 3 cm up to 10 - 15 cm per day), and then the floodwaters are distributed through the canal systems to crop fields. As a result, large volumes of silt are transported down the rivers that subsequently supply important nutrients for the Summer-Autumn rice crop. However, the peak of water level during this stage can rise quickly, leading to overtopping of embankments that threatens crop success.

- *A second flooding period*, during September and October, when floodwaters reach high levels (over 4.0 m at Tan Chau, and over 3.5 m at Chau Doc observatory).

- *The third period* is the flood recession, usually starting by the end of October, when the flow spilling from Cambodia has decreased, and floodwater recedes gradually until December. The Autumn-Winter rice crop (also called as the third crop), is cultivated during these stages, from August to December. These floodwaters enter the delta from two directions: a) perpendicular direction from the main river courses; and b) from the Vietnam - Cambodia border area directly. The border flows spill over after flooding and silt deposition in the most flooded areas of Cambodia, and subsequently overflows into the floodplain unit (see section 4.3.1.2). Moreover, the National Center for Meteo-Hydrological Forecasting of Vietnam distinguishes four river flood-warning levels, according to the peak of water level at Tan Chau, and Chau Doc stations of An Giang, and modified from (Le et al., 2007), as outlined in Table 4.2.

Table 4.2 River flood-warning levels (m) in the MRD classified by the National Center for Meteo-Hydrological Forecasting of Vietnam.

Level	Station		Description
	Tan Chau (in the Mekong River)	Chau Doc (in the Bassac River)	
I	≤ 3.0 m	≤2.5 m	Possible flood conditions: river water level is high, threaten low embankments; flooding in very low-lying areas; infrastructure safe.
II	≤ 3.6 m	≤ 3.0 m	Dangerous flood condition: floodplain inundation expected, towns & cities still generally protected by flood defenses; high velocity river flows pose danger of bank and dyke erosion; bridge foundations at risk from scour; infrastructure generally safe.
III	≤ 4.2 m	≤ 3.5 m	Very dangerous flood condition: all low-lying areas submerged including low-lying areas of towns & cities; safety of river protection in jeopardy, damage to infrastructure begins.
Over III	> 4.2 m	> 3.5 m	Emergency flood condition: general and widespread uncontrollable flooding; dyke failure a certainty and probably uncontrollable; damage to infrastructure severe.

As also seen in Table 4.1, coastal districts along the MRD coast can be affected by flooding and inundation in different ways. These can be high upstream flow discharge, high rainfall during the wet season in combination with high tidal levels from the east sea and the west sea, or waves influenced by the southwest monsoon overtopping coastal defenses. Human activities, such as illegal cutting down of trees that protect riverbanks, can also exacerbate flooding. While not quite so obvious, human activities tend to alter the ecological system in a river basin that will have an impact on the hydrology of the catchment, it is also the fact that wider catchment processes influence floods. In particular, activities such as the denudation of forest and watershed areas can lead to an increase in flood frequency.

- Numerous researchers indicate that ***rising sea levels are likely to contribute to seawater incursion in coastal areas*** (Lawrie, 2007; Oude Essink et al., 2010). In the case of the MRD, the coastal districts are most vulnerable. Saline incursion is influenced by factors such as high tide, low upstream water flow and low rainfall during the dry season (Hoang et al., 2012). Additionally, during the prevalent northeasterly monsoon coinciding with strong waves associated with the dry season, saltwater can intrude further towards interior fields, thereby impacting freshwater supplies for crop production and domestic drinking water. However, saltwater can also be a resource to assist with diversified farming systems (e.g., rice-shrimp) - an example of adaptation (see Figure 4.2).

Figure 4.2 These photos were taken during the dry season in 2012: a) The canal, and b) the west bank of the Mekong River in Phu My Tan - An Giang were heavily affected by drought. The water table levels were remarkably reduced to 1.5 m in height in the canal exposing 6 m in length of the bank of the river.

Before 1980, Nguyen and Savenije (2006) indicated that in the MRD, about 63% of the agricultural land (amounting to 1.7 - 2.1 million ha out of 3 million ha) were annually affected

by seawater incursion during the dry season. In the 1980's and 1990's, a number of salinity control projects were implemented, leading to closure of dams and sluice gates in the navigable canals connecting the branches of the delta. Nguyen and Nguyen (1999) indicated that the water intakes along the estuary branches needed to be closed for considerable periods of time (from weeks to one or two months each year) to prevent seawater incursion. As a result, salinity is currently influencing only 28% area of the delta every year. The Long Xuyen Quadrant area, including a part of Kien Giang province is directly affected by saltwater from the west sea during the dry season. The tide in the west sea is diurnal with a small tidal amplitude and most of the west coast channels have salinity control gates. However, two main Channels, Vam Rang and Ha Giang, are still open, enabling saltwater incursion that can threaten this area. In the Ca Mau peninsula, because it is surrounded by both the east sea and the west sea, saltwater incursion is likely to be serious and particularly complex. Two different tide regimes affect the flow in the canal system and restrict the transfer of freshwater from the Bassac River towards the interior fields. However, the saltwater cannot intrude further inland because of the existence of a relatively large area of mangrove fringe considered to be an effective natural barrier. Mazda (2007) also indicates that mangrove forests play important roles in supplying significant livelihoods for people living there, and a home for a variety of fauna and flora wetland species. Apart from the detrimental consequences, seawater incursion intakes during the dry season can effectively reduce acidity from the acid sulphate soil (ASS) group that occupies some areas of the delta, including Kien Giang (Tran, 1999). As a result, these areas can be used to cultivate a Winter-Spring rice crop.

- Since 3 ka BP there has been extensive progradation of the delta seaward along the sea coast, particularly in southern Ca Mau peninsula (Nguyen et al., 2000; Tanabe et al., 2003a); however, there are varying patterns of ***shoreline change, including shoreline erosion*** at a regional scale, particularly in some coastal districts along the MRD coast. Shoreline erosion is causing considerable concern, and several possible causes have been identified to explain such erosion. These include:

1) Increased *impacts of tides, waves, and currents* due to sea-level rise, coinciding with the stronger dominant northeasterly monsoon that accelerates the speed of coastal erosion.

2) Coupled human activities, together with the impacts of sea-level rise, causing shoreline erosion due to a *reduction in the sediment budget*, following the construction of several dams in the upstream of the Mekong River since 1993 according the several reports by the MRC.

3) Specifically, *mangrove degradation* has occurred for several reasons from human activities, such as: a) deliberate destruction of mangrove forests in the Vietnam war during the period of 1962 - 1971; b) clearing by local people who did not appreciate the role of mangroves in protecting coastal areas and exploited these forests for timber, aquaculture and shrimp farming; c) water pollution due to shrimp farming and aquaculture causing further mangrove degradation; and d) the impact of closed sea dykes which did not receive sufficient attention from the government (Nguyen et al., 2008; Duke et al., 2010; Kiengiangbiosphereserve.com.vn).

Apart from the human activities that induced shoreline change, the east coastal zone consists of the mouths of the main river distributaries, stretching from the Tien Giang coast to Ca Mau cape (southeastern Ca Mau peninsula), whose flow may increase erosion, particularly during the dry season. The coast from Tien Giang coast to Ganh Hao estuary (Bac Lieu province) is characterised by sedimentation in the river mouths, and the sandy beach ridges formed parallel to the coast, which can be adversely affected by erosion. The coast from Ganh Hao estuary to Ca Mau cape (southeastern Ca Mau peninsula) is characterised by a mixed tidal flat, and shoreline change is more complex there. Particularly in Ca Mau cape, because it is quite far from the influences of the main river, the sediment budget is not abundant. However, sediment is being reworked due to stronger northeasterly waves and currents, and is subsequently being deposited and resulting in the expansion of Ca Mau cape westward. Additionally, when high tide in the east sea coincides with high tide in the west sea, it creates “interferential tidal waves” rarely found elsewhere in the world. Under these conditions, the water literally stops flowing and alluvium is accumulated at a much higher rate than in any other places (Phan and Hoang, 1993). The tropical climate with high annual rainfall, and calm water conditions combine with the semi-diurnal tide, creating significant areas of environment suitable for mangroves. In contrast, the west coastal zone, from Ca Mau cape (southwestern Ca Mau peninsula) to Ha Tien (Kien Giang), seems more stable. The coast does not have any sandy beach ridges, and sediments consist of light gray silty clays, with little organic matter. Sediment supply is limited and deposits are not subject to vigorous waves with high tidal amplitudes; this contrasts with the mouths of the active distributaries associated with the Mekong and Bassac Rivers (Nguyen et al., 2000). This area also has high rainfall, which is favourable for mangrove growth. However, mangroves cannot develop far and often form a narrow marginal community along the coastline due to the deficiency of sediment supply.

Figure 4.3 shows the widening of the mangrove fringe as it gradually extended seaward between 2008 (left), and 2013 (right) on a typical pattern of districts An Minh, and An Bien along the Kien Giang coast, derived from Google Earth. It is interesting to note that, these results differ from the published study by Shearman et al. (2013) which indicated that the area of mangrove forest in the entire MRD appears to have remained relatively stable, during the last 20 years with a modest reduction of only 0.14%. Shearman et al. (2013) mapped only the mangroves that occurred in the active river mouths, and did not consider the rapidly changing wetlands of Kien Giang or Ca Mau, indicating the need for a local approach to achieve the appropriate assessment.

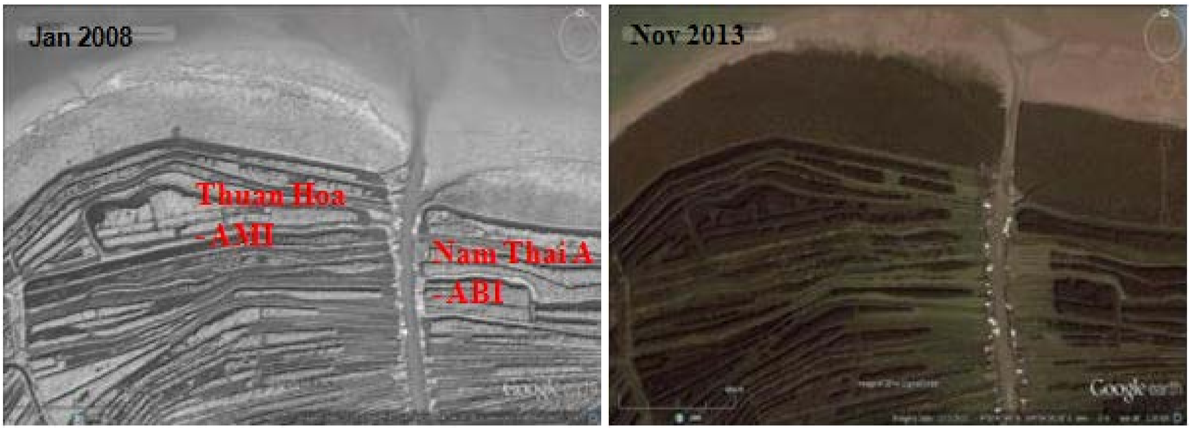


Figure 4.3 Accretion of mangrove fringes along the coast of Thuan Hoa commune - An Minh district and Nam Thai A commune - An Bien district, (derived from Google Earth).

4.3.2 Social conditions in the MRD

The MRD has been shaped by a dynamic system of socio-economic development called "the River-Water Civilisation", with most people have settled along the river and canal levees. Agriculture is more productive in the MRD than in many other parts of Vietnam. Although the economy of the delta has recently shifted with gradually decreasing proportions of agriculture, rice production will continue to play a central role in the economy, food security, and poverty reduction.

4.3.2.1 Population and landuse

According to statistical data from GSO (2012), the MRD has a comparatively high population density, being the second most densely populated area in Vietnam, with an average of 429 inhabitants/ km^2; the Red River Delta is the most densely populated area with an average of 961 inhabitants/ km^2. Within the delta, coastal provinces, including Kien Giang have been experiencing the highest population growth (see Appendix 9a), with a population growth rate

of 0.5% per year (between 2008 and 2009). Other social factors such as the proportion of inhabitants living in rural areas as opposed to urban areas (e.g., rural population vs. urban population), the proportion of the female population (e.g., female vs. male), and proportion of ethnic minorities (e.g., ethnic minority composition) should be taken into account.

Overall, the urban areas have benefited more strongly from economic growth than their rural counterparts, resulting in spatial disparities in living conditions. Rural residents have poorer access to education and health care as well as other basic services such as clean water, sanitation and transportation than urban ones. To date, the entire MRD has a high proportion of rural population, accounting for over 75% (GSO, 2012). However, in the cases of emerging cities, such as Can Tho, and Rach Gia, the dramatic rates of urban population growth are of concern because they strain capacity to handle of the full range of economic, social, and environmental issues. In addition, the proportion of female population in the MRD accounted for over 50%. Females are likely to be more vulnerable compared to males due to facing difficulties such as lower income, and a higher percentage of illiteracy. Vulnerability of women may also be influenced by difficulties gaining access to formal forms of credit and regarding recognition of land tenure. There are people of many different ethnicities living in the MRD, consisting of three main ethnic minorities, namely Hoa (Chinese), Cham, and Khmer (Cambodian). While the Kinh (Vietnamese) group accounts for the majority, living in most places throughout the region, ethnic minorities Hoa, Cham, and Khmer live scattered in some areas of provinces such as Kien Giang and Ca Mau. In fact, there exists a strong correlation between ethnicity and poverty in the delta. Generally, Kinh peoples are richer, and live in urban regions, whereas other ethnic groups such as Cham, and Khmer are usually poor, live in rural regions with less sanitation, and lower literacy, etc. Poorer people are likely to be the most vulnerable group in the delta as most of their activities and infrastructure are highly dependent on the river water regime, and in the context of climate change, particularly sea-level rise.

Landuse change, together with agricultural development in the MRD generally can be divided into three major periods since 1975. These include the:

- Rice expansion during the period 1975 - 1990.
- Rice intensification during the period 1991 - 1999.
- Agricultural diversification from 2000 to present. Since 15 June 2000, when the Vietnamese government released resolution 09/NQ-CP, many farmers, particularly in Kien

Giang and Ca Mau transformed their coastal, saline rice fields (the Winter-Spring crop seasonally) into shrimp ponds. During that year, rice-shrimp farming area increased by 0.08 million ha in Kien Giang, and 0.12 million ha in Ca Mau (Nguyen et al., 2008). Consequently, thousands of hectares of mangrove forests were rapidly destroyed for conversion to shrimp farming (Le et al., 2003). Generally, the 09/NQ-CP resolution at governmental scale seems to be basically a beneficial decision because it can bring economic returns, gradually changing the economic structure in the coastal provinces and contributing to food supply, employment, increased income and reduction of poverty in the delta by extension of aquaculture in saltwater. In fact, cash income from shrimp farming earns a farmer ten times more than the national average income from rice production.

The key problem has been that a centralised top down approach was strongly applied thus not considering the experiences and all expectations of local people. It addressed the fact that some ecologically sensitive habitats, such as mangrove forests have been cut down to build ponds for shrimp production. A steady stream of organic waste, chemicals, and antibiotics from shrimp farms can pollute groundwater or coastal areas. Consequently, massive shrimp farms have been shut down due to disease. In addition, salt from these ponds can also seep into the groundwater and onto agricultural land. Eventually, adjacent farmers cannot produce a second rice crop either (the Winter-Spring crop during the rainy season). Russell et al. (2012) indicate that seawater comes through breached dykes following removal of protective mangroves, and will inundate crops and aquaculture ponds, and wash away stock (e.g., shrimp), leading to pond abandonment. Farmers in some coastal districts have shifted to sugarcane production as a perennial crop to minimise loss due to future breaches. One of the issues that emerges from these experiences is the need for a local approach that is the best way to assist policy makers in the promulgation of appropriate and feasible decisions.

The different landuse patterns in Vietnam are classified by MONRE (see Appendix 4). As of 1 January 2011, the total area for which landuse has been mapped in the MRD has been around 4 million ha. Of which, a majority of the total area (64.5%) has been used for agricultural production, including landuse for annual and perennial crops, producing a massive amount of rice, which accounted for 46% of the total national food production, and 90% of rice yield for export (GSO, 2011). However, the MRD also has the smallest proportion of forest area in Vietnam. Only 7.7% of the total area of the delta is forested; this figure includes productive, protective, and special-use forestlands. These forests are mainly in

two provinces Ca Mau, and Kien Giang, which accounted for ~67% of the entire delta's forest area. Additionally, a minority of the total area (~9.3%) was classified as non-agricultural land, while the remainder (~1%) was unused land (see Appendix 9a.1).

4.3.2.2 Economy

In recent years, the economy of the delta has shifted with gradually decreasing proportions under Agriculture-Forestry-Fishery production, and increasing proportions of Industry-Construction, and supporting Service sectors in the region. However, the agricultural sector's importance for the MRD is also mirrored in the regional GDP profile, which contributes 38% of GDP (GSO, 2011). There is an increasing trend in all main sectors in the MRD that are about 121% for Agriculture-Forestry-Fishery sector, 118% for Industry-Construction sector, and 120% for Service sector respectively during the period of 2005 - 2011 (see Appendix 9b.1).

One of the central contradictions of the economy's development in the MRD is that, even though the delta has achieved a relatively high income, it is lagging behind Vietnam's other regions in socioeconomic aspects, particularly the poverty ratio, education, health care service, and living conditions (e.g., a number of households living in solid houses) (Matthias et al., 2012). Despite a considerable decline in poverty since 1998, there are around 4 million poor people (accounting for about 23%) living in the delta. Within eight key national socioeconomic zones, namely Red River Delta, North East, North West, North Central Coast, South Central Coast, Central Highlands, South East, and the MRD classified by the Ministry of Construction in Vietnam (MOC), there is the highest number of poor people in the MRD. Additionally, this delta has the highest percentage of "near poor" people who are vulnerable to falling back into poverty through adverse impacts on household livelihoods and income reductions due to climate change and sea-level rise. Poverty, therefore, still remains a challenge for this region.

The educational performance in the delta is strikingly poor. There were 6.6% of children aged 5, and inhabitants older in the MRD that had never attended school, while only 2.1% of inhabitants in the Red River Delta fall in this category, according to a national survey in 2009. In fact, inequalities exist in terms of gender. About 62% of the above-mentioned people, aged 5 and older that had never attended school, were female. In addition, the MRD features a relatively high illiteracy rate among the population aged 15 and older, amounting to 8.4%, in

which 64% were female. Similar disparities can also be observed, when comparing rural to urban areas. While 7.1% of the delta's rural population aged 5 and older never attended school (GSO, 2010), the figure for the urban areas amounts to only 4.9%. The rate of illiteracy among the population aged 15, and older of the MRD was 9% in rural areas compared to only 6% in urban areas (GSO, 2010). It is also argued that these figures hide the disparity between different social groups. In 1999, the primary school enrolment rate among the Kinh majority was relatively high at 93.4%, compared to only 76.3% among the Khmer minority. The secondary school enrolment of the Kinh was about 67.5%, while the enrolment rate among the Khmer was relatively low at 22.5% (Baulch et al., 2007). Moreover, the delta is in an even more unfavourable situation when considering higher education, and university attendance. There were only 8.1% of its inhabitants born between 1987 and 1990 that have ever attended university in the MRD, compared to the Red River Delta and the South East where the figure was 25%. Furthermore, there was only 2.9% of the same cohort who graduated from university in the MRD (with only 2.7% among women, compared to 3.0% among men). These values were the lowest in Vietnam with the national average being 5.2%, in terms of university graduations. Only 9.7% of the delta's economically active population aged 15 and older have ever completed vocational or professional training within the formal educational system (7.9% among women, and 11.3% among the men). These values were also the lowest in Vietnam with the national average being 17.6%, in terms of professional training (GSO, 2010).

Additionally, the figures indicate significant health-care deficiencies in the delta. The values of 20.5 patient beds in medical facilities per 10 000 inhabitants in the MRD were the lowest in Vietnam. Similarly, the number of doctors, nurses and midwives were also relatively low (4.8, 5.0, and 2.6, respectively, per 10 000 inhabitants). The MRD lags far behind the national average in all these categories, and has the lowest regional values with respect to doctors and nurses (GSO, 2011). Private providers of health care, therefore, play an important role in the MRD. There were 47% of out-patient treatments exercised in private health facilities, which was the highest value for the whole of Vietnam, the national average being at 38% (GSO, 2009).

Only 8% of the delta's households were living in fully solid houses, 22% of the households lived in houses with none of these elements made of solid materials, and the remainder 70% having houses being partly solid materials. These figures indicate that, housing conditions in

the MRD lag behind the national average, according to which 47% of the Vietnamese households lived in fully solid houses (GSO, 2010). These figures can to a certain extent be explained by the different climatic conditions in Vietnam's north and south as well as by the relatively low typhoon occurrence in the MRD in the past, making fully solid houses less necessary than in the more typhoon-exposed areas in central and northern Vietnam. However, housing upgrades are foremost in terms of the manifestation of socioeconomic progress.

The MRD's transport infrastructure is not as well developed as in other regions in Vietnam (MOT). This is because the region has not had extensive railway systems, and instead waterway transportation plays an important role in the two main river branches, coupled with hundreds of smaller lateral or parallel irrigation and drainage canals. Waterway transportation accounts for 70 - 80% of means of transportation, satisfying 70 - 80% of the passenger transportation demand, and 30 - 35% of inner goods transportation (Traffic-in-the-Mekong-Delta, 1999). The major part of national highways in the MRD are inter- and intra- province roads that were constructed before August 1945 by the French, with an average width of 5 - 6 m. About 60% of national highways are paved; however, 40% of these have been degraded, and damaged over time. In the rainy season, especially during floods, many roads such as parts of national highways 1A and 61 are under water, and some areas of the delta may be isolated from others, posing particular difficulties in evacuation and rescue activities.

4.4 Profile of the case study area

Several researchers indicate that awareness in terms of impacts of climate change, particularly sea-level rise, has come from a global or national scale, but there is need for specific impact assessments and adaptation strategies that are local (Harvey and Woodroffe, 2008), and more aligned with social, and integrated perspectives on vulnerability (Fussel and Klein, 2006). There is also a need for new approaches that involve stakeholders, more sophisticated socioeconomic scenarios, and consideration of adaptation measures, decision-support tools and enhancement of adaptive capacity as ways of reducing vulnerability to climate change (UNFCCC, 2005). This study focuses on seven coastal districts within the Kien Giang province (KGI) as a case study to assess coastal vulnerability for several specific reasons. These are:

- There have been fewer studies on the impacts of sea-level rise conducted in the western part of the delta than the eastern part.

- The Kien Giang coast is predicted to be one of the most vulnerable coastal areas to impacts of climate change, particularly to sea-level rise along the coast of the MRD. In terms of biophysical factors, there are possible explanations for this, because: 1) the coast is a very low-lying area together with 2) the highest projected sea-level rise derived from The-Second-Scenarios-VN (2011) (see Appendix 7e), and 3) it has the least sediment supply due to its location farthest from the active river mouths.
- The Kien Giang coast is likely to be moderately affected by impacts in terms of social factors due to several reasons. The Kien Giang coast is a relatively densely populated area, with relatively high proportions of rural people, and ethnic households, with limited availability of agricultural land within coastal provinces in the MRD.
- Generally, ability to manage the impacts of sea-level rise in coastal provinces in the MRD currently seems to be relatively low. Kien Giang is one of four provinces in the dynamic economic zone in the MRD (see Appendix 9b.1), and emerging as an economic spotlight in 2013. It may be possible that, improving economic conditions for the province can strengthen the ability to reduce adverse impacts.
- Last but not least, most information and datasets for the case study vulnerability assessment are available, accessible, and useable.

4.4.1 Overview of the Kien Giang coast

Kien Giang is a coastal province in the MRD, that adjoins Cambodia with a 56.8-km long border. Ca Mau and Bac Lieu provinces are located on the southern, and eastern borders; and the southeastern border provinces are An Giang, Can Tho City and Hau Giang. To the west is the west sea (also known as the Gulf of Thailand) with a coastline that is 208 km long. Kien Giang has two parts, a mainland section (9^{o}23'50"- 10^{o}32'30" N, 104^{o}26'40"- 105^{o}32'40" E), and offshore islands (about 105 islands). This thesis concentrates on the mainland with a total area of approximately 5 640 km^2.

Kien Giang has 15 district level and town administrative units, consisting of Rach Gia City, Ha Tien Town which is an important deep sea port connecting the city with a wide array of destinations in the region, and 13 other districts, including 118 communes and towns within those districts. The study area, consists of the seven coastal districts (on the mainland), namely: Ha Tien (HTI), Kien Luong (KL), Hon Dat (HD), Rach Gia (RGI), Chau Thanh (CT), An Bien (ABI), and An Minh (AMI), that is presented in Figure 4.4.

4.4.2 Natural systems in the seven coastal districts

Located in a very low-lying area, directly influenced by the tidal regime from the west sea, the coastal districts cover about 300 000 ha, accounting for 47% of the total area of Kien Giang. Generally, these have a favourable climate, rarely affected directly by natural disasters, such as tropical typhoons or storms. It is warm and sunny year-round; and this climate supports abundant living and production.

4.4.2.1 Digital Elevation Model

A Digital Elevation Model (DEM) with the 15 m resolution was derived for the seven coastal districts from the project (Code BDKH.08) conducted by Tran et al. (2013), and is presented in Figure 4.4.

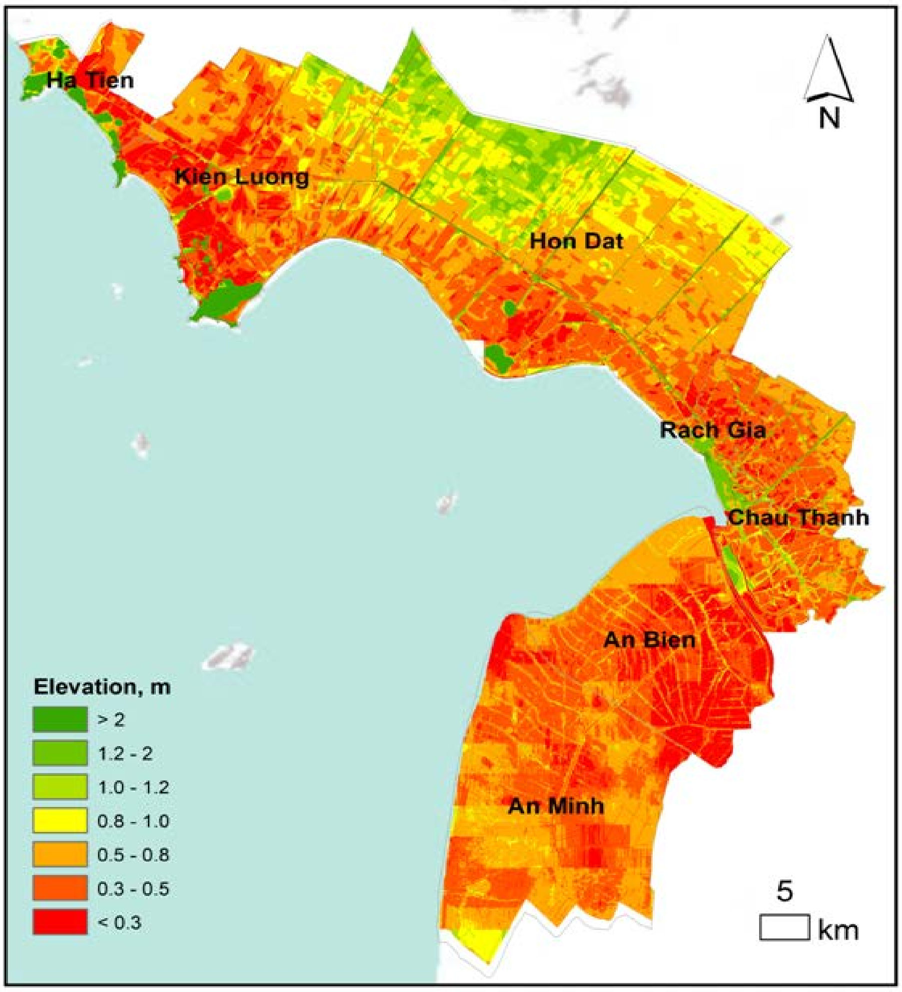


Figure 4.4 The Digital Elevation Model for the seven coastal districts, (derived from the project conducted by Tran et al., 2013).

As can be seen in Figure 4.4, the seven coastal districts along the Kien Giang coast are very flat, except for several isolated mountainous outcrops in the districts of Ha Tien, Kien Luong,

and Hon Dat. Approximately 83% of the total area is below 1 m above mean sea level (MSL), and the area is at risk from high tide levels (see Appendix 8b). Further results derived from this DEM will be determined and discussed in chapter 5 (sub-section 5.3.2). Integrated with the geological data of Tran (1986), the topography and geology in the study area can be divided into three major forms:

- *The region is located in the Long Xuyen quadrangle*, including parts of districts Ha Tien, Kien Luong, Hon Dat, and Rach Gia, having average elevations of 0.8 - 1.2 m, known as the flood openings in Kien Giang, which were formed by young sediment from the main river channels. The coastal sediments contained abundant sulphate, which has been reduced in the anaerobic conditions to form potential ASS rich in pyrite minerals in the low-lying plains. These areas are flooded during the wet season, but when drained can become very acidic. These areas are able to support *Melaleuca* forests.
- *Plains* are largely distributed in the districts of Chau Thanh, An Bien, and An Minh, and located in the Ca Mau peninsula. These areas were established by the alluvial sedimentation from the Bassac River with an average height of 0.3 to 0.5 m above MSL, together with many canals, and rivers. These areas are characterised by mangrove fringes, distributed mainly in An Minh and An Bien. It is important to note that, these could be underwater at high tide if they are not well protected by mangrove fringes or man-made coastal defences.
- *Low hills* are scattered in some parts of districts Ha Tien, Kien Luong, and Hon Dat, with the average height of up to 200 m. These hills consist of granite and mountain limestone (e.g., Chua Hang and Hon Me). Kien Giang has abundant mineral resources (e.g., peat, limestone, building stone, clay, etc), metal minerals (e.g., iron), and semi-precious stones (e.g., black quartz-opal), compared to other provinces in the MRD.

4.4.2.2 Climate change and sea-level rise scenarios for Kien Giang

a. Overview

The Kien Giang coast is influenced by a diurnal tide, with an amplitude of 0.5 - 0.8 m (Phan and Hoang, 1993). The river-flood season in Kien Giang usually occurs from July to November, with the peak of water level in October, coinciding with the stronger southwesterly monsoon. Average rainfall is 1 600 - 2 000 mm/ year. The rainy season starts from May to November. August has the highest rainfall of 300 - 500 mm. In contrast, the dry season is characterised by low flow, coinciding with the northeasterly monsoon. It usually

lasts from December to June with May having the lowest flow. In addition, from December to April, is the dry season with low rainfall, and March has the lowest rainfall.

b. Climate change and sea-level rise scenarios

Recently IMHEN completed statistical downscaling for the whole MRD, with MAGICC/SCENGEN (Wigley, 2008) for the primary climate variables such as temperature and rainfall, together with the regionally downscaled scenarios for sea-level rise (IMHEN, 2010b) and the latest hydrological river flow scenarios developed in the Mekong mainstream above Kratie by the Mekong River Commission (IMHEN, 2010a). The scenarios developed by the MRC were based on PRECIS (Jones et al., 2004), and have been used in a number of reports prepared by IMHEN relating to impacts of climate change in the Mekong River upstream of Vietnam.

Simulations predicted an increase in monthly average temperature, monthly average rainfall, and sea-level rise scenarios for Kien Giang for the two time periods 2030 and 2050, relative to 1980 - 1999 based on SRES B2 and A2. The annual temperature in Kien Giang is projected to increase similarly for the B2 and A2 scenarios by 0.3 - 0.7°C to 2030 and by 0.5 - 1.2°C to 2050, respectively (see Appendix 7b). Moreover, rainfall is projected to increase slightly in the rainy months, with the biggest increase projected for October, increasing from 7.4% by 2030 to 13.5% by 2050 for medium scenario B2, while under the A2 scenario it is projected to increase from 7.6% by 2030 to only 12.9% by 2050. On the contrary, rainfall will tend to decrease slightly in dry months, with the biggest decrease projected to occur in March from -10.8% by 2030, and -10.9% by 2050 for a B2, while from -19.5% by 2030, and only -18.7% by 2050 for A2 respectively (see Appendix 7d). The modelling of rainfall indicates that flooding and inundation in Kien Giang during the rainy season, together with drought and other adverse effects during the dry season could become exacerbated in the period 2030-2050. Furthermore, the sea level from Ca Mau cape (Ca Mau) to Ha Tien (Kien Giang) (along the west sea) is predicted to increase by 15 cm by 2030, and 30 cm 2050 under scenario B2; while under the higher scenario of A1FI sea level ir projected to increase by 16 cm by 2030, and 32 cm by 2050 (IMHEN, 2010a, b). Coastal modeling has also been completed using scenario B2 only, because of the very minor differences between the two scenarios medium and high in 2030, and 2050 (Mackey and Russell, 2011). It is important to note that modelling scenarios of flood depth, and seawater incursion in 2030, and 2050 for Kien Giang under scenario A2 were used with the predicted rising sea levels of 15 cm by 2030, and 30 cm 2050.

The level, therefore, will high tides reach to 1.2 m above present MSL, if rises 30 cm by 2050, leading to easy overtopping of embankments with threats to inland.

4.4.2.3 Flood depth and flood setting

Flooding is an integral to the function of the MRD. Indeed, surface water is needed for rice crops, which are the main livelihood of most local people. In fact, people are adapted to living with floods to a certain level. When thresholds are exceeded, flooding can become a nuisance (e.g., if inundation levels are deep, then dykes along canals and around paddy fields can be overtopped, leading to flooding of houses and crop and other damage).

There have been several studies of flood hazard mapping focusing on the depth of the flood as the key hazard indicator (Bormudoi et al., 2008; Merz et al., 2007; Penning-Rowsell and Chatterton, 1977; Townsend and Walsh, 1998). In a study on climate change impact from flood hazard, vulnerability and risk of the Long Xuyen Quadrangle was studied by Dinh et al. (2012) who indicate that the depth of flood is considered the most important of these flood proxies. Thereby, flood depth is used as a flood proxy in this study to assess the potential impacts in this thesis.

Simulated, and projected simulation maps of flood depth for the study area have been reported by several researchers to assess the areas most exposed to flood impacts (IMHEN, 2010a; Mackey and Russell, 2011; Tran et al., 2013) (see chapter 3, Table 3.7). A map of the extreme historical flood depth (m) that occurred in 2000 for the study area was used to estimate the current influences (see Appendix 8c.1). The 2000 flood was an extreme event, considered to be a 1 in 100 year flood. This flood event has been combined with projected sea-level rise, and the Mekong Basin rainfall and river flow under the A2 scenario to produce the maps of flood depth for 2030, and 2050 (see Appendices 8c.2 and 8c.3). As these are based on an extreme flood event, the inundation-depicted does not represent permanent inundation, but shows expected inundation during periods of extreme flood. The frequency of the "*1 in 100 year*" flood may or may not vary, and would be dependent on rainfall across the whole Mekong Basin, covering several countries (i.e., it will change markedly if climate changes, it is non stationary).

4.4.2.4 Salinity and seawater incursion setting

a. Seawater incursion

During the dry season, seawater incursion in the study area is mainly influenced by the tidal regime of the west sea. It seems to become exacerbated at high tide, integrated with projected sea-level rise, and decreased rainfall during the dry months. The maximum extent of saline incursion inland occurs in combination with the lowest rainfall and flow through river and canal networks, and coincides with a stronger influence by the northeasterly monsoon. Fortunately, seawater incursion cannot enter far inland even in the dry season because of the small tidal range. Salinity was used as a key proxy to assess the potential impacts of seawater incursion in this thesis. The major ramification of salinity in the study area is related to agricultural production (see chapter 3, Table 3.10).

Maps of drought and salinity incursion (historical and in the future) scenarios for the study area, were derived from several studies (Le and Le, 2013; Mackey and Russell, 2011) (see chapter 3, Table 3.7). A map of the maximum seawater incursion (ppt) observed in 2010 using salinity data collected from stations in the study area, was used to identify the areas most exposed to saline incursions (see Appendix 8d.5). In addition, an event simulating extreme historical drought and salinity incursion observed in May 1998 (see Appendix 8d.1) combined with projected sea-level rise, and water flow through the river and canal network, has been used by Mackey and Russell (2011) to produce maps of potential seawater incursion in 2030, and 2050 (see Appendices 8d.2 and 8d.3). It is important to note that, the projected extent of seawater incursion is determined, based on maximum isohalines that are lines of equal salinity concentration.

b. Soil types

Because Kien Giang comprises low plains; alluvial sedimentation formed by river silt and deposition of marine sediments is the basis for most soils. Soils have a high proportion of clay (45 - 58%); they are over 70 cm thick, with high organic contents, and can be divided into three main categories:

- Alluvi*sols/deltaic soils* occupy 5.4% of the natural area of the province, and are mainly distributed in Chau Thanh, and scattered in Rach Gia, and Hon Dat. These soils are the best for agricultural activities.
- *Saline soils* include: regular saline soils (accounting for 3.6%), which are distributed mainly on the coasts of An Bien, and An Minh, and scattered in Hon Dat, and Rach Gia.

These soils are often good for one rice crop a year, integrated with aquaculture. Seasonal saline soils (accounting for 40.4%) occur along the coastal districts during the dry season. These soils are strongly affected by the tide and useful for growing coconut, pineapple, sugarcane, and other produce during the dry season, combined with one rice crop a year during the rainy season.

- *Acid sulphate soils (ASS),* (accounting for 40%), are distributed mainly in Ha Tien, Kien Luong, Hon Dat, and An Minh. These soils are good for, such as Acacia, *Melaleuca*, pineapple. Soils must be improved to support other crops. It is a widely held view that distribution of soil types, particularly saline soils along the Kien Giang coast, can influence the observed and projected extent of seawater incursion (see a map of soil type distribution for the study obtained from undated MONRE in Appendix 3c). Soil types have been taken into account in this study when estimating the potential impacts of seawater incursion.

4.4.2.5 Shoreline change

Overall, the west coast of the MRD is undergoing less shoreline change than other sections of the delta. This shoreline generally remains stable with protection by a 300 - 400 m wide fringe of mangrove forest, combined with the small tidal range, and wave height. However, waves erode the coast gradually, and when integrated with projected sea-level rise shoreline change could worsen.

The coastline of Kien Giang is characterised by three main landform types, comprising limestone or granite headlands interspersed by small embayments in the north (e.g., Ha Tien), a large embayment leading into a large estuary in the centre (e.g., Rach Gia bay), and a straight segment of coastline in the south (e.g., An Bien and An Minh). The shoreline of Kien Giang is charaterised by mangrove fringes, covering about 65% of the coast's length. According to recent surveys by scientists from GIZ Kien Giang, the area of mangroves in Kien Giang has been estimated to be nearly 5 500 ha in 2006, an increase of 1 500 ha compared to 1999 because of mangrove restoration programs. Other coastal districts Ha Tien, Rach Gia, and Chau Thanh have small areas of mangrove forest. However, the condition of mangrove forests along the Kien Giang coast is relatively poor, with a strip of mangrove varying in width from 10 - 500 m (Duke et al., 2010). During a period from 2005 - 2011, there was a steady decrease of area of protective mangrove forests based on statistical data obtained from the Kien Giang Statistical Office 2012 (see Appendix 9a.4). An estimate of about 50%

area of the Kien Giang coastline has been found to be eroded or eroding due to cutting of these mangroves (Kiengiangbiospherereserve.com.vn).

Several researchers have recently attempted to assess the shoreline condition based on the change in mangrove fringes in specific sites along the coast of the MRD, such as studies conducted by Duke et al. (2010) in the Kien Giang coast, and Shearman et al. (2013) in the mouths of the Mekong and Bassac Rivers. The relationship between the change in mangroves and shoreline condition in the Kien Giang coast will be determined in sub-section 4.5.3.3b. It is believed that the adjacent of landuse along the Kien Giang coast, particularly the area of mangrove fringe can be related to shoreline protection (see a map of the adjacent of landuse along the Kien Giang coast obtained from the GIS database of MARD in 2010 in Appendix 9a.2c). Therefore, the adjacent landuse along the Kien Giang coast should be taken into account when estimating susceptibility to shoreline change.

In this thesis, satellite images were used to assess observed shoreline change along the Kien Giang coast. Landsat images are particularly useful in mapping natural resources and have been used widely to detect erosion and accretion along a coast (Alhin and Niemeyer, 2009; Ekercin, 2007; Hereher, 2011; Kuenzer et al., 2011). A set of ten Landsat satellite images over a period of 40 years, from 1973 to 2013, was used to undertake shoreline change comparison for this study. The resulting interpretations of shoreline position for the Kien Giang coast were used to assign and determine the shoreline displacement variable of the shoreline change sub-component that will be presented in chapter 5 (sub-section 5.3.3.1).

4.5.3 Social factors in the study area

Generally, the main human pressures acting as drivers in the coastal districts of Kien Giang are demographic trends, including population and economic growth, and pressures on land for developing. These social factors make the study area likely to become one of the most vulnerable areas, particularly when coupled with the detrimental effects of flooding and inundation, seawater incursion, and shoreline change.

4.5.3.1 Overview

With a total population of more than 1.7 million in 2011, the economy of Kien Giang grew robustly in the period 2001 - 2010, with an annual GDP growth rate of 12% as compared with a growth rate of only 8% in the previous period of 1996 - 2000. In 2010, the total GDP of the

province reached US$ 1 783 million. Although Kien Giang has a more mixed economy with cement production and tourism, being key main emerging differences, agriculture continues to contribute a relatively high proportion to the province's economy. The economic growth of the province is expected to be 9% for the period 2010 - 2030, and 8% for the period 2030 - 2050. However, Mackey and Russell (2011) indicate that adaptive capacities of local authorities in Kien Giang in relation to climate change issues are relatively low, and despite a long history of disaster management response planning, regional sector and socioeconomic development planning includes inadequate reference to climate change adaptation measures.

4.5.3.2 Societal factors

a. Population density

Statistical data derived from the Kien Giang Statistical Office's Book in 2012 indicate that an average provincial population density in 2011 was 271 inhabitant/ km^2, which was slightly higher than the average national population density (260 inhabitant/ km^2). Average population density of coastal districts in 2011 was 308 inhabitant/ km^2, which was slightly higher than the provincial population density. Rach Gia was the most densely populated district (of 2 246 inhabitant/ km^2), and was much higher than other coastal districts. Hon Dat had the lowest population density (only 164 inhabitant/ km^2) (see Appendix 9c.1). It is likely that Rach Gia is the most sensitive area in terms of population density, while Hon Dat is the least sensitive area. If the provincial population growth is expected to be 1.3% per year, it can be assumed that the population may reach 2.17 million in 2030, and 2.81 million in 2050. This highlights the fact that detailed data is needed at district level from plans, master plans, and strategies on provincial developments in socioeconomic, education and health in Vietnam for the year 2020, plus a vision for 2030, or 2050.

b. Rural and urban people

Statistical data derived from the Kien Giang Statistical Office's Book in 2012 indicate that about 73% of rural people were in the entire province in 2011, whereas coastal districts had only 62% of rural people. The highest proportion of rural people (94%) was in An Minh, and An Bien (91%). These areas are the most sensitive areas, due to the high proportion of rural people (see Appendix 9c.2).

c. Female people and ethnicity group

Statistical data derived from the Kien Giang Statistical Office's Book in 2012 indicate that there were a few differences between percentages of females and males in 2011, in which 49% of people in the entire province were female, with a slightly higher proportion of females in coastal districts (50%) (see Appendix 9c.3). It is believed that females in coastal districts are likely to be less sensitive than females living in other parts of Kien Giang (see sub-section 4.3.2.1).

Kien Giang has about 10 ethnic minority groups, accounting for nearly 17% of the total provincial population. Khmer is the dominant group (13%), followed by Hoa (3%) and others (Tay, Nung, Muong, Cham, Ngai, H'mong, Ede) contributing less than 1%. Data derived from the District Survey in Kien Giang conducted in 2011 indicate that there were 15% of the ethnic minority groups in coastal districts, which was a little less than the proportion of provincial ethnic minority groups. Specifically, Chau Thanh had 38% of the ethnic minority groups, which was the highest, compared to other coastal districts. An Minh had the lowest proportion of ethnic minority groups (only 2%). It appears that Chau Thanh is the most sensitive area, while An Minh is the least sensitive area, in terms of ethnic groups (see Appendix 9c.4).

4.5.3.3 Landuse

a. Landuse

During the period 2005 - 2011, in Kien Giang, there was generally a decrease in the proportion of area of perennial cropland, forestry land, and fishery land. There was also an increase in the proportion of area of rice land. There were increases in the proportion of areas of homesteads, special-use land, and others in terms of non-agricultural land category, and there was a decrease in the area of unused land (see Appendix 9a.3). Specifically, statistical data derived from the Kien Giang Statistic Office 2012 indicates that 71.9% of the total area of Kien Giang was agricultural production land, which was remarkably higher than the proportion for the entire delta (64.5%). In addition, Kien Giang has a greater proportion of forestland (14.4%) compared to the entire delta (only 7.7%) (see Appendix 9a.2). However, Kien Giang has less non-agricultural land (7.6%) than the entire delta (9.3%), having only 0.8% of unused land, compared with 1% for the delta.

These data suggest that using weighting methods helps avoid over-estimation of the contribution or importance of each landuse category in measuring the most sensitive, in terms of landuse, as advocated by Yoo and Kim (2008). The results obtained using weighted methods are also more objective, as advocated by Wang et al. (2011); and visualise the most feasible decisions more accurately using mapping techniques, as advocated by numerous authors (Kubal et al., 2009; Wang et al., 2011), provided by (Saaty, 1980; Saaty, 1994). A map of landuse for the study area obtained from MONRE (2008), is presented in Appendix 9a.2 that was used to estimate the potential impacts on the basis of landuse (see chapter 5, sub-section 5.4.2.2).

b. Mangrove and Melaleuca forests

Mangrove provides a natural protection for the MRD coast. Data obtained from surveys conducted by scientists in the GIZ Kien Giang project from 2008 - 2011 indicate that there is a diversity of mangrove species in Kien Giang (about 30 out of 50 species found in Vietnam). Of which, *Avicennia alba* (one of white mangrove species) is the dominant species on the margin of the Kien Giang coast (see Appendix 6). In 2009, there was a large area of mangroves mainly in four districts, comprising 2 300 ha in An Bien, 900 ha in An Minh, 800 ha in Hon Dat, and 680 ha in Kien Luong (Kiengiangbiosphere reserve.com.vn) (see a map of forest distribution in the study obtained from Sub-FIPI (2008) in Appendix 9a.4). Together with mangrove forests, *Melaleuca* forests also play an important role in local economies and confer considerable environmental benefits to the region. *Melaleuca* forestry occurs mainly in districts, such as Kien Luong, Hon Dat, and An Minh. Currently, the main alternative wood products from *Melaleuca* forests are of low value and sell for well below the cost of production. *Melaleuca* sold for chip manufacture sells for 380VND per kg (ca. 500 000VND/ m^3, equivalent to US$ 25.6 per m^3) at road/canal side.

The first line of defense from the effects of wave action on the coast is mangroves. Behind the mangroves, protection of crops and urban structures is achieved through the construction of earth sea dykes, although it is expensive to build and maintain dykes. If mangroves are removed or eroded, strong waves that overtop a dyke, or flow through breached dykes, can destroy houses and farm infrastructure. Earth dykes can be breached within only a single wet season. In some parts along the coast, such as Hon Dat where agriculture occurs behind the sea dykes, seawater that comes through breached dykes will inundate crops and aquaculture ponds, leading to their abandonment. The fragmented mangrove system allows waves to

penetrate to the back of the abandoned pond advancing erosion in steps of 50 - 100 m (Russell et al., 2012).

As mentioned in chapter 3, sub-components of the adaptive capacity component of the study were represented by assigning functions of socioeconomic, technological, and infrastructure sub-components (Yusuf and Francisco, 2009). These three sub-components will be described in the following sub-sections 4.5.3.4 to 4.5.3.6.

4.5.3.4 Socioeconomic conditions

a. Overview

The Kien Giang economy is based on agriculture (46.66%), industry (22.93%), and the service sector (30.41%), according to the statistics derived from the Kien Giang Statistical Office in 2012 (see Appendix 4.8.3.2). Agriculture continues to contribute a relatively high proportion to the province's economy (46%, compared to 38% for the MRD as a whole), and the proportion of forestry and fishery sectors the agriculture sector is high in Kien Giang. Agricultural activities employ a high percentage of people in the province, providing livelihoods for more than 75% of the people there. In 2005, there were only 240 registered small and medium companies in Kien Giang, but there has been significant increases of more than 3 600 companies in 2011, of which most are in the agro-processing sectors. Those companies have invested in modern technology such as cold storages, packing and sorting equipment to be capable of supplying high quality products to highly demanding overseas markets.

The Kien Giang coast can be divided into 2 main concentrated zones for agricultural activities. These are:

- *The Kien Luong/Hon Dat Square* that has a large area for intensive rice crops, comprising a more saline area in the southwest of Hon Dat's main canal/road, and a freshwater area in the northeast of the district.
- *An Bien, and An Minh* that have a large area for mostly rice/shrimp, located on the west side of the Cai Lon River, which experiences considerable saline incursion (see Figure 4.5).

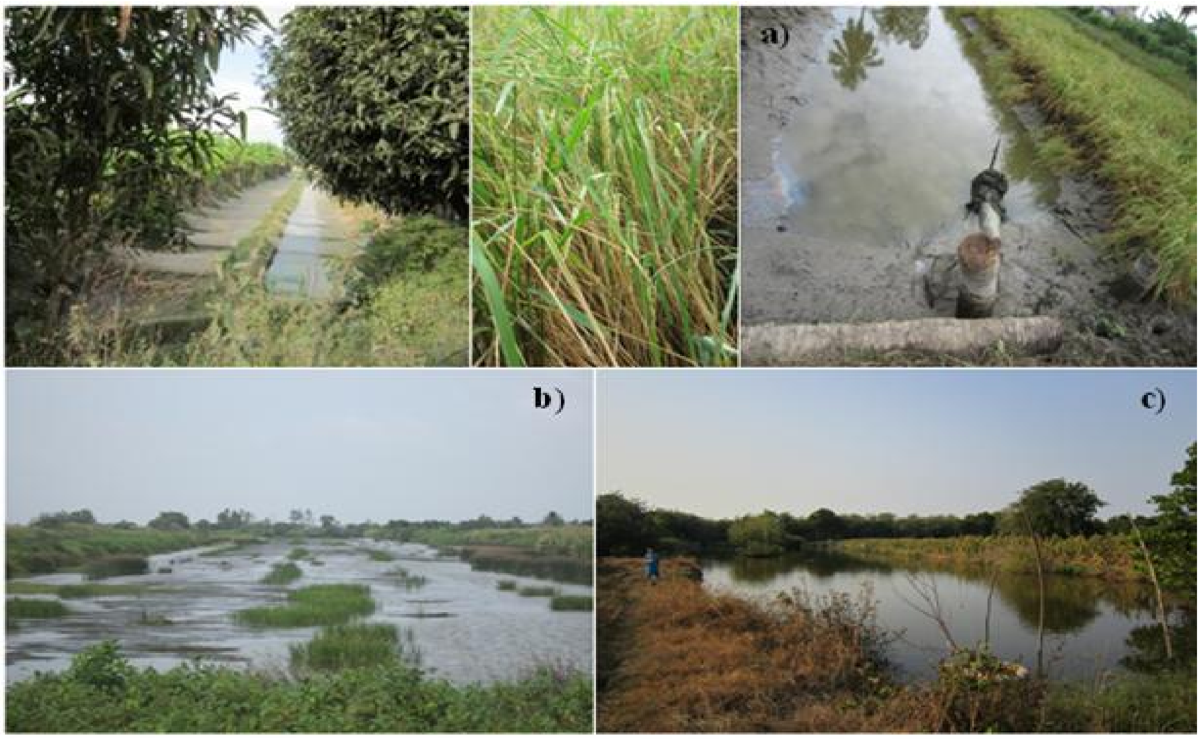


Figure 4.5 Fishery farming in high salinity incursion in KGI: These photos were taken during the dry season; a) Shrimp nursery, rice tolerant of high salinity, and drainages of rice-shrimp pond module in U Minh Thuong in 2012; b) Rice-shrimp pond in An Minh in 2013; and c) Fishery farming associated with mangroves in An Bien in 2015.

Furthermore, salt is extracted from productive saltpans scattered along the Kien Giang coast, such as in Kien Luong. Figure 4.6 shows a large conversion of cultivated land to salt ponds in Kien Luong during the period of 2000 - 2010, derived from Google Earth. This area was very productive during the dry season (March 2006) (middle), and inundated during the wet season (October 2010) (right).

Figure 4.6 Landuse change from 2000 - 2010 (derived from the Google Earth): Salt ponds are dominant in Ap Cau Thang village, Duong Hoa commune, Kien Luong district.

b. Income and poverty ratio

Data derived from the Kien Giang district Survey 2011 indicate that, there was an average provincial GDP per capita of US$ 972, being a little less at US$ 949 for the coastal districts.

Two districts Rach Gia, and Ha Tien experienced much higher income, while other districts experienced smaller. An Minh, and An Bien experienced the lowest income (see Appendix 9d.1). Additionally, statistical data derived from the Kien Giang Statistical Office in 2012 indicate that, there was an average poverty ratio (proportion of poverty per household) of 7.2% for the entire province, which was slightly higher than for the coastal districts (only 6.6%). Two districts An Bien, and An Minh experienced the highest poverty ratios (see Appendix 9d.1). If people have a higher income, they are likely to be better prepared to decrease the potential impacts, while if people are struggling with poverty, they do not have enough financial resources to respond to adverse impacts.

There is a strong correlation between the poverty ratio and ethnicity in the study area (see sub-section 4.5.3.2c). The poverty ratio of ethnic groups is still high (e.g., the poverty ratio of Khmer group is 18%), which is much higher than those proportions of the entire province, and in coastal areas.

c. Health services

Health services, as used here, refers to the capacity of a health establishment serving a number of inhabitants, together with the abundance of medical and pharmacy staff at district level. Statistical data derived from the Kien Giang Statistical Office, 2012 indicate that there was slightly higher than average capacity of people per health establishment estimated to be 11 056 inhabitants per establishment in coastal districts, and 10 435 inhabitants per establishment for the entire province. Statistic also demonstrate the in the limited number of health staff, particularly in coastal districts, with each health staff responsible for the care of 477 inhabitants, but health staff were responsible for only 331 inhabitants in the province. Ha Tien experienced the lowest capacity per health establishment (5 734 inhabitants), whereas, Chau Thanh experienced the highest capacity per health staff, with individual staff caring for 781 inhabitants (see Appendix 9d.1).

d. Education

Education, as used here, refers to the capacities of a kindergarten in terms of number of kids, and a primary and secondary school in terms of number of pupils, together with the abundance of teachers respectively at district level. Statistical data derived from the Kien Giang Statistical Office 2012 show that for coastal provinces there were 616 kids/ kindergarten and 23.2 kids under a teacher's supervision, while for all provinces there was

significantly less proportion of kids/ kindergarten (468), and a similar figure at 23 kids under a teacher's supervision. In addition, there were 582 pupils/ primary and secondary school, and 18.3 pupils under a teacher's supervision for coastal provinces, which is significantly less than the 535 pupils/ primary and secondary school, and a slightly less figure at 17 pupils under a teacher's supervision for the province. The lowest capacity of a kindergarten was in Hon Dat at 256 kids, and the highest figure of kids under a teacher's supervision, in terms of kindergarten was in Kien Luong at 28 kids. Additionally, the lowest capacity of a primary and secondary school was in An Minh (415 pupils), and the highest figure of pupils under a teacher's supervision, in terms of primary and secondary school was in Rach Gia (21 pupils) (see Appendix 9d.1).

4.5.3.5 Infrastructure conditions

Infrastructure conditions, as used here, include road transport, solid house structures, and telephone subscribers. Investments in infrastructure in Kien Giang have grown robustly at more than 10% per year. In 2010, it had an estimated infrastructure value of US$ 224 million.

a. Transport network

Road (inland) networks in Kien Giang can be classified into four types, comprising international or national highways, provincial, district, and small roads connecting to communes and lower administrations. Actual designs of new/improved roads are based on flood records and local conditions. National roads are designed for "*the 1 in 100 year floods*", and provincial roads for "*the 1 in 50 year floods*". There are three national roads, numbered 80, 63, and 61, within the province. Statistical data from the Kien Giang Statistical Office 2012 indicate that, the province experienced high road density of 91% at communal level, while slightly less road density of 86% at the communal level of coastal districts (see a map of the road network for study derived from Tran et al. (2013) in Appendix 9d.2). An Minh and Rach Gia have the lowest road densities at communal level (see Appendix 9d.2).

Figure 4.7 These photos were taken during the dry season in 2013: a) Ferries; and b) Boats are the main water vehicles using unofficial travel waterways between smaller urban centers.

In addition, water transport is also a key means of travel through channels into communes, where roads are not yet built. Ferries and boats are convenient vehicles, which are used to connect settlements within, and outside the province (see Figure 4.7). There is one main inland fishing port at Tac Cau located at the south of Rach Gia. Despite its key location on the border with Cambodia, the lack of a mainland deep-water port has been noted as a key factor restricting the province's growth. There are two airports, one at Rach Gia, and the other on the Island of Phu Quoc, which play an important role in supporting the province's development. It is beyond the scope of this thesis to examine the capacities of water transport, port, and airports in terms of the transport network.

b. Solid houses

Statistical data of the Kien Giang Statistical Office 2012 indicate that there 93% of provincial households have solid houses, and also in coastal districts (93.3%), which is much greater than in the delta as a whole (only 78%). An Bien and An Minh have the most lowest proportions of solid houses, which may make them more vulnerable to flood and other impacts (see Appendix 9d.2).

Figure 4.8 Built up areas: These photos were taken during the dry season in 2013 and 2015; a) The polder areas under-construction, and b) Houses built up along the river's bank in Ha Tien; c) The first polder areas of urban expansion of Vietnam, and d) Houses in Rach Gia; Houses built up along the river's bank: e) in Hon Dat, f) in An Bien, and g) in An Minh.

Figure 4.8 presents built-up areas in Kien Giang. Most solid houses, comprising fully and partly solid houses are built up to run parallel to the embankments of rivers and creeks. There are also three polder areas of urban expansion in Kien Giang, first built in Rach Gia, and two under-construction sites in Ha Tien and Kien Luong.

c. Communication network and telephone subscribers

Telephone subscribers, as used here, refers to the proportion fixed-line telephone subscribers at the district level. Statistical data from the Kien Giang Statistical Office 2012 showed a deficiency of fixed-line telephone subscribers, particularly in seven coastal districts; 17.1

inhabitants had to share a fixed-line telephone subscriber, which is a little less than the 14.2 inhabitants per fixed-line telephone subscriber for the entire province. Specifically, the lowest number of a fixed-line telephones subscriber was in Hon Dat (37.6 inhabitants), whereas the highest capacity was in Rach Gia (7.5 inhabitants) (see Appendix 9d.2). It is beyond the scope of this thesis to examine the capacities of mobile telephone subscribers, and internet subscribers (ADSL) in terms of communication networks.

4.5.3.6 Technological conditions

Technological conditions, as used here, consist of irrigation and drainage systems, and the electricity coverage network.

a. Irrigation and drainage system

Irrigation and drainage system, as used here, includes the system of rivers, and river embankments, sea dykes, canals, and sluice gates (see a map of this system for the study obtained from SIWRP (2010) in Appendix 9d.3). There are three major rivers in Kien Giang, comprising the Cai Lon, Cai Be, and Giang Thanh. The Cai Lon and Cai Be Rivers originate from the Bassac River, and flow to the Gulf of Thailand (the west sea), while the Giang Thanh River originates from Cambodia, and flows to the west sea. There is a complicated canal system, comprising an old Vinh Te Canal, and a set of 20 year-old canals, such as Ha Tien - Rach Gia, Cai San, Rach Gia - Long Xuyen, T3, T4, and T5, which provide irrigation and drainage, including washing acid from the soil, agriculture and transportation. Together with mangrove barriers, sea dykes (comprising earthen sea dykes and concrete sea dykes) are built to protect the Kien Giang coast (see Figure 4.9).

Figure 4.9 Mangroves and sea dykes built to protect the Kien Giang coast: These photos were taken during the dry season in 2013, and 2015: a) concrete sea dykes in Ha Tien, soft protection: fence and mangroves b), and c) in Hon Dat, and f) in An Bien, and g) earthen sea dykes in An Minh; d) sluice gate in Hon Dat, and e) canal in Rach Gia.

b. Electricity coverage

Electricity network, as used here, refers to electricity transformer stations, and high voltage power lines (see a map of this network for study obtained from Tran et al. (2013) in Appendix 9d.3). Kien Giang has a relatively modern and extensive power distribution system. Statistical data obtained from the Kien Giang Statistical Office 2012 indicate that there is 100% access to electricity at the district level. The province is connected by the 110 kV inter-province, and the 220kV, and 500kV national backbone power grid. Coastal districts in the north and central parts are expected to have better capacities of electricity than coastal districts in the southern part. However, there are annually about 20 power outages, each of half to full day duration, that primarily occur in the dry season. Many industries therefore have back-up diesel generators.

4.5 Chapter summary

Vietnam is projected to be one of the most vulnerable countries to climate change, particularly in the MRD, where rising sea levels, seawater incursion and flood risk are already affecting vulnerable coastal communities. The delta plays a crucial role for the region in terms of food security and socioeconomic development; however, it is one of the most low-lying and densely populated areas, with many poor households. This chapter has provided an overview of the MRD, including a regional approach and downscaling to obtain local scale data for seven coastal districts along the Kien Giang coast to provide background to their vulnerability in terms of physical and social factors, and consideration of adaptation measures, decision-support tools and enhancement of adaptive capacity as ways of reducing vulnerability to climate change. A variety of sources was used, such as fieldwork, statistics, Landsat images, and relevant previous projects for the study area (see Appendix 5a).

Scenarios for Kien Giang for the two time periods 2030, and 2050, relative to 1980 - 1999 based on SRES B2, and A2 indicate that the annual temperature in Kien Giang is projected to increase, together with slight increase in the rainy months, and slight decrease in the dry months of rainfall. Additionally, seas levels are projected to rise by 15 cm by 2030, and 30 cm 2050 under A2. Preliminary outcomes for the study area are summarised in Appendix 10.

An Bien, and An Minh, and a large area along much of the Kien Giang coast experience high seawater incursion (> 8ppt) during the dry season, in terms of measuring exposure. On the other hand, several areas of the districts Hon Dat, Kien Luong, and Ha Tien experienced from

moderate (0.5 - 1m) to high (> 1m) flood depth. The extent of flooding was less in areas of Rach Gia, and Chau Thanh during the rainy season. Overall, the Kien Giang coast of the western MRD is characterised by mangrove fringes and is undergoing less shoreline change than other sections of the delta; however, about 50% of this coastline was observed to have eroded or be currently eroding due to cutting of the mangrove fringes. Moreover, in 2030 and 2050 there is predicted to be an increase in the extent of seawater incursion and flood depth for the study area, particularly for the land along the Kien Giang coast. That is largely due to projected rising sea levels, changing rainfall, and removal of mangroves.

Comparing delta, provincial and coastal district scales, in terms of measuring sensitivity, indicates that generally coastal districts would seem to be more sensitive than the whole province due to having a higher proportion of population density, although they appear less sensitive than those due to less rural people, and ethnic minority groups. In addition, coastal districts may be more sensitive than the province due to having the greater proportion of non-agricultural land.

Kien Giang province as a whole, and coastal districts, in terms of measuring adaptive capacity, would seem to have better capabilities to reduce the potential impacts of climate change than the delta because of having higher incomes. Education in coastal districts was high in the province, thus coastal districts would seem to have better capabilities to manage the potential impacts. In addition, coastal districts would seem to have better capabilities to manage the potential impacts than the province as a whole because of having the lowest proportion of poverty, the highest proportion of households having solid houses, and the proportion of inhabitants per fixed-line telephone subscriber. It also highlights the fact that, it hard to access data in details within district level from plans, master plans, and strategies on provincial developments in socioeconomic, education and health in Vietnam for the year 2020, vision toward 2030, or 2050.

Accordingly, following this background, the vulnerability assessment for the study will adopt methods to aggregate using multi-criteria analysis, and visualise assessment outcomes to assist local authority decision makers in identifying particularly vulnerable areas and selecting the best alternative from several feasible alternatives under diverse priorities, based on determination of *"where"* is likely to be the most exposed to the impacts, and *"who and what"* are likely to be the most sensitive, and *"who and what"* are likely to be the appropriate

actions to reduce the potential impacts. The next chapter applies integrated GIS, and multi-criteria decision making, using AHP, to assess the vulnerability for the study area (see chapter 3, sub-sections 3.4.1, and 3.4.2). Results and discussions for the study area will be presented in the following chapters.

Chapter Five

Potential impacts of climate change, particularly sea-level rise

5.1 Aims of this chapter

The overall objective of this chapter is to assess the potential impacts of climate change, particularly sea-level rise, for seven coastal districts along the Kien Giang coast, using the Spatial Analyst, and extension tool, the analytical hierarchy process tool (AHP), and the Digital Shoreline Analysis System tool (DSAS). The chapter is structured as follows. Section 5.2 briefly introduces steps involved in order to represent potential impacts. Section 5.3 presents and discusses mapping of the exposure component by aggregating three sub-components: seawater incursion, flood risk, and shoreline change. The output was scaled to a range of five levels, namely: very high, high, moderate, low, and very low, based on the degree to which the study area is exposed to these impacts. Section 5.4 presents and discusses mapping of the sensitivity component by aggregating the two sub-components: societal, and landuse factors. Results are reported in a range of five levels related to their stability, in which, an area of very high sensitivity is likely to display a very low stability. Section 5.5 presents and discusses mapping of potential impacts by aggregating the two components: exposure, and sensitivity. This enables identification and visualisation of "*where*", (i.e., hotspots), together with "*who, and what*" is most likely to be exposed and sensitive to the impacts. A summary of this chapter is presented in section 5.6.

Objectives of this chapter are two-fold. The first objective is to generate data for exposure and sensitivity to be used in evaluation of potential impacts. The second objective is to aggregate those two components for use in the final vulnerability study (chapter 6, section 6.4).

5.2 Introduction

The combination of exposure and sensitivity, as used here, defines the degree of potential impacts of climate change on a system (Schauser et al., 2010). As mentioned in chapter 3, the following steps were considered in order to represent potential impacts. These include:

- Organise the hierarchical structure from six variables used in three sub-components into the exposure component, together with eleven sub-variables into seven variables used in

two sub-components into the sensitivity component, to obtain potential impacts of the study area (see detail on how these were derived in Figure 3.3).

- Classify these sub-variables and variables prior to their aggregation (see Table 3.14).
- Reclassify these sub-components, and components to be used in the aggregate mapping of potential impacts. This involved pair-wise comparisons of sub-variables, variables, sub-components, and components following the fundamental AHP rule scale and procedure originally developed by Saaty (1980). Simultaneously, relative weights of these variables, sub-components, and components were obtained.

Table 5.1 Key variables and their functional relationships in representing exposure and sensitivity.

No	Component/ sub-component/ Variable	Ranking					The functional relationships
		Very low	Low	Moderate	High	Very high	
E	**Exposure**	Jenks (Natural Breaks) was used to reclassify the range					
E1	*Seawater incursion*	Jenks was used to reclassify the range					
	Salinity, ppt		< 4	4 - 8	> 8		↑
	Soil types	Water bodies, Alluvial soils	Acrisols & Gray soils	PASS	AASS	Seasonal & regular saline soils	
E2	*Flood*	Jenks was used to reclassify the range					
	Flood depth, m	0 – 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0	↑
	Elevation, m	> 2	1.2 – 2	1.2 - 1	1.0 - 0.8 & 0.8 – 0.5	0.5 – 0.3 & < 0.3	↓
E3	*Shoreline change*						
	Shoreline displacement, m/year	> 15.0 Accretion	5.0 – 15.0	-5.0 – 5.0	-15.0 - -5.0	< -15.0 Erosion	↓
	Adjacent landuse	Mangroves	Man-made infrastructure	Fishery farming	Agriculture	Built-up	↑
S	**Sensitivity**	Jenks was used to reclassify the range					
S1	*Societal factors*	Jenks was used to reclassify the range					
	Pop. density, pers/km^2	164 - 170	197	309	461 - 531	2,246	↑
	Rural pop, %	7	32	58	82	86 – 94	↑
	Ethnic groups, %	2	11	14	15	38	↑
	Female pop, %	49	49.2	49.3	49.5 – 50.2	50.9	↑
S2	*Landuse factors*		Unused land	Agricultural land		Non-agri.land	
	Landuse areas		The bare land	Water bodies, wetland, grassland	Forest, farmland	Built-up	↑

Note: An arrow (↑) indicates a positive influence on the exposure or sensitivity, and an arrow (↓) indicates a negative influence; Potential acid sulphate soils (PASS), and active acid sulphate soils (AASS).

A summary of the classification of variables and their functional relationships in representing two components: exposure and sensitivity respectively, is presented in Table 5.1. Exposure and sensitivity were combined to provide an indication of the hotspots, patterns or areas in the study area most likely to be affected by the potential impacts. Specifically, "*the indication of*

where", associated with *"the societal factors"* indicates *"who"* is most likely to be sensitive, and affected (i.e., which population groups could be the most sensitive, how population density is affected). In addition to this, *"the indication of where"*, associated with *"the biophysical information"* indicates "*what*" is most likely to be the sensitive, and affected (i.e., which sorts of landuse are likely to be the most affected).

5.3 Exposure component

Exposure, as used here, refers to the degree to which the study area is exposed to impacts, related to seawater incursion, flood risk, and shoreline change. The reasons why these threats have been taken into account have been indicated and discussed in the previous chapter (sub-section 4.4.2). The seawater incursion sub-component was considered extremely important, and was assigned the priority [9] when aggregating the exposure component. This was followed by the flood risk sub-component which was assigned a priority of [7]. The shoreline change sub-component, which is moderately important, was assigned the least priority of [3]. The prioritisation of these sub-components was undertaken for several reasons:

- Seawater incursion during the dry season has recently become an issue of concern across the MRD, due to the extent of damage to crops, local livelihoods, and infrastructure and the feasibility and cost of mitigation measures. From an agricultural viewpoint, the extent of salinity incursion is considered a major problem, resulting in a decrease in rice productivity, which has negative effects on the principal source of income for a majority of local people. Furthermore, it can indirectly threaten food security at regional and national scales. Seawater incursion is likely to be most markedly affected by sea-level rise (Smajgl et al., 2015). It is also impacted by anthropological factors, such as landuse change (Bastakoti et al., 2014). Since 2000, there have been dramatic changes in landuse, especially in the coastal and saline-affected areas of the delta, and including significant reduction of mangrove forests as farmers remove mangroves to make way for shrimp ponds. Several researchers have studied the trend by which local farmers have begun raising shrimp, enabling them to generate a short-term source of income by meeting demand for shrimp from the growing global market (Preston and Clayton, 2003; Tran et al., 2012; Tran et al., 2014a) (see chapter 4, sub-section 4.4.2). Salinity incursion is not only influenced by landuse changes in the coastal zone but also rising water demands in the upstream parts of the delta and the basin, contributing to a decline in inflows of freshwater during the dry season.

- It appears that about 83% of the study area is below 1 m elevation above MSL, based on the 15-m DEM, which attests to potential exposure to inundation from high tides (i.e.,

much is apparently below highest tide levels and could be potentially inundated) (see sub-section 5.3.2.2). The extent of seawater incursion will be exacerbated with inundation into adjacent coastal and low-lying surrounding areas with projected rising sea levels. Rainfall reduction, a decrease in mangrove area, and future dyke breaches can also have adverse effects on agricultural activities.

- The threat of flooding and inundation during the rainy season is considered a regular seasonal feature, and most of the local people have adapted to flooding to undertake on agricultural activities. The Government of Vietnam adopted a "Living with floods" strategy for the MRD in 1999, meaning more attention to floodwaters, flood protection and the conservation of natural systems and ecosystem services. The flood may occur, but is a minor problem if good drainage conditions offset the possible impacts (Bastakoti et al., 2014).

- The most dangerous form of flood in the entire MRD in terms of loss of human life and damage is the riverine flood. In this case high flow discharge originates from upstream during the wet season. Fortunately, the study is located relatively far from the Bassac River and riverine flooding is limited. Floods in the study area occur following overflow from the Vietnam-Cambodia border, in combination with high rainfall, and high tidal levels from the west sea; these effects coincide during the southwest monsoon.

- The shoreline along the study area seems to be relatively stable with little change, observed in historical imagery in Google Earth. However, the dramatic reduction in sediment loads in the Mekong mainstream (and the Bassac River, in particular), affects sedimentation and deposition on the Kien Giang coastline, with a decrease in the area of mangroves, and other impacts from human activities, causing the shoreline to erode faster than previously thought.

5.3.1 Mapping of the seawater incursion sub-component

The seawater incursion sub-component, as described in the previous chapter (sub-section 4.4.2.4), refers to a complex interaction between two variables: seawater incursion, and soil type. Objectives of this sub-section are two-fold. The first objective is to evaluate seawater incursion exposure for the study area up to 2050. The second objective is to use the aggregated sub-component in the broader study of exposure. The seawater incursion variable is considered to be more important than the soil type variable in order to represent the sub-component. A map showing the seawater incursion sub-component exposure levels for the study area, is presented in Figure 5.1. This map was reclassified into 9 categories by using the

Jenks classification method (Jenks), and mapping using 5 levels from very low to very high. Areas shaded red, indicate very high exposure, and while those shaded dark green indicate areas with very low exposure (see details in Appendix 11a.2). Relative weights of the variables used in aggregation were obtained simultaneously using AHP (see details in Appendix 11a.1). A summary of overall aggregated rankings for each district, according to proportions of the study area classed as very high to high exposure is shown in Appendix 14.

5.3.1.1 Seawater incursion variable

The seawater incursion variable for the study area was based on the map of seawater incursion observed in 2010 according to the maximum isohaline (lines of equal salinity concentration). It was classified into 3 classes; values below 4 ppt were assigned low exposure; moderate exposure values were between 4 and 8 ppt; and values above 8 ppt were considered to have high exposure (see Table 5.1). Furthermore, two maps showing modelled seawater incursion in 2030, and 2050, compared to a baseline map observed in May 1998, were used (presented maps in chapter 4 Appendices 8d.5, 8d.2, and 8d.3, respectively). Table 5.2 gives a summary of proportions of the study area in each category in 2010, 2030, and 2050 (see in detail for each district in Appendix 11a.2).

Table 5.2 Proportions of the study area classed as low to high in terms of salinity incursion exposure.

Coastal district	Seawater incursion, % of area		
	Low < 4 ppt	Moderate 4 - 8	High > 8
Observed in 2010	31.60	9.83	58.57
Modelled in 2030	31.66	4.26	64.08
Modelled in 2050	33.57	5.10	*61.33*

Note: See details of classification in chapter 3, Tables 3.10, and 5.1.

Table 5.2 shows that 58.57% of the area (equivalent to 175 700 ha) was exposed to high seawater incursion in 2010, including the entire area of three districts An Minh, An Bien, and Ha Tien (see Appendix 8d.5), and considerable areas in Chau Thanh (65.72%), Rach Gia (about 63%), and Kien Luong (52.45%) (see Appendix 11a.2). An Minh is most at risk because it is further from the Bassac, and the Giang Thanh Rivers, and therefore receives limited floods in the wet season.

Table 5.2 also indicates a likely increase in the high salinity incursion area to 64.08% (~192 000 ha) in 2030, and a slightly lesser increase to 61.33% (~184 000 ha) in 2050. Maps of modelled seawater incursion showed large increases in Rach Gia, Chau Thanh, and Kien Luong in 2030, while some areas appear to be less affected in 2050.

5.3.1.2 Soil type variable

As mentioned in chapter 4, sub-section 4.4.2.4, it has generally been assumed that projections of seawater incursion for the study can be more accurate if combined with soil types. The soil type variable for the study area was based on the soil map (presented in Appendix 3c). Six main soil type categories were identified and then reclassified into 5 classes representing susceptibility to seawater incursion in this study (see details in Table 5.1).

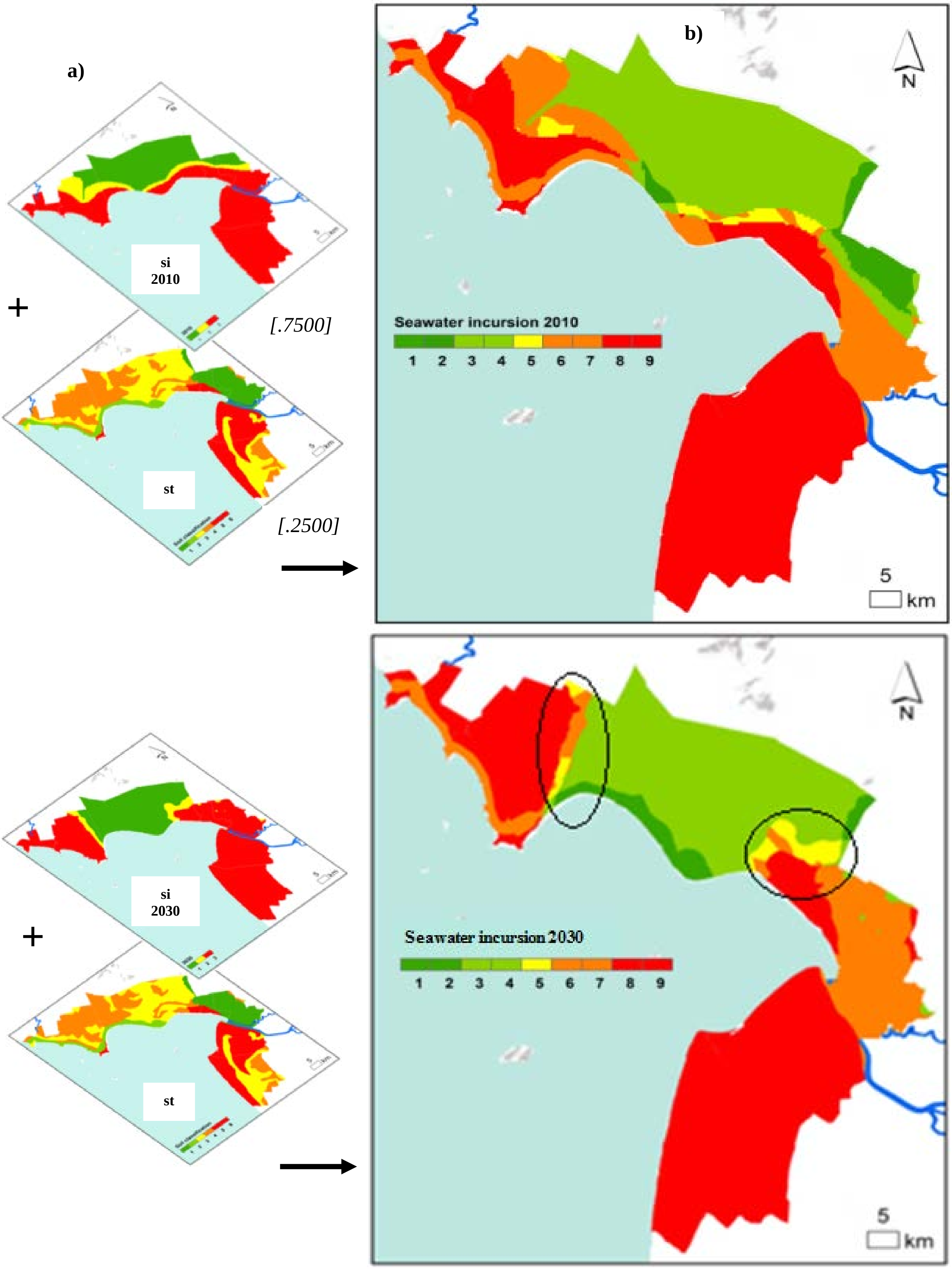
- The alluvial soils were assigned very low exposure, and assigned a value of 1.
- The acrisols and gray soils were assigned as low exposure with a value of 2.
- Potential acid sulphate soils (PASS), and active acid sulphate soils (ASS) were ranked with values of 3 and 4, representing moderate and high exposure, respectively.
- Finally, seasonal and regular saline soils were combined, and assigned the highest exposure value of 5.

Results obtained from this soil map variable indicated the largest proportion of area representing moderate exposure (31.9%, ~95 700 ha), is mainly in An Minh, and Hon Dat, and scattered within An Bien, Kien Luong, and Ha Tien. In particular, An Bien appears to have the greatest exposure, due to it having the largest extent of seasonal saline soils. The second largest proportion consisted of high exposure (29.37%, ~88 100 ha), and was distributed mainly in Kien Luong, and Hon Dat, and scattered in An Minh, Chau Thanh, and Ha Tien. This was followed by the very high exposure (20.41%, ~61 200 ha) class, which was mainly distributed in the adjacent coastal areas of An Bien, An Minh, and scattered in Kien Luong, Chau Thanh, and Rach Gia. The very low exposure (12.89%, ~38 700 ha) class was distributed mainly in Chau Thanh, and Rach Gia, and scattered in Hon Dat. The low exposure (5.43%, ~16 300 ha) class had the smallest extent and was distributed mainly in the adjacent coastal areas of Ha Tien to Hon Dat.

5.3.1.3 Aggregation of seawater incursion sub-component

Figure 5.1 displays GIS-AHP mapping of seawater incursion sub-components for the study area observed in 2010, and modelled in 2030, and 2050. Only the map of seawater incursion

sub-component in 2010 was used in the aggregate of the exposure (see sub-section 5.3.4). In Figure 5.1, the left hand side a) shows maps of classified variables used in the analysis, whereas the right hand side b) displays maps of reclassified seawater incursion sub-components obtained.



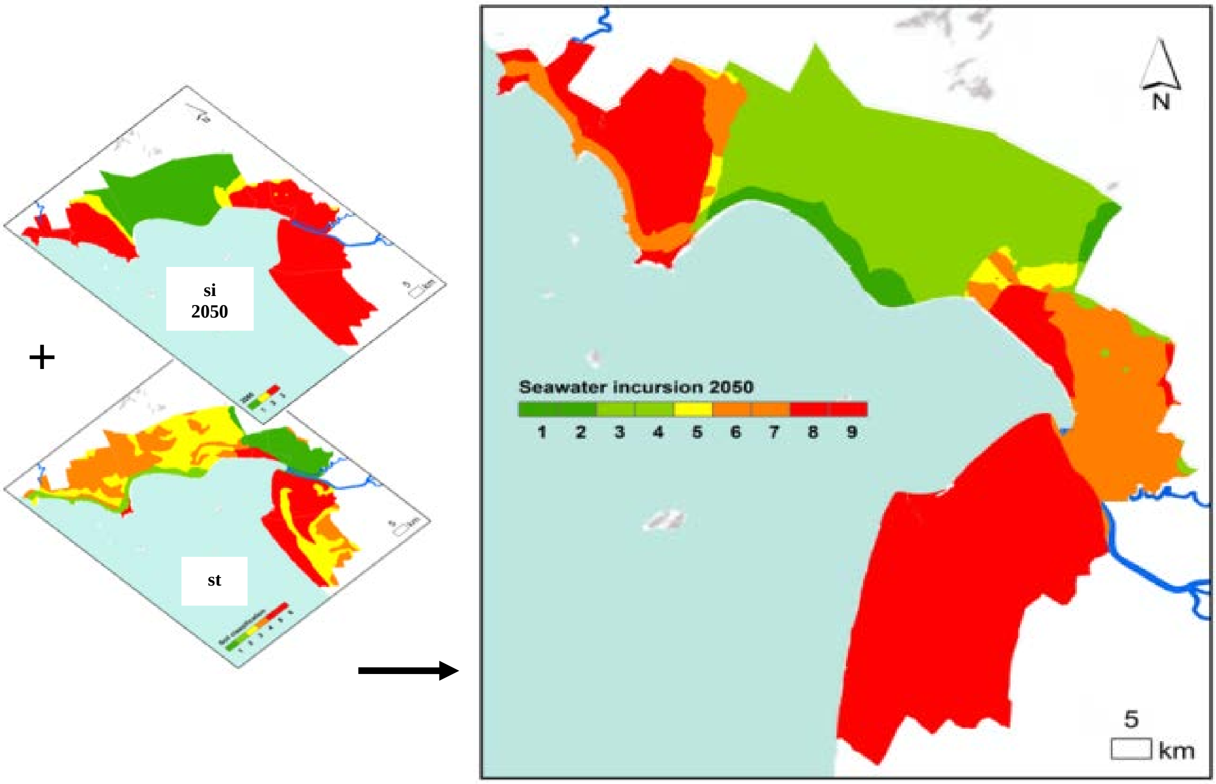


Figure 5.1 GIS-AHP mapping of seawater incursion sub-component: a) aggregate of classified variables: seawater incursion variables [si], observed in 2010, and modelled in 2030, and 2050, and soil type variable [st]; and b) reclassified seawater incursion sub-components [SI], observed in 2010, and modelled in 2030, and 2050, respectively.

Note: The sub-component was reclassified in a range of 1 – 9 by using the Jenks natural breaks algorithm in ArcGIS: values of 1 and 2 representing very low exposure (least) as shaded dark green; values of 3 and 4 representing low exposure as shaded green; a value of 5 representing moderate exposure as shaded yellow; values of 6 and 7 representing high exposure as shaded orange; and finally, values of 8 and 9 representing very high exposure (the most) as shaded red. Numbers in square brackets are presented together with variables indicating relative weights of those variables, simultaneously obtained by AHP. Black circles show areas most changeable in seawater incursion exposure in 2030, compared to 2010 and 2050.

As seen in Figure 5.1, the model results of seawater incursion [si] on the left hand side in a) for 2030, and 2050 have linear change between Kien Luong, and Hon Dat, as well as between Hon Dat and Rach Gia which is quite different from that observed in 2010. The reclassified [si] sub-component, as shown in b) reflects the seawater incursion exposure sub-component in 2010, 2030, and 2050. This is likely to be due to the relative weight of the seawater incursion variable obtained [*.7500*], which is much higher than those of the soil type variable obtained [*.2500*] in representing the sub-component. The red in [si] maps is not, of course, the same as the red in the reclassifed maps [SI]: red in [si] is values above 8 ppt, but red in [SI] is values of 8 and 9 out of 9 classes set by Jenks, indicating the area most likely to be salty, and consists of much of the above 8 ppt area; except that some where soils are not so risky may be shown as less vulnerable, and perhaps some areas with salty soil but values between 4 and 8 ppt might be considered at risk. Some caveats apply, (i.e., the 8 ppt and above zone in the [si]

maps was not expected to match the red zone in the reclassified [SI] maps as the [st] map will modify the final outcome and Jenks assigns areas that are highly exposed, or red).

Figure 5.1 also indicates that there is significant variability in seawater incursion, with very high to high seawater incursion exposure in Kien Luong, and very low to low exposure in Chau Thanh (see details in Appendix 11a.2). The analysed results for Chau Thanh indicated a marked increase in low to very low exposure in 2010, obtained for [si] (21.8% of area, ~6 228 ha), and for [SI] (up to 34.78%, ~9 587 ha). This was followed by 0 - 2.53% in 2030, and by 0 - 4.24% in 2050. A possible explanation for this may be due to the aggregation of the values between 4 and 8 ppt zone, and the distribution of water bodies or alluvisol areas. It also indicated a slight increase in very high to high exposure for Kien Luong from 52.45% for [si] - 80.36% for [SI] in 2010, a marked increase by 79.05 - 85.8% in 2030, and a slight increase by 66.6 - 78.53% in 2050, respectively. A possible explanation for this may be the aggregation of the values within the 4 and 8 ppt zone, and a large proportion of AASS. Although it has not clearly explained the relationship between the variables of seawater incursion and soil type, saline sulphate-rich groundwater appears in some agricultural areas. Moreover, the results in Kien Luong also provide support for the premise that the interaction of humans (i.e., reclamation activities, drainage or excavation of ASS) combined with projected sea-level rise has exacerbated adverse effects (if soils are drained, excavated or exposed to the air by a lowering of the water table, the acid produced by the oxidation can damage the environment severely). Surprisingly, it has not only captured the weighting in the analysis with areas that have moderate seawater incursion and high soil type exposures being classified as having high seawater exposure, but it is also appropriate based on an agricultural point of view. The maps of [SI] shown in b), when augmented with supporting text, can offer an overview of the nature and extent of problems that are likely to result from a relative rise in sea level along the coast.

Overall aggregated rankings within seven districts are summarised in Appendix 14 according to proportions of the study area classed as very high to high, in terms of seawater incursion exposure based on the observed salinities in 2010. The rankings indicated that An Minh is most likely to be exposed to salinity incursion (ranked at 7). This result in An Minh is explained because 100% of that district is classed as high in terms of seawater incursion exposure (> 8 ppt, ranked at 7), and it has predominantly saline soils with a large proportion of ASS (ranked at 6). However, one discrepant ranking in the sub-component for Rach Gia

should be interpreted with caution. The ranking for [si] with the value of 3, and those of [st] with the value of 5 were combined in order to represent those of [SI] with the value of 2.

Determining [SI] is very dependent on the input data. This can be shown by comparison of two maps of [si] observed in 1998, one obtained from Le and Le (2013) (see chapter 4 Appendix 8d.4), and another obtained from Mackey and Russell (2011) (see Appendix 8d.1).

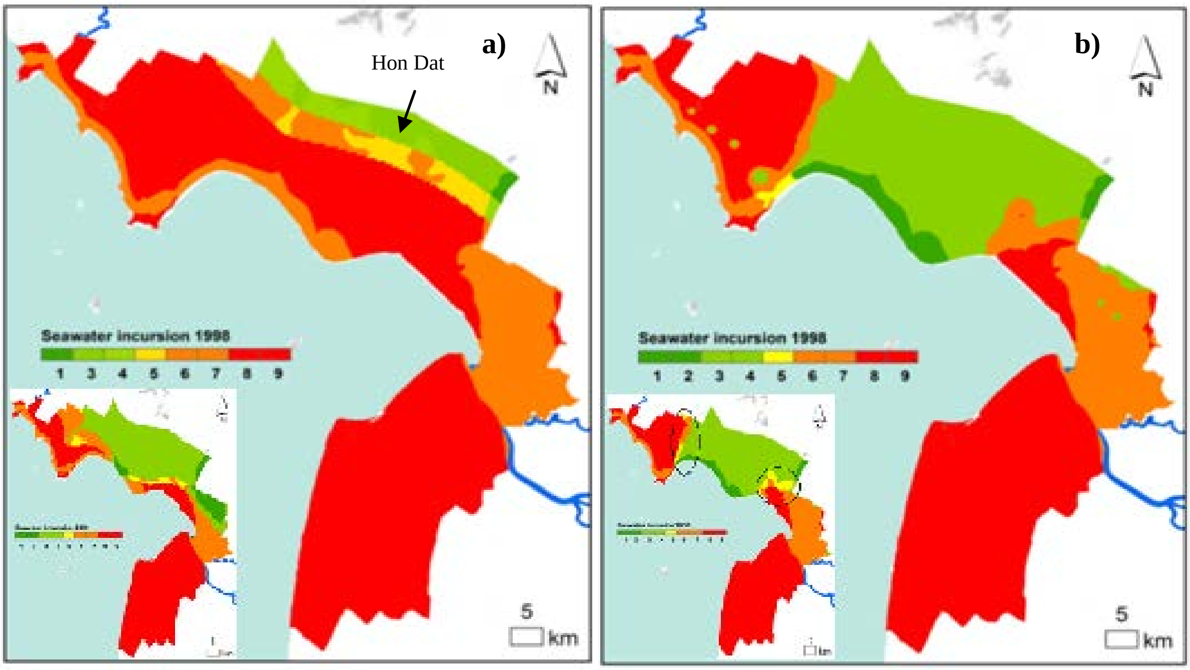


Figure 5.2 A comparison of GIS-AHP mapping of seawater incursion sub-component in 1998: a) reclassified seawater incursion sub-component generated from seawater incursion variable by Le and Le (2013); and b) from seawater incursion variable by Mackey and Russell (2011).

Note: small insets present seawater incursion sub-component in 2010 generated in this study using the AHP tool.

As seen in Figure 5.2, there was a marked difference in projected seawater incursion areas in the two maps (see Hon Dat, in particular). There was also a clear difference between [SI] when compared with [st], as shown in the insets, respectively (Figure 5.2a, in particular). This may be explained because there was a deficiency in seawater incursion data observed from stations in 1998 as indicated by Le and Le (2013). Since 2004, there have been several new stations built for observing and monitoring salinity within the MRD, enabling a better map of seawater incursion observed in 2010 as discussed by Le and Le (2013). Moreover, the 2030 and 2050 models are of unknown reliability; in particular, Kien Luong and Hon Dat are anomalous and, therefore, have not been used further in this thesis.

5.3.2 Mapping of the flood risk sub-component

As mentioned in chapter 3, in order to represent the flood risk sub-component, two variables flood depth, and elevation, were used. The flood depth variable is considered to be more important than the elevation variable. Objectives of this sub-section are two-fold. The first objective is to evaluate flood exposure for the study area with regard to climate change in the period up to 2050. The second objective is to aggregate the sub-components in the exposure component. A map showing the sub-component exposure levels for the study area is presented in Figure 5.3. The sub-component map was reclassified into 9 categories using Jenks, and mapped into 5 levels from very low to very high, with proportions of the study area reported in Appendix 11b.2. A summary of overall aggregated rankings for each district, according to proportions of the study area classed as very high to high exposure is shown in Appendix 14. Relative weights of the variables of the aggregate using AHP, simultaneously, were obtained (see details in Appendix 11b.1).

5.3.2.1 Flood depth variable

The flood depth variable for the study area was based on the map of flood extents observed in 2000. The variable was classified into 5 classes. Values below 0.2 m were assigned very low exposure. Low-exposure was between 0.2 and 0.5 m. Moderate-exposure values lie above 0.5 to below 1 m. High-exposure lies between 1 and 2 m. Values above 2 m were considered to have very high exposure (see Table 5.1). Furthermore, two maps of modelled simulations of flood extents in 2030 and 2050 were used in order to assess the flood exposures in the future (presented maps in Appendices 8c.1 to 8c.3, respectively). Table 5.3 gives a summary of proportions of the study area classed as low to high exposure obtained from mapping of three flood depth variables in 2000, 2030, and 2050, respectively (see in detail for each district in Appendix 11b.2).

Table 5.3 Proportions of the study area classed as very low to very high in terms of flood depth exposure.

Coastal district	Flood depth , % of area				
	Very low 0 – 0.2 m	Low 0.2 – 0.5	Moderate 0.5 - 1	High 1 – 2	Very high > 2
Observed in 2000	29.87	15.57	22.41	31.75	0.41
Modelled in 2030	18.93	22.36	24.36	33.83	0.53
Modelled in 2050	11.45	20.88	15.55	33.87	18.24

Note: See details of classification in Table 5.1.

As seen in Table 5.3, the study area appeared to have large proportions of high flood depth exposure (31.75%, ~95 250 ha) in 2000, (33.83%, ~101 500 ha) in 2030, and (33.81%, ~101 430 ha) in 2050. In addition, there were minor proportions of very high exposure (0.41%, ~1 230 ha) in 2000, (0.53%, ~1 600 ha) in 2030, and a major proportion of which was 18.24%, ~54 720 ha in 2050, mainly occurring in a half of Hon Dat (45.63%), and northwest Kien Luong (14.08%) (see Appendices 8c and 11b.2). A possible explanation for these results may be due to a marked increase in water flow through the river and canal network in Kien Giang, particularly in Hon Dat, obtained from the hydrological modelling in 2030, and 2050 during the wet season (Mackey and Russell, 2011). Hon Dat is likely to be the worst exposed district to flood depth during the wet season, although it is the least exposed to seawater incursion during the dry season. It is likely to become more exacerbated in 2030, and particularly in 2050 with a large increase in very high exposure.

Adjacent coastal and low-lying surrounding areas appear to have elevations below 1 m above MSL (i.e., parts of An Bien, and An Minh), which are scarcely above the high tide level. They are, therefore expected to have relatively high exposure to flood risk associated with projected sea-level rise and coincident stronger southwesterly monsoons. However, they appear to have a relatively low flood exposure indicated by the green colour (see Figure 5.3a). Although these three maps obtained have successfully demonstrated the integration of GIS, hydrology and hydraulic simulations associated with projected sea-level rise, they have certain limitations in terms of tide gauge data, and broad variation in elevations. It has commonly been assumed that the estimation of the degree of exposure to flood for the study can be improved when more accurate or finer resolution elevation data is combined to create the flood risk sub-component, as discussed in the following sub-section.

5.3.2.2 Elevation variable

A Digital Elevation Model with the resolution of 15 m for the study area (see chapter 3 sub-section 3.5.2.2, and chapter 4 sub-section 4.4.2.1) was used as the most detailed digital topographic dataset available (see Appendix 8b). Only 5 levels instead of 7 categories were reported, in order to make the area indicator suitable for the local scale with assigned values below 0.5 m representing very high exposure, whereas those between 0.5 - 1 m were considered to be high exposure. The mangroves are the most appropriate benchmark for distinguishing tidal ranges, and they exhibit elevations of 0.3 - 0.5 m above MSL. Also, low-lying areas landward of mangroves are likely to be very vulnerable; their elevations, which

often are lower than 1 m, may be easily submerged, especially during high tides. The elevations of 1.2 - 1 m were assigned moderate exposure. These are the heights to which sluice gates, or earthen dykes are built, and beyond which rice paddies do not receive seawater. Elevations between 1.2 - 2 m were considered to be low exposure, and those values above 2 m above MSL represent very low exposure. The elevations of 2 m and above were considered related only to minor flood exposure (see details in Table 5.1). Table 5.4 summarises proportions classed as very low to very high in terms of elevation exposure.

Table 5.4 Proportions of the study area classed as very low to very high in terms of elevation exposure.

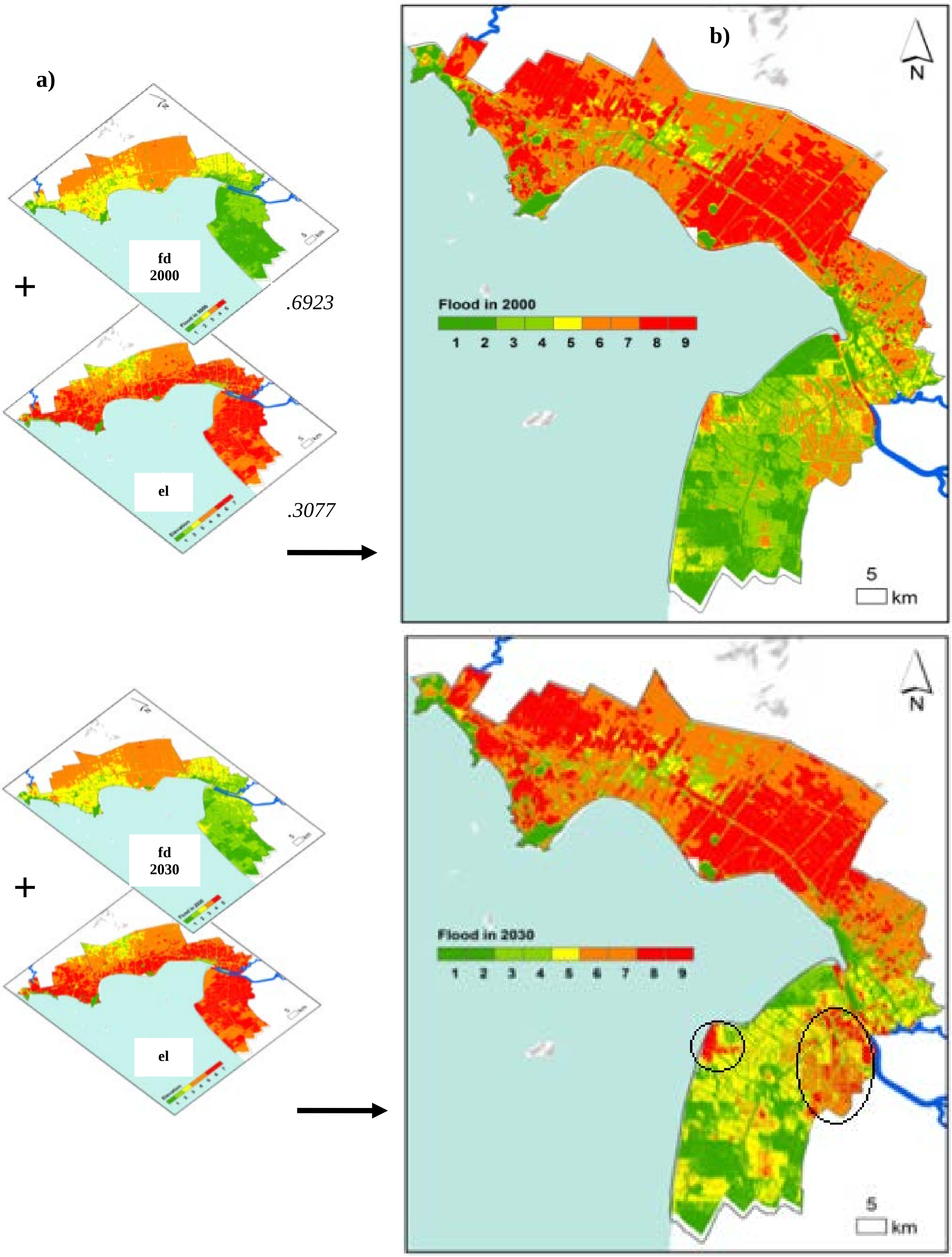
Coastal district	Elevation , % of area				
	Very low > 2 m	Low 2.0 – 1.2	Moderate 1.2 – 1.0	High 1.0 – (0.8) - 0.5	Very high < 0.5 – (< 0.3)
An Bien	0.0	0.3	0.6	29.0	70.1
An Minh	0.0	0.5	2.9	39.1	57.5
Chau Thanh	0.2	5.2	5.6	30.9	58.2
Hon Dat	1.9	11.6	18.1	34.2	34.2
Ha Tien	15.6	4.8	4.2	25.6	49.8
Kien Luong	5.2	2.8	4.3	37.7	50.0
Rach Gia	0.7	17.2	5.4	21.2	55.5
Seven coastal districts	*2.4*	*6.1*	*8.2*	*32.9*	*50.3*

Note: See details of classification in Table 5.1.

Table 5.4 indicates that about 83% of the area (~249 000 ha) is below 1 m above MSL; this area is going to be most at risk as the high tide is approximately 1 m. An Bien is the district most likely to be exposed to flood risk because it is almost entirely below 1 m (> 99%). The second largest proportion (96.7%) occurs in An Minh. This was followed by 89% in Chau Thanh, 87.7% in Kien Luong, 76.7% in Rach Gia, and 75.4% in Ha Tien. The least proportion was 68.4% in Hon Dat.

5.3.2.3 Aggregation of flood risk sub-component

Figure 5.3 presents GIS-AHP mapping of flood risk sub-components for the study area observed in 2000, and modelled in 2030 and 2050. Figure 5.3a displays maps of classified flood depth variables [fd] in 2000, and modelled in 2030 and 2050. Figure 5.3b displays three maps of reclassified flood risk sub-components [FR]. Only the map of [FR] in 2000 was used in the aggregate of the exposure (see sub-section 5.3.4). Table 5.5 summarises proportions of the study area classed as very low to very high in terms of flood exposure.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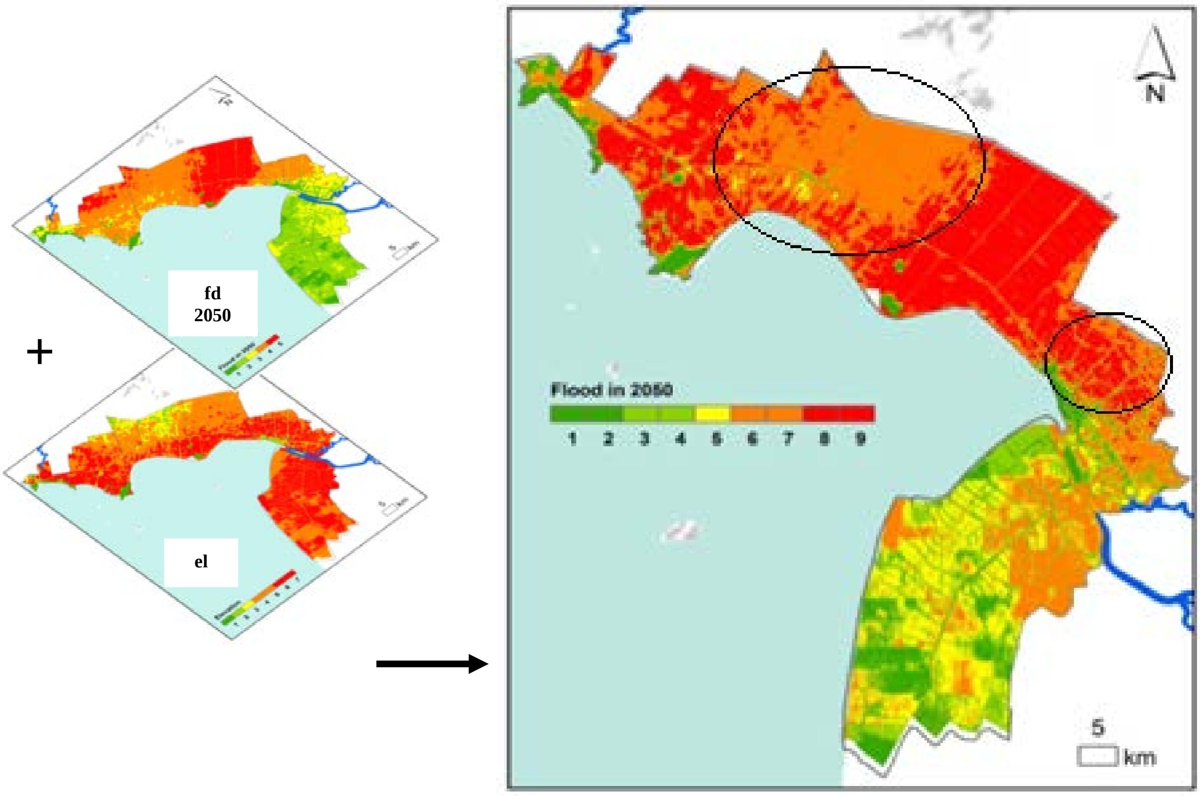


Figure 5.3 GIS-AHP mapping of flood risk sub-component: a) aggregate of classified variables: flood depths [fd], observed in 2000, and modelled in 2030, and 2050, and elevation variable [el]; and b) reclassified flood risk sub-components [FR], observed in 2000, and modelled in 2030, and 2050, respectively.

Note: As described in Figure 5.1. Numbers in brackets are presented together with variables indicating relative weights of those variables, simultaneously obtained by AHP. Black circles show areas most changeable in flood risk exposure in 2030, and 2050, compared to 2010.

Table 5.5 Proportions of the study area classed as very low to very high in terms of flood risk exposure.

Coastal district	Flood risk sub-component using AHP , % of area				
	Very low 1 – 2	Low 3 - 4	Moderate 5	High 6-7	Very high 8- 9
Observed in 2000	16.59	20.36	7.60	30.87	24.59
Modelled in 2030	13.16	15.07	13.23	30.16	28.38
Modelled in 2050	8.41	11.95	11.89	36.64	31.11

Note: See details of reclassifying values of results using Jenks in Figure 5.1.

As seen in Figure 5.3 on the left side a), the maps of [fd] show areas on the northern side of Kien Giang, including Ha Tien, Kien Luong, Hon Dat, and Rach Gia that are more likely to be more exposed to flood than those on the southern side, including Chau Thanh, An Bien, and An Minh. The model result for [fd] in 2050 has markedly changed compared to results in 2010 and 2030 with areas in Kien Luong, Hon Dat, and Rach Gia becoming more inundated. The results in the model of [fd] are primarily simulated from the river.

As with the seawater, flood depth is an observed depth of water, and the proportions are set by thresholds, while Jenks is used to categorise [FR]. The analysed results obtained from [fd] (see Table 5.3), and [FR] (see Table 5.5) were not the same, but they do indicate marked increases in very high exposure to flood for the study area from 0.41% (~1 230 ha) for [fd] - up to 24.59% (~73 800 ha) for [FR] in 2010, 0.53% (~1 590 ha) for [fd] - 28.38% (~85 150 ha) for [FR] in 2030, and 18.24% (~54 720 ha) for [fd] - 31.11% (~93 330 ha) for [FR] in 2050, respectively (see details for each coastal district in Appendix 11b.2). An Bien appeared to account for an extension of the proportion of area representing very high to high exposure, in terms of [FR]: 28.09% in 2010, 35.32% in 2030, and 43.93% in 2050, while the proportion in An Minh was 5.6% in 2010, 10.11% in 2030, and 15.31% in 2050. A possible explanation for these results may be due to the aggregate of the flood depths of 0.5 - 1 m zone in An Bien and An Minh and the almost entire areas below 1 m, because elevation will modify it (see Table 5.4 and Appendix 11b.2). In fact, these areas are very low and it is expected they would rank high to very high exposure because they can be easily submerged at high tides, and even more so with projected sea-level rise and influences of stronger southwesterly monsoons. This finding, therefore, further supports the idea of the aggregate of finer elevations for local scale in representing the flood risk sub-component.

Overall aggregated rankings of each district within seven districts are summarised in Appendix 14 according to proportions of the study area classed as very high to high exposure in representing [FR]. The rankings of each district in [fd] are similar to those in [FR], and were consistent with the idea that [fd] is considered to be more important than [el] in representing [FR]. In addition, Hon Dat is the district most likely to be exposed to flood (ranked at 7). The explanation may be that flood from the Bassac River (or Cambodia) traverses Hon Dat. This result in Hon Dat may also explain why an area of 85% following aggregation was classed as very high to high flood depth exposure (ranked at 7), and even the least proportion of area (34.2%) was classed as very high to high exposure in terms of their elevations (ranked at 1).

5.3.3 Mapping of the shoreline change sub-component

The Kien Giang coast generally remains stable with protection by a 300 - 400 m wide fringe of mangrove forest, experiencing a small tidal range and wave height (see chapter 4, sub-section 4.4.2.5). In the contexts of climate change, particularly sea-level rise, combined with human induced effects, however, the coast may be markedly changed. The shoreline change

sub-component, as used here, refers to two variables: shoreline displacement, and coastal adjacent landuse. In representing the shoreline change sub-component, the shoreline displacement variable is considered to be more important than the adjacent landuse variable. Objectives of this sub-section are two-fold. The first objective is to evaluate the shoreline change that has occurred in the study area in the period of last 40 years. The second objective is to use those sub-components in the aggregate of the exposure study. A map showing the sub-component exposure levels for the study area is presented in Figure 5.6. The sub-component map was reclassified into 9 categories by using Jenks, and mapped using 5 levels from very low to very high, shaded as for the shoreline change sub-component, with proportions of the study area reported in Appendix 14. Relative weights of the variables of the aggregate using AHP were obtained simultaneously (see details in Appendix 11c.4).

5.3.3.1 Shoreline displacement variable

a. Overview

Shoreline erosion may be accelerated by projected rising sea levels. Past patterns of shoreline change can be determined using rapid assessment techniques to assess rates of change and clearly identify a feature position at discrete times.

Studies of shoreline dynamics are critically dependent on the spatial and temporal scale of analysis. Solomon (2005) indicated that temporal changes in shorelines may be driven by inter-annual and decadal scale fluctuations in response to atmospheric and hydrodynamic forcing, while spatial variation is a function of geological and geomorphologic conditions, which control coastal erosion and sediment supply. Additionally, there are three time scales at which shoreline dynamics operate based on different causes of shoreline movement. First, there is short-term variation as a result of individual large storm events (Donnelly et al., 2001), seasonal changes in wave energy, and circulation in the near-shore zone (Masselink and Pattiaratchi, 2001). These occur at small spatial scales detectable with beach topographical profiling techniques employed at regular intervals to measure variations daily, and annually, with durations less than 10 years (Anfuso et al., 2007). Second, there is medium term variation of decadal changes in wave energy, and coastal morphodynamics (Shand et al., 2001) observed from sources such as satellite images, maps and charts that are used to reconstruct spatial and temporal shoreline changes with a period of 10 - 60 years (Jimenez and Sanchez-Arcilla, 1993). Finally, there is long-term variation in relation to climate and sediment supply

(Orford et al., 2002), and relative sea-level change, with a period of more than 60 years (Anfuso et al., 2007).

Measuring historical shoreline change has been formalised in the Digital Shoreline Analysis System version 4.3, an extension to ArcGIS developed by the USGS (Thieler et al., 2009). The extension consists of three key components: defining a baseline, generating orthogonal transects at a user-defined separation along the coast, and calculating rates of change (end point rate, linear regression rate, weighted linear regression, etc). ArcGIS 10 was used to digitise satellite imagery and create shoreline positions in specific years for the study area (see chapter 3, sub-section 3.4.2.2).

Landsat imagery, freely available from the USGS, was geo-referenced to UTM WGS-1984 zone 48N projection and coordinate system. Imagery acquired to date includes a range of Landsat images that enable a comprehensive assessment along the Kien Giang coast. Two scenes (p135-r53 and p126-r53) capture the entire coast of Kien Giang. The shoreline positions for Kien Giang in 1973, 1979, 1992, 1995, 1997, 2003, 2004, 2007, 2009, and 2013 were compared (see Table 5.6), obtained from MSS, TM, ETM$^+$, and OLI_TIRS sensors, with resolutions of 30 m, and 60 m.

Table 5.6 A list of Landsat images used for the study.

No.	Images	Date	Resolution, m	Path	Row	RMSe, m
1	Landsat 1 MSS	07/20/1973	60x60	135	53	7.03759
2	Landsat 3 MSS	01/26/1979	60x60	135	53	0.71946
3	Landsat 5- TM	12/01/1992	30x30	126	53	8.52077
4	Landsat 5- TM	12/10/1995	30x30	126	53	0.16133
5	Landsat 5- TM	01/13/1997	30x30	126	53	5.74391
6	Landsat 7- ETM$^+$	02/07/2003	30x30	126	53	9.06718
7	Landsat 7- ETM$^+$	02/10/2004	30x30	126	53	8.83740
8	Landsat 7- ETM$^+$	12/03/2007	30x30	126	53	8.82677
9	Landsat 5- TM	01/14/2009	30x30	126	53	0.00010
10	Landsat 8-OLI_TIRS	05/01/2013	30x30	126	53	7.03759

Note: Landsat 1, 3 were only at path 135 and row 53, while others were at path 126 and row 53.

Transects were created at 50m intervals along the baseline to cross the shoreline positions in the study area. Each baseline segment must be placed entirely onshore (or landward, assigned as the value of “0”) or offshore (or seaward assigned as the value of “1”) with regard to the shorelines. A baseline was created using a 600 m buffer from the shoreline in 2009. DSAS assigns a unique ID to each transect. Originating from the baseline, transects intersect all shorelines and DSAS calculates the distances of the shorelines from the baseline. By

subtracting the distance between the baseline from the earliest imagery (the shoreline in 1973) and the distance between the baseline and the latest imagery (the shoreline in 2013), DSAS calculates the net shoreline movement (NSM). The end point rate (EPR) is calculated by dividing the NSM by the numbers of years between the earliest and the latest year (a medium term variation of 40 years in the study area); therefore, the EPR is obtained in m/year. On the basis of the positions of shorelines compared to the baseline, DSAS calculates if the shoreline change involved net erosion or accretion. It is accretion if the distance between the baseline and the earliest year is smaller than the distance between the baseline and the latest year. An inverse distance addresses erosion. DSAS generates results in numerical form with positive numbers for accretion and negative numbers for erosion. Then, all attributes of transects obtained were transferred into the shoreline in 2009. After this new shoreline was buffered at 1 km distance, it was converted into raster data that was used to estimate the shoreline change sub-component.

b. Uncertainty sources

Trends and rates of shoreline change are only reliable within the measurement errors that determine the accuracy of each shoreline position (Hapke et al., 2006). Several sources of uncertainty may affect the historical shoreline mapping and change rates. These errors are assumed to be uncorrelated and random, and can be quantified by calculating the square root of the sum of the squares of all uncertainty factors (Fletcher et al., 2003). Seasonal error, geometric or rectification error, digitising error, and pixel error were taken into account in this analysis.

First, Landsat images were selected during the dry season to avoid seasonal error; an exception was an image in mid July 1973. Second, geometry error is calculated from the residual of the study area Ground Control Points by Root Mean Square Error (RMSe) (Cenci et al., 2013). Furthermore, Table 5.6 presents a series of the RMS errors of satellite image rectification. Third, digitising error is evaluated by delineating the same feature, on the same image, several times and calculating the error as the standard deviation of position residuals for that feature (Virdis et al., 2012). The digitising method of mapping the shoreline was used to extract shoreline positions from the satellite images. Each shoreline position was mapped three times to reduce uncertainty in the mapping process. However, it is not able to avoid uncertainty to extract shoreline positions from Landsat images with coarse resolutions, especially for those scattered mangroves (see Appendix 11c.3). The uncertainty error

digitising from Landsat images was estimated as ± 15 m (Angnuureng et al., 2013). Finally, the pixel size of the satellite image is important in constraining the accuracy of shoreline estimation. Extracting the shoreline from Landsat images generates a shoreline with a probability of an undetectable error, equivalent to the size of a one Landsat image pixel. Thereby, two shorelines extracted from Landsat image 1 (in 1973) and Landsat image 3 (in 1979) can have an error of ± 60 m, while other shorelines can have an error of ± 30 m.

The uncertainty of results from EPR for shoreline displacement, therefore, is a quadrature addition of the uncertainties in each year's shoreline position, divided by the number of years between the shoreline surveys. That is also called the annualised error for the shoreline displacement over a period of time (Morton et al., 2004; Hapke et al., 2010; Angnuureng et al., 2013). The rate of shoreline displacement in the study area, therefore, may have a total error estimation of ±1.56 m/year during a period of 40 years.

c. Shoreline displacement

Rates of shoreline change were calculated for 3 956 transects generated at 50 m intervals along the Kien Giang coast (~208 km), using the EPR method in the DSAS extension in ArcGIS. Historic shoreline locations with transects were spatially compared to interpret rates of shoreline displacements. The results obtained using DSAS indicate that a range of rates of historical shoreline displacement over the study area varied up to 1.51 km of erosion to 1.4 km of accretion (net shoreline movement), and from -37.95 to 35.12 m/year (end point rate) over a period of last 40 years (1973 - 2013). The analyses of EPR indicate the trend of shoreline displacement along the Kien Giang coast over the last 40 years that is presented in Figure 5.4, and described detail for each coastal district in Appendix 11c.2.

Shoreline displacement was a difficult variable to determine, because erosion is episodic and Landsat images are fairly coarse resolution. In addition, erosion was commonly restricted to small parts of an otherwise stable coast. The shores with erosion rates of more than -15.0 m/yr considered to be of a very high exposure assigning a value of 5, whereas those in the range of -5.0 to -15.0 m/yr were assigned a value of 4 representing high exposure. Shoreline change rates in the range ± 5.0 m/yr and were assigned a value of 3 representing moderate exposure (see Table 5.1). Such coasts can be said to be relatively stable in the medium term.

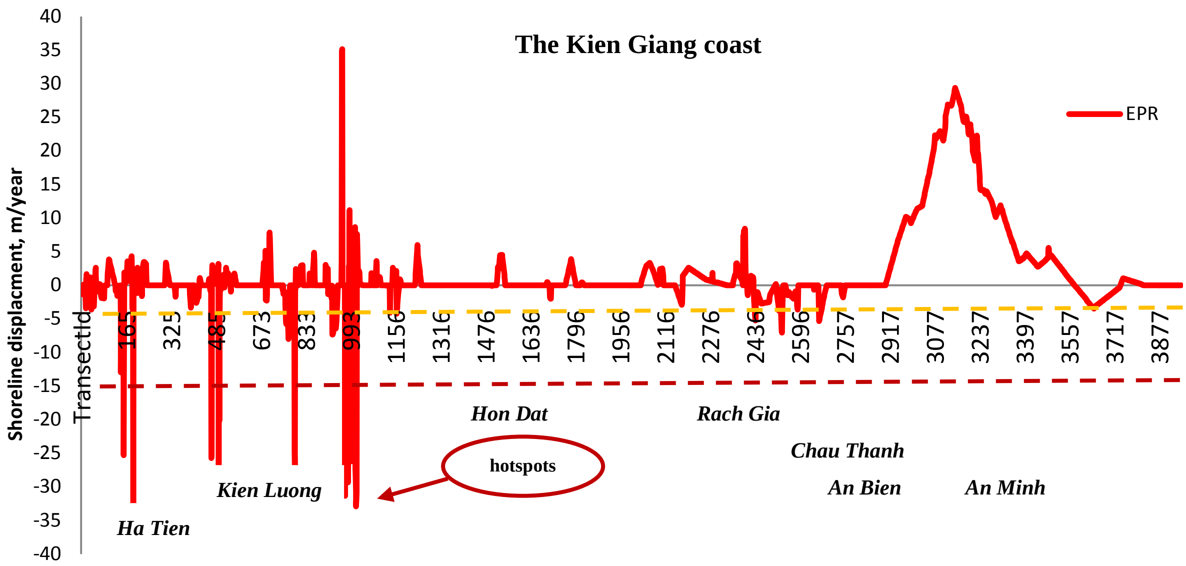


Figure 5.4 The trend of shoreline displacement over 1973 - 2013.

Note: The orientation of transects starts from the northwest (the Ha Tien coast) to the south (the An Minh coast); the yellow-dotted line indicates moderate erosion (-5 m/yr), and the dark red-dotted line shows a high erosion rate trend (-15 m/yr).

Figure 5.4 also reveals a relatively stable trend of shoreline position along the Kien Giang coast over 1973 - 2013, except some hotspots that eroded in Ha Tien, and Kien Luong. A possible explanation for these results may be related to the tendency to increase the errors due to casting transects at curved positions rather than straight sections of shorelines. In addition, the An Bien, and An Minh coasts appear to have experienced rapid accretion. Interestingly, these coasts have fringes of large mangroves as effective protective barriers, compared to other coasts (see Appendix 11c.1).

Table 5.7 Proportions of coastal change obtained from the results in EPR during 1973 - 2013.

	Shoreline change	Kien Giang	Ha Tien	Kien Luong	Hon Dat	Rach Gia	Chau Thanh	An Bien	An Minh
1	Very low (very high accretion rate): EPR > 15 m/yr	*4.87*	0.00	0.22	0.00	0.00	0.00	22.64	8.89
2	Low (high accretion rate): 5 < EPR <15	*6.67*	0.00	1.89	0.00	1.87	0.00	21.32	16.4
3	Moderate: -5 < EPR <5	*86.34*	98.73	92.89	100	96.63	100	55.66	74.71
4	High (high erosion rate): -15 < EPR <-5	*1.44*	0.76	2.22	0.00	1.5	0.00	0.38	0.00
5	Very high (very high erosion rate): -15 m/yr > EPR	*0.68*	0.51	2.78	0.00	0.00	0.00	0.00	0.00

Note: see details of classification in Table 5.1.

The proportions of coastal change obtained from the results in EPR, presented in Table 5.7, also indicate that only 2.12% of the Kien Giang coast (equivalent to a length of 4.43 km) eroded quickly, representing very high to high exposure, while the majority (86.34%, eq. 179.58 km) showed relative stability. Only 0.51% length of the Ha Tien coast (0.1 km) and 2.78% of the Kien Luong coast (1.29 km) eroded at a very high rate.

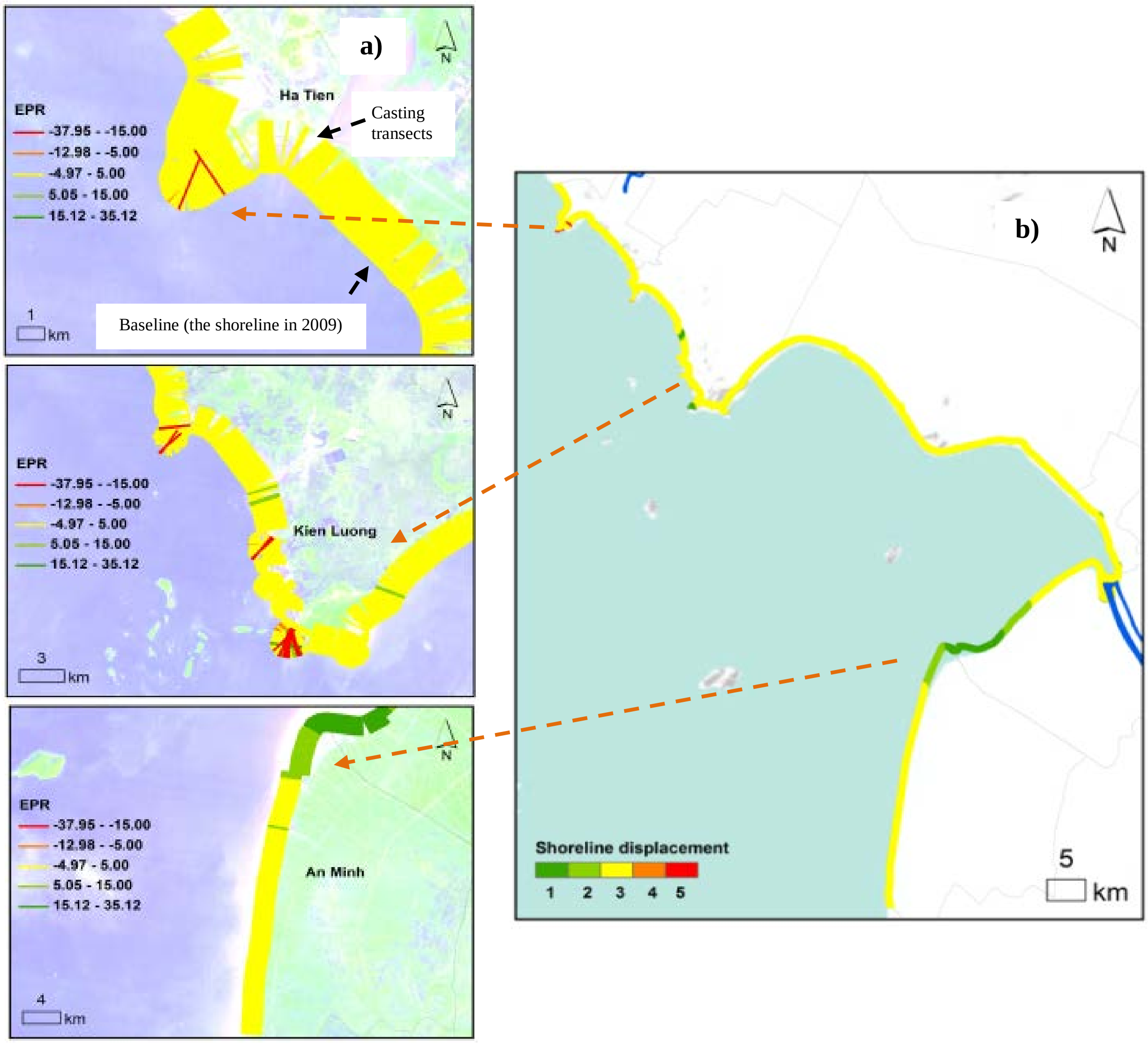


Figure 5.5 GIS-DSAS mapping of shoreline displacement variable over 1973 - 2013: a) Transect rate-of-change calculations obtained using DSAS for Ha Tien, Kien Luong, and An Minh, respectively; and b) The shoreline displacement variable of the Kien Giang coast [sd].

Note: see details of classification in Table 5.1.

Figure 5.5 presents GIS-DSAS mapping of the shoreline displacement variable for the Kien Giang coast. In Figure 5.5, the left hand side a) displays maps of transects and rate-of-change calculations obtained using DSAS, whereas the right hand side b) shows the map of the shoreline displacement variable for the Kien Giang coast classified into 5 classes, from very high exposure (most eroded rate), shaded red, to very low exposure (most accreted rate),

shaded dark green. In order to represent the shoreline displacement, several steps were followed.

- First, the transect rate-of-change calculations were classified into 5 classes and represented as new features along the shoreline in 2009.
- Second, a 1-km buffer polygon was created around this new shoreline; third, the polygon was converted into raster.
- Finally, the raster shoreline was reclassified into 5 classes to generate the shoreline displacement variable.

The linear regression rate (LRR) refers to the result of estimating the average rate of change using a number of shoreline positions over time, with the change statistic of fitting a least-squared regression line to all shoreline points for each transect. The linear regression rate is the slope of the line. LRR, therefore, was used to analyse the medium term shoreline change (over the last 40 years) of the Kien Giang's shoreline. In this study, the total data uncertainty was ± 1.56 m, and confidence interval was 95% (95% CI) determined as a weighted linear rate parameter. The analyses of LRR showed a range from -19.1 to 31.2 m/yr over a period of 1973 - 2013 (see Table 5.8). The results also indicated an average erosion rate of 4.8 m/yr (whereas an average accretion rate of 5.7 m/yr) occurred along the shoreline. The shoreline along the Kien Giang coast is expected to be fairly stable, compared to other studies, such as with a mean shoreline erosion LRR of 33.24 m/yr along the east of Ca Mau cape in Ca Mau, one of coastal provinces in the western part of the delta, indicated by Tran et al. (2014b), an erosion rate of 15 m/yr occurred along the Mekong riverbank indicated by Lam et al. (2011), loss of land, due to erosion of up to 30 m/yr in some areas of Soc Trang recorded by Schmitt et al. (2013).

Table 5.8 Coastal change obtained from the results in LRR during 1973 - 2013.

Shoreline	Numbers of transects value ≥ 0 stable and accreted	The analyses of LRR, a range of m/yr over last 40 years
Ha Tien	*335*	-14.7 to 25.9
Kien Luong	*656*	-19.1 to 23.5
Hon Dat	*842*	-1.9 to 8.4
Rach Gia	*213*	-3.0 to 14.5
Chau Thanh	*27*	-5.5 to 4.2
An Bien	*307*	-4.5 to 31.2
An Minh	*195*	-18.2 to 30.6
Kien Giang	*2,567 (~65%)*	*-19.1 to 31.2*

Note: Positions of shoreline, which is marked by the seaward side of the thin mangrove fringe along the Kien Giang coast.

Table 5.8 also reveals that accretion was dominant, observed along ~65% of the Kien Giang coastline (2 567 transects). It seems to be that the Hon Dat, Rach Gia, and Chau Thanh coasts were the most stable, with an average range from -5.5 to 14.5 m/yr over last 40 years, in terms of LRR. On the other hand, the coasts in Ha Tien, Kien Luong, An Bien, and An Minh seemed to be the most changeable, with an average range from -19.1 to 31.2 m/yr. However, values of accretion are much higher than values of erosion, particularly those in the An Bien, and An Minh coasts.

This approach provides only limited insight into likely shoreline change. Combining historic data using Landsat satellite images (at a coarse resolution of 30x30 m and 60x60 m of each cell-size) and the DSAS tool provides only a general overview of shoreline displacement at specific places along the Kien Giang coast over a medium term period. However, there is an urgent need to purchase high spatial resolution imagery, such as historic aerial photos, Lidars, and SPOT5 over a long-term (at least over 60 years) captured entire the Kien Giang coast to get better quality results. Several researchers indicate that spatial physical shoreline dynamics over time such as reduction in sediment supply and human pressures such as mangrove overexploitation (Ellison and Zouh, 2012), shrimp farm expansion (Nguyen et al., 2013; Tran et al., 2013; Tran et al., 2014a) together with impacts of projected sea-level rise can cause rapid shoreline erosion. It has commonly been assumed that adjacent landuse of the study area should be taken into account to classify the further coastal erosion to human landuse and development that will be provided in the following sub-sections.

5.3.3.2 Adjacent landuse variable

The adjacent coastal areas are considered most at risk, particularly impacts of sea-level rise, and other physical factors such as high tides, strong waves, together with anthropogenic impacts. The Kien Giang coast is characterised by mangroves (present along 65% of the shoreline), which have not undergone much change to their seaward extent (Nguyen et al., 2013). The shoreline remains quite stable with the protection of a thin line of mangroves that historical imagery in Google Earth suggested little change (see Appendix 11c.1). Only 37% of this shoreline was experiencing mangrove loss that might be due to several reasons such as mangroves were illegally cut down to provide firewood and building materials; a seriously limiting factor in the local response that most of local community members do not know of the importance of mangrove forests as natural coastal stabilisers (Duke et al., 2010). It is the fact that mangroves provide a thin green line of salt-tolerant vegetation that buffers and

protects valuable farming lands from rising seas and storm damage. Behind the mangroves, protection of agricultural land and settlements was much more achievable through construction of earth sea dykes. However, a large area of mangroves has been reduced on their landward side through conversion to shrimp farms since 2000. The expansion of shrimp farms together with the impacts of projected sea-level rise makes the shoreline much more prone to erosion (Lam et al., 2011; Nguyen et al., 2013; Tran et al., 2013; Tran et al., 2014a). Furthermore, inappropriate regulations for the management of mangrove forests and institutions for shrimp management coupled with weak official oversight and poor coordination among relevant ministries and departments have all contributed to the massive mangrove loss (Le, 2008).

Coastal erosion generally threatens coastal investment, destroys habitats and infrastructure, damages sources of livelihood of coastal dwellers, affects coastal ecology, and negatively impacts the coastal environment. The analysis from DSAS shows that there is little change to position of the shoreline in Kien Giang, which is marked by the seaward side of the thin mangrove fringe; however, the landward side of this fringe has shrunk. Therefore, a map of the adjacent landuse of the study (accounts for ~3% area of the study area, ~9 000 ha) was used in order to supplement the shoreline change sub-component (see chapter 4, Appendix 9a.2c). It examines where different aspects of landuse will be emphasised, that may capture the relation between the shoreline change and landuse. It is important to note that another map of landuse for the entire study area, which is at a different scale and source, will be used in representing the landuse sensitivity sub-component, described in sub-section 5.4.2.

The mangroves are natural coastal vegetation, which can promote sedimentation, so may erode slowly (or even build seaward, or support artificial infrastructure, such as earthen dykes). By contrast, unprotected agricultural land is very susceptible to erosion. There are 7 main categories of adjacent coastal landuse, which were reclassified into 5 classes:

- Mangroves (natural and planted), grass land, etc assigning a value of 1, associated with water bodies assigning a value of 2, both representing very low sensitivity.
- Man-made infrastructure: sluice gates assigned a value of 3, and dykes assigned a value of 4, both representing low sensitivity.
- Fishery farming (farming with forest and other forests) assigned a value of 5, representing moderate sensitivity.

- Agricultural production (farming and crops) assigned a value of 6, representing high sensitivity.
- Built-up (rural and urban settlements) assigned a value of 7, representing very high sensitivity (see Table 5.1); with proportions of the study area presented in Table 5.9.

Table 5.9 Proportions of the study area classed as very low to very high in terms of adjacent coastal landuse.

Coastal district	Adjacent coastal landuse in 2010 , % of area					The furthest landward distance, km
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6	Very high 7	
An Bien	23.55	8.68	66.39	0.08	1.30	2.7
An Minh	11.03	4.01	82.59	0.00	2.37	2.1
Chau Thanh*	-	-	-	-	-	-
Hon Dat	28.61	8.97	59.21	2.57	0.65	1.2
Ha Tien**	22.80	2.33	74.87	0.00	0.00	1.7
Kien Luong	11.01	1.48	86.72	0.00	0.78	4.5
Rach Gia*	-	-	-	-	-	-
Seven coastal districts	*16.83*	*4.62*	*76.80*	*0.53*	*1.22*	

Note: (*) Data on the adjacent landuse variables were unavailable for Chau Thanh and Rach Gia.

Table 5.9 shows the lack of adequate data relating to the adjacent landuse variable obtained; data is unavailable for the entire coastal areas adjacent to Rach Gia, and in Chau Thanh, and some parts of Ha Tien. The Kien Giang coast appears to have a major proportion of area representing moderate sensitivity in terms of the adjacent landuse (76.8% of area, ~6 850 ha). Hon Dat appears to have the largest proportion experiencing very high to high sensitivity, in terms of adjacent coastal landuse (3.22%, ~59 ha). This was followed by 2.37% (~62 ha) for An Minh, and then by 1.38% (~14 ha) for An Bien. The least proportion, 0.78% (~23 ha) was for Kien Luong. It is necessary to treat this adjacent landuse with caution, as inspection of Google Earth shows that there are settlements, some with relatively dense population (e.g., along the Ha Tien coast, particularly in the Ha Tien embayment, shows that there is a town with a relatively dense population living) that are not apparent in the landuse data (e.g., it indicated that there has not any built-up 1.7 km area landward of the Ha Tien coast). The settlements in Ha Tien and others will be provided in the next chapter, sub-section 6.4.3.4.

5.3.3.3 Aggregation of shoreline change sub-component

Figure 5.6 presents the GIS-AHP mapping of the shoreline change sub-component. In Figure 5.6, the left hand side a) presents maps of two classified variables used in the analysis, and the middle b) shows the map of reclassified shoreline change sub-component, whereas the right

hand side c) shows extracted maps representing shoreline change for the Hon Dat coast; proportions of the study area presented in Table 5.10. This table showed that nearly 83.5% of area (~6 270 ha) representing very high to high exposure to [SC], comprising the largest proportion in Hon Dat (91.03%, ~1 650 ha), followed by Kien Luong (90.93%, ~1 940 ha), An Minh (87.75%, ~1 950 ha), Ha Tien (87.26%, ~425 ha), and An Bien (34.63%, ~300 ha). The low proportion was 0.14% (~2 ha) in Rach Gia, and the least proportion was (0%) in Chau Thanh.

Table 5.10 Proportions of the study area classed as very low to very high in representing shoreline change exposure.

Coastal district	Shoreline change sub-component using AHP , % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6-7	Very high 8- 9
An Bien	3.20	16.35	45.82	26.42	8.21
An Minh	1.37	2.85	8.03	32.43	55.32
Chau Thanh			100.00		
Hon Dat	0.00	0.00	8.98	28.27	62.76
Ha Tien	0.00	0.00	12.74	14.11	73.15
Kien Luong	0.00	0.67	8.40	9.92	81.01
Rach Gia	0.74	1.60	97.52	0.14	0.00
Seven coastal districts	*0.47*	*2.96*	*13.09*	*23.25*	*60.24*

Note: See details of reclassifying values of results using Jenks in Figure 5.1.

It seems to be unexpected results for the Kien Giang coast indicating very high to high [SC] obtained (83.5%) (see Table 5.10), differ from the aggregating the results in LRR obtained, indicated that only 35.1% of the Kien Giang coastline have undergone erosion (see Table 5.8), and the result indicating moderate [al], considered as fishery activities, obtained (76.8%) (see Table 5.9). These proportions are set by thresholds, by Jenks, and extracted from Landsat images with fairly coarse resolutions, however, they are roughly possible, due to only 21.45% of area of the shoreline protected by barriers (mangroves, and human infrastructure) (see Table 5.9), and active and eroded mangrove loss occurred 37% of the shoreline, observed by Duke et al. (2010). It is necessary to treat these results with caution, they indicate that [al], especially the area of mangroves will modify [sd], and then supplement [SC].

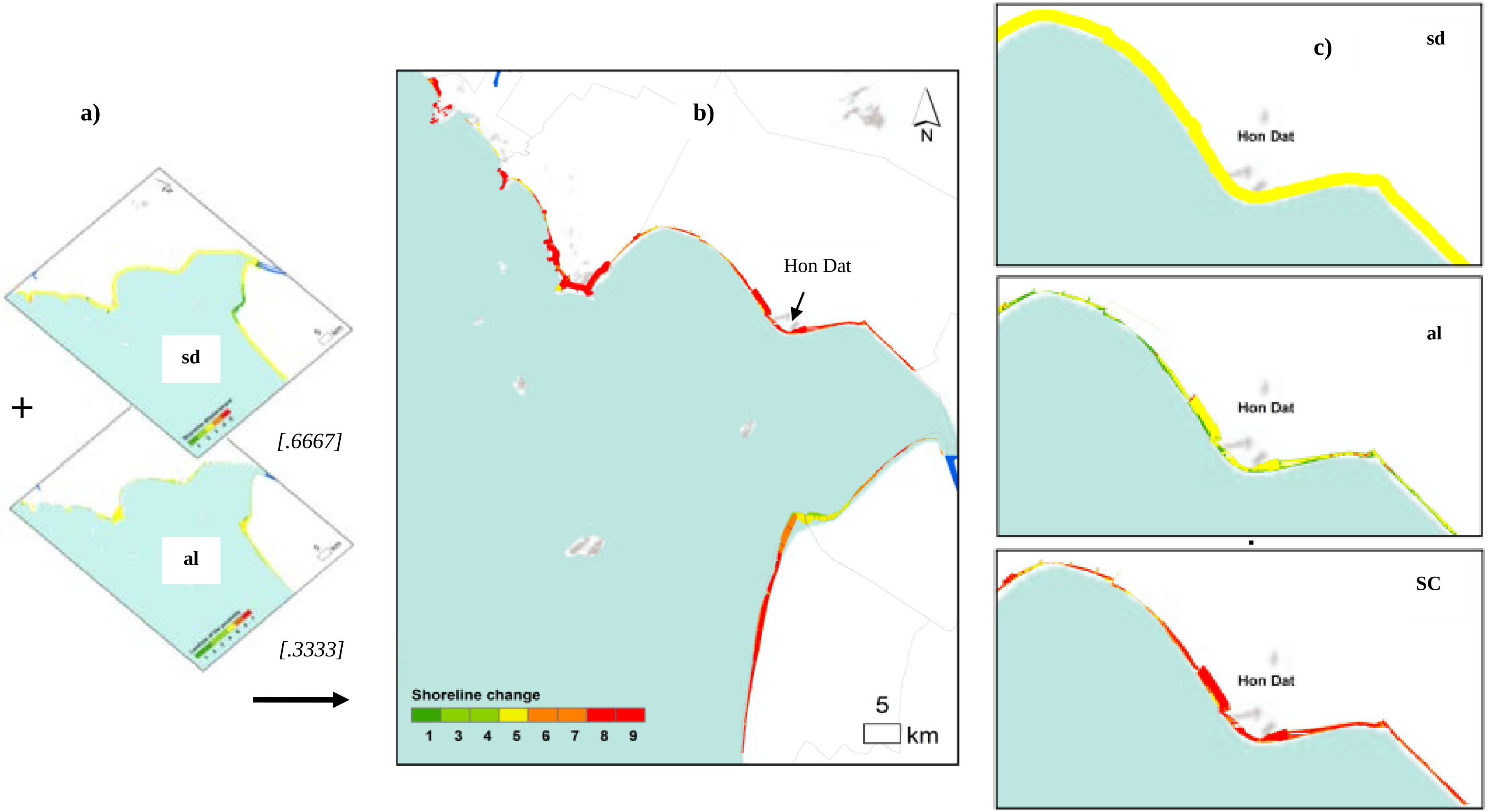


Figure 5.6 GIS-AHP mapping of shoreline change sub-component: a) Aggregate of classified variables for the Kien Giang coast: shoreline displacement [sd], and coastal adjacent landuse [al]; b) Reclassified shoreline change sub-component for the Kien Giang coast [SC]; and c) Extracted the shoreline sub-component for the Hon Dat coast.

Note: As described in Figure 5.1. Numbers in square brackets are presented together with variables indicating relative weights of those variables, obtained by AHP. As [sd] presented in Figure 5.5b, and [al] presented in chapter 4, Appendix 9a.2.

Appendix 14 gives a summary of overall aggregated rankings within the seven districts, according to proportions of the study area classed as very high to high [SC]. Hon Dat appeared to have the largest proportion (ranked at 7) because of the aggregate of least proportion of coastal erosion from LRR (11.6%, ranked at 1), and the largest proportion of representing very high to high [al] (3.22%, ranked at 7). This finding also indicates a strong relation between adjacent coastal landuse and shoreline change. However, it highlighted the discrepancy on the rankings of [SC] obtained, for Kien Luong (90.93%, ranked at 6), An Minh (87.75%, ranked at 5), Ha Tien (87.26%, ranked at 4), and particularly for An Bien with a much smaller proportion (only 34.63%, ranked at 3). For instance, An Minh ranked only at 5 because of the aggregate of the result in erosion obtained from LRR ranked at 7, and the result obtained from [al] ranked at 6. A possible explanation for these results may be the lack of adequate data provided in the previous sub-sections. It is important to keep in mind that all these results are relative values, and identification and visualisation the pattern is more useful and significant to give policy makers or planners a generalised overview of potential impacts of sea-level rise induced shoreline erosion and landuse change.

5.3.4 Mapping of the exposure component

Figure 5.7 shows the exposure map derived from the aggregation of three maps of [SI], [FR], and [SC], obtained from the previous sub-sections. The exposure map was reclassified into 9 categories by using Jenks, and mapped using 5 levels from very low to very high, shaded as for this component, with proportions of the study area presented in Table 5.11. Relative weights of sub-components of the aggregate using AHP, were obtained simultaneously (see details in Appendix 11d).

Table 5.11 Proportions of the study area classed as very low to very high in representing exposure.

Coastal district	Exposure using AHP , % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6 - 7	Very high 8 – 9
An Bien	0.05	0.79	0.48	45.25	53.43
An Minh	0.00	0.07	0.75	82.57	16.60
Chau Thanh	12.28	22.08	22.99	38.51	4.14
Hon Dat	2.50	19.58	37.02	26.61	14.28
Ha Tien	0.23	10.54	10.06	22.91	56.26
Kien Luong	0.73	6.16	5.93	27.93	59.25
Rach Gia	9.41	26.47	9.69	34.38	20.05
7 districts	*2.51*	*11.35*	*17.13*	*41.68*	*27.32*

Note: See details of reclassifying values of results using Jenks in Figure 5.1.

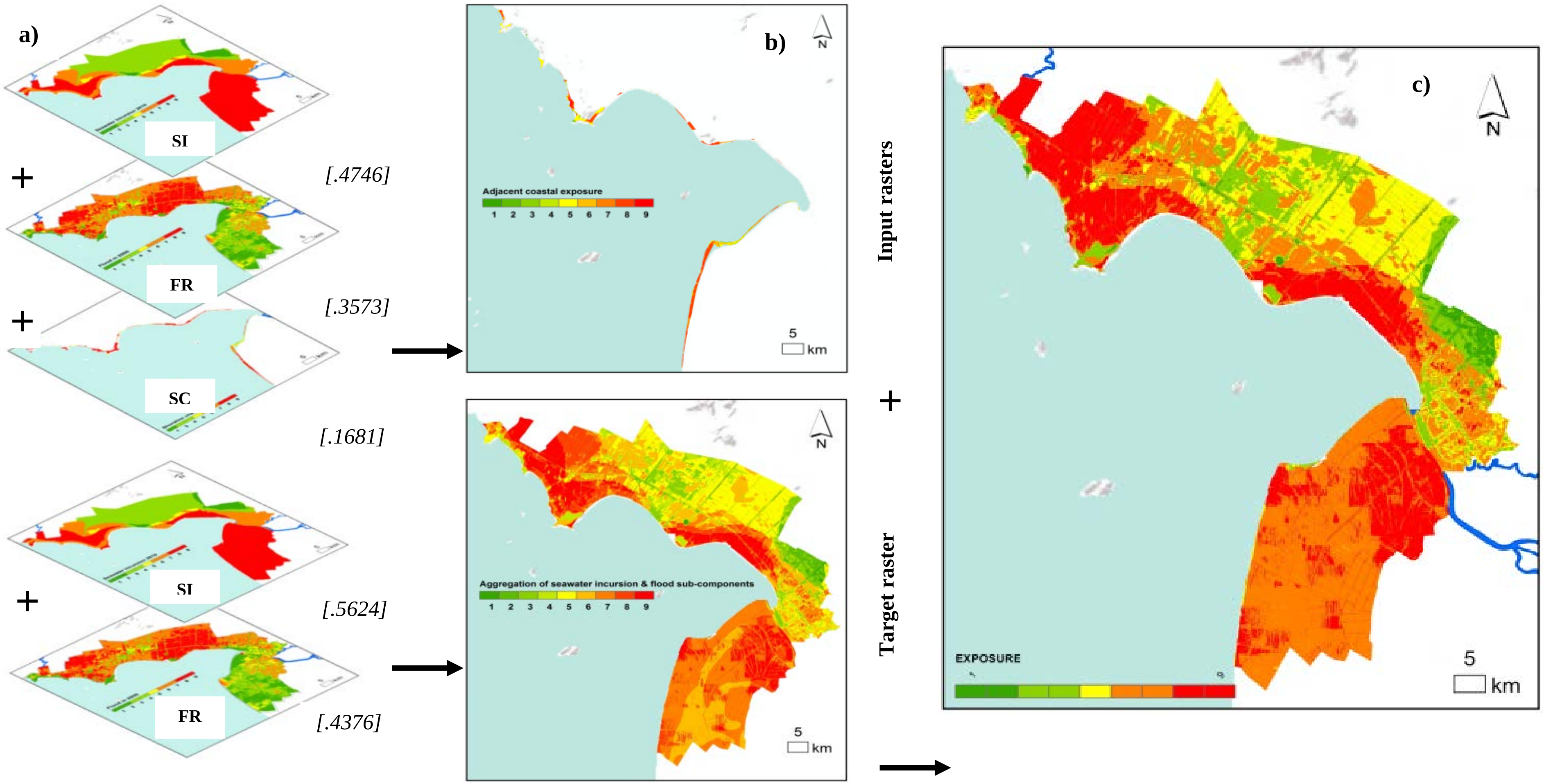


Figure 5.7 GIS-AHP mapping of exposure component: a) aggregate of reclassified sub-components: seawater incursion [SI], flood risk [FR], and shoreline change [SC]; b) mosaic raster dataset[5]: input rasters and target raster; and c) reclassified exposure [E].

Note: As described in Figure 5.1. Numbers in square brackets are presented together with sub-components indicating relative weights of those sub-components, obtained by AHP. As [SI], [FR], and [SC] presented in Figures 5.1b (2010), 5.3b (2000), and 5.6b, respectively.

[5] Three sub-components: [SI], [FR], and [SC] were aggregated by AHP to generate the input raster, whereas two sub-components: [SI] and [FR] were aggregated by AHP to generate the target raster, which is considered the first raster in the list of input rasters. And then, mosaics multiple input rasters into the target raster to get the final outcome.

In Figure 5.7, the middle b) displays maps of raster dataset that were used to produce the mosaic exposure map, whereas the left hand side c) shows the map of reclassified exposure. Figure 5.7c indicates that almost all of the entire districts of An Minh and An Bien are most at risk to potential impacts, as well as within district areas (shaded red) in the north and southeast of Ha Tien, three fifths of Kien Luong, southeast and southwest of Hon Dat, and south of Rach Gia. There is 69% of the study area (~207 000 ha) representing very high to high [E] to potential impacts (see Table 5.11). An Minh appeared to have the largest proportion (99.17% of area, ~58 600 ha), followed by 98.68% (~39 500 ha) in An Bien, 87.18% (~41 200 ha) in Kien Luong, 79.17% (~7 900 ha) in Ha Tien, 54.43% (~5 600 ha) in Rach Gia, and 42.65% (~12 200 ha) in Chau Thanh. The least proportion was 40.89% (~42 500 ha) in Hon Dat.

5.3.5 Discussion

5.3.5.1 Coastal exposure study

A large proportion of the study area is mapped as very high to high [E] (69%, ~207 000 ha) (see Table 5.11), focusing on 27.32% of area (~78 300 ha) representing very high [E] (shaded red), comprising 59.25% of area (~28 000 ha) in Kien Luong, 53.43% (~21 400 ha) in An Bien, 14.28% (~14 850 ha) in Hon Dat, 16.6% (~9 830 ha) in An Minh, 56.26% (~5 600 ha) in Ha Tien, 20.05% (~2 100 ha) in Rach Gia, and only 4.14% (~1 200 ha) in Chau Thanh (see Figure 5.7c). Although these results are relative values, and the proportions are sensitive to the thresholds adopted, weightings used, and the classification of apparent breaks (Jenks), the geographical pattern provides a valuable overview for policy makers and planners.

In general, the study area is expected to be highly exposed to potential impacts due to several reasons. Nearly 60% of area is considered high salinity with over 8 ppt observed in 2010 (Table 5.2), and ~20% of area appears to have seasonal and regularly saline soils (see sub-section 5.3.1.2); ~32% of area is submerged with ≥ 1 m depth observed from the river-flood in 2000 (Table 5.3), and ~83% of area is below 1 m above MSL, which is going to be most at risk, especially at high tides (Table 5.4); and ~35% of the Kien Giang coastline has undergone erosion (Table 5.8), and ~21% of area of the adjacent coastal area protected by barriers (mangroves, and human infrastructure) with other ~77% of area appearing as fishery activities (see Table 5.9)

Moreover, overall aggregated rankings in this study have been undertaken, in order to provide initial indications of exposure, especially for provincial and district policy makers. Table 5.12 gives a summary of overall aggregated rankings for each district according to proportions of the study area representing very high to high [E].

Table 5.12 Overall aggregated rankings for each district obtained by aggregating three sub-components: seawater incursion, flood risk, and shoreline change in representing the exposure component.

Rank	Seawater incursion	Flood	Shoreline change	*Exposure*
1	Hon Dat	An Minh	Chau Thanh	*Hon Dat*
2	Rach Gia	An Bien	Rach Gia	*Chau Thanh*
3	Chau Thanh	Chau Thanh	An Bien	*Rach Gia*
4	Kien Luong	Rach Gia	Ha Tien	*Ha Tien*
5	Ha Tien	Ha Tien	An Minh	*Kien Luong*
6	An Bien	Kien Luong	Kien Luong	*An Bien*
7	**An Minh**	**Hon Dat**	**Hon Dat**	***An Minh***

Note: A value of 7 indicates the highest rank within seven districts, while a value of 1 indicates the least rank in representing the exposure (see details in Appendix 14); The colour indicates districts exposure with red, yellow, and green colours representing districts high, moderate, and low exposure, respectively.

Interestingly, it was found that the rankings of [E] for districts seem to reflect their rankings of [SI] considered as the highest priority. Table 5.12 indicates An Minh appears to have the largest proportion of area representing very high to high [E] (99.17%, ranked at 7) due to the largest proportion experiencing very high to high [SI] (100%, ranked at 7), the least proportion very high to high [FR] (5.6%, ranked at 1), and the large proportion very high to high [SC] (87.57%, ranked at 3) (see Appendices 11a.2, 11b.2, and Table 5.10). On the other hand, Hon Dat appears to have the least proportion representing very high to high [E] (40.89%, ranked at 1) because of the least proportion experiencing very high to high [SI] (15.16%, ranked at 1), the largest proportion very high to high [FR] (85.1%, ranked at 7), and the largest proportion very high to high [SC] (91.03%, ranked at 7).

This study is the first empirical study examining exposure to seawater incursion, flood risk, and shoreline erosion by using GIS integrated with AHP, six variables into the three sub-components were to be used in the aggregate. The map of exposure levels shown in Figure 5.7c, when augmented with supporting text, can give policy makers or planners a generalised overview the areas of incursion, inundation, and erosion that are likely to be exacerbated by a relative rise in sea level. It enables identification and prioritisation of the areas most likely to be exposed to the impacts indicated by areas shaded red.

As mentioned in chapter 3, sub-section 3.4.2.3, it is believed that AHP is a valuable technique for multiple criteria decision-making. AHP provides the objective mathematics to process the inescapably subjective and personal preferences of an individual or a group in making decisions (Saaty, 2001). It assists decision makers in organising and evaluating the significance of the criteria and alternative solutions of a decision. It helps the decision makers find the one that best suits their needs rather than prescribing a correct decision. However, AHP is based on subjective judgements; in fact, these judgements are not always consistent. Consistency, as used here, refers to thinking in the same way throughout an entire circumstance. The judgements about sub-variables, variables, sub-components, and the three main components were applied, based on their contributions to the impacts of climate change, particularly sea-level rise, using pair-wise comparisons. The choice of variables and their priorities within pair-wise comparisons for the study area depended on a number of factors including required level of existing analyses, accuracy, data available, and the author's knowledge and experience.

It is important to keep in mind that changes in judgements can influence the mapping outcome. This will be examined by changing the priorities of variables in order to represent exposure in the following sub-section. The weight value of the exposure study is summarised in equations as follows. The consistency ratios (CR) obtained were acceptable in the way demonstrated by Saaty (1980; 1994) (see Appendix 15). The results in Equation 5.1.1 show relative weights of three layers assigning three sub-components [SI], [FR], and [SC] obtained, in terms of representing the exposure in the analysis (see Figure 5.7). A summary of those relative weights in order to represent [E] is presented in Equation 5.1. Moreover, the results in Equation 5.1.2 show that relative weights of two layers variables: [si], and [st] in mapping [SI], relative weights of two [fd], and [el] in mapping [FR], and relative weights of two [sd], and [al] in mapping [SC], which were aggregated to obtain relative weight of the exposure study (see Figures 5.1, 5.3, and 5.6). A summary of those relative weights in order to represent [E] is presented in Equation 5.1.3.

$\mathbf{Layer_E} = \mathbf{0.5185} * \text{layer}_{SI} + \mathbf{0.3975} * \text{layer}_{FR} + \mathbf{0.0841} * \text{layer}_{SC}$ **[Equation 5.1]**

$\Leftrightarrow \mathbf{Layer_E} = [½ * (0.4746 + 0.5624) * \text{layer}_{SI}] + [½ * (0.3573 + 0.4376) * \text{layer}_{FR}] + (½ * 0.1681 * \text{layer}_{SC})$ **[Equation 5.1.1[6]]**

[6] See Figure 5.7a.

⇔ $\mathbf{Layer_E} = 0.5185 * (0.7500 * layer_{si} + 0.2500 * layer_{st}) + 0.3975 * (0.6923 * layer_{fd} + 0.3077 * layer_{el}) + 0.0841 * (0.6667 * layer_{sd} + 0.3333 * layer_{al})$ **[Equation 5.1.2[7]]**

⇔ $\mathbf{Layer_E} = (0.3889 * layer_{si} + 0.1296 * layer_{st}) + (0.2752 * layer_{fd} + 0.1223 * layer_{el}) + (0.0560 * layer_{sd} + 0.0280 * layer_{al})$ **[Equation 5.1.3]**

Note: Abbreviation of variables, sub-components constituent to the exposure, and relative weights of those variables, and sub-components, obtained by AHP as presented in Figures 5.1, 5.3, 5.6, and 5.7. See a summary of those relative weights in Appendix 15.

These equations produced by the AHP analysis provide objective mathematics that have captured subjective judgements using pair-wise comparisons. They are portrayed spatially using GIS in order to represent the exposure, which is assigned its relative value as 1 (that is visualised in Figure 5.7c). The [SI] is considered as the highest priority (its relative value obtained as 0.5185). The second priority is [FR] (its relative value obtained as 0.3975). The least is [SC] (its relative value obtained as 0.0841). These values also may be useful to give a general idea for local authorities to re-analyse their wise-priorities for potential impacts in the context of climate change, particularly sea-level rise, within the limitation of their budget capacity.

5.3.5.2 Evaluation of changing priorities of variables based on pair-wise comparisons

One of the strengths of AHP proposed by Saaty (1980) is its ability to carry out a consistency check of the subjective pair-wise judgements. Figure 5.8 presents an example of changes in priorities of the six variables combined into the 3 sub-components representing exposure, whereas Table 5.13 presents a comparison of relative weights from changing their priorities obtained, in representing the exposure by using AHP. On the right hand side b) of Figure 5.8, priorities of six variables were changed, but remained the principle of their pair-wise comparisons ([SI] > [FR] > [SC]; [si] > [st], [fd] > [el], and [sd] > [al]) in representing the alternative adjusted exposure. Specifically, the priority assigned to soil type [st] was markedly increased, together with a significant increase in shoreline change [SC] by increasing the priority of adjacent coastal landuse [al].

[7] See Figures 5.1a, 5.3a, and 5.6a.

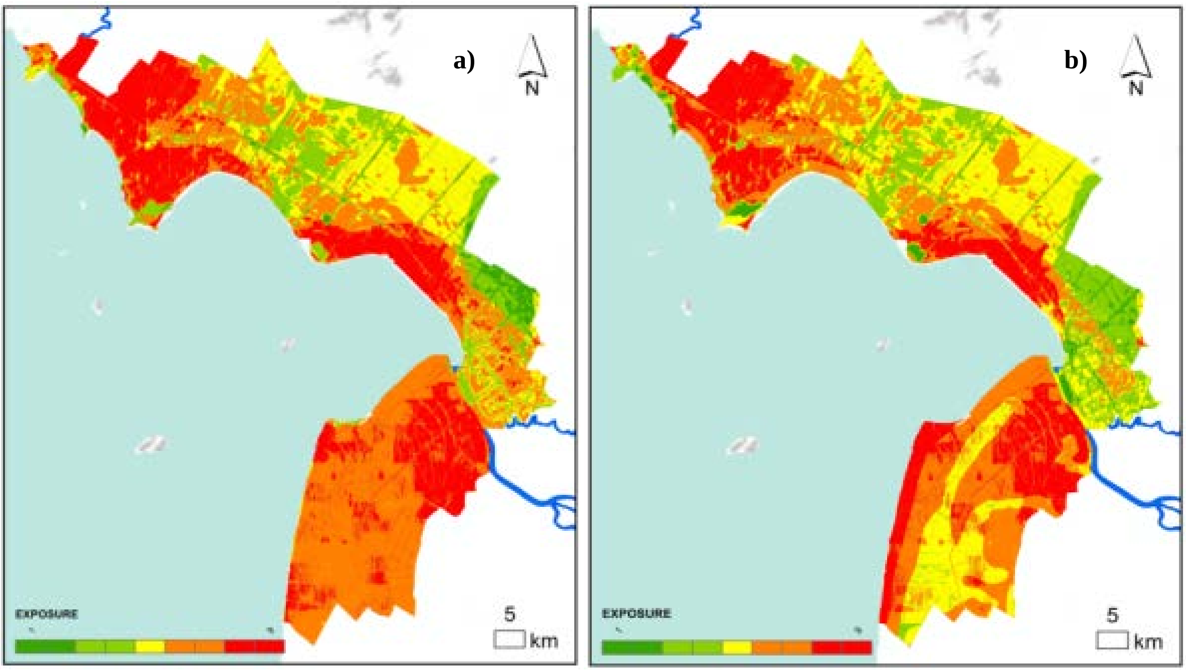


Figure 5.8 An example for GIS- AHP mapping of exposure component by changing priorities of variables in pair-wise comparisons: a) exposure used in vulnerability analysis; and b) alternative adjusted exposure (with increase weighting of soil type [st] and adjacent coastal landuse [al]).

Note: a) as presented in Figure 5.7c.

Table 5.13 A comparison of the relative weights of the variables obtained by changing priorities of variables using AHP in representing exposure.

	$Layer_{si}$	$Layer_{st}$	$Layer_{fd}$	$Layer_{el}$	$Layer_{sd}$	$Layer_{al}$
$Layer_E$ in a)	0.3889	0.1296	0.2752	0.1223	0.0560	0.0280
	$Layer_{SI}$ = 0.5185		$Layer_{FR}$ = 0.3975		$Layer_{SC}$ = 0.0841	
$Layer_E$ in b)	0.3000	0.1969	0.2341	0.1193	0.0695	0.0804
	$Layer_{SI}$ = 0.4969		$Layer_{FR}$ = 0.3534		$Layer_{SC}$ = 0.1499	

Note: $layer_E$ in a) as presented in Equation 5.1.3, while $layer_E$ in b) see Appendix 16.

As seen in Figure 5.8, there are some subtle changes to mapping exposure between a) and b). Maps look similar, except strongly changes in small areas in Kien Luong, Chau Thanh, and An Bien, and a larger area in An Minh, so exposure seems realistic. Similarly, Equation 5.1.4 summarises those relative weights obtained, in order to represent the alternative adjusted exposure (see details in Appendix 16).

$$\mathbf{Layer_E} = (0.3000 * layer_{si} + 0.1969 * layer_{st}) + (0.2341 * layer_{fd} + 0.1193 * layer_{el}) + (0.0695 * layer_{sd} + 0.0804 * layer_{al})$$ **[Equation 5.1.4[8]]**

[8] As presented in Figure 5.8b. See Table 5.13.

This alternative exposure in Figure 5.8b seems reflects more closely the map of soil type (see Figure 5.1a). Table 5.13 also indicates that there has been the significant change in the weight value of [st] (an increase from 0.1296 to 0.1969), and the weight value of [al] (an increase from 0.0280 to 0.0804). It should be underlined that the results of AHP also illustrate the perception of experts regarding human-nature interaction and the threat posed by climate change, particularly sea-level rise. It can thus be an implication for further practice that it might involve groups of local experts, including physical and social experts that can resolve discrepancies of evaluations. Apart from the limitation of AHP, GIS-based multi-criteria approaches, in this thesis, integrated AHP into GIS methods, are easy applicable and can be projected to other coastal areas.

5.4 Sensitivity component

The sensitivity, as used here, reflects the potential to be affected, or display the stability that is a complex interaction between society and land-use sensitivity factors. It indicates the area that displays the least stability, meaning the area that is the most sensitive. "*Who (is sensitive)*" is always of a greater interest than "*What (is sensitive)*". Therefore, societal factors are considered to be more important than landuse factors, in terms of representing the sensitivity. In this study, societal factors sensitivity was judged to have an extremely high influence and was assigned a priority of [9], while the study landuse factors sensitivity was judged to have a very strong influence and assigned a priority of [7].

5.4.1 Mapping of the societal factors sensitivity sub-component

Four variables, comprising population density, proportions of rural people, ethnic minorities, and female people, were used in representing the societal sensitivity sub-component. However, one of the limitations with all available variables is that data were only available obtained at entire district level. A map showing the sub-component for the study area is presented in Figure 5.9. Objectives of this sub-section are two-fold. The first objective is to evaluate societal sensitivity for the study area. The second objective is to use those sub-components in the aggregate of the sensitivity study. The sub-component map was reclassified into 9 categories by using Jenks, and mapped using 5 levels from very low to very high, shaded as for the societal sensitivity sub-component, with proportions of the study area reported in Table 5.14. Relative weights of the variables of the aggregate using AHP, simultaneously, were obtained (see details in Appendix 12a).

5.4.1.1 Overview

Statistical data obtained from the Kien Giang Statistical Office's Book in 2012 indicated the population density of the entire Kien Giang in 2011 (271 inhabitants/ km^2) that was slightly higher than the national average population density (260 inhabitants/ km^2); however, there has markedly higher proportion of population density of the seven coastal districts in Kien Giang (308 inhabitants/ km^2) (see details in Appendix 10). In addition, there was about 73% of the population living in rural areas for the entire province in 2011, whereas only 62% for the seven coastal districts were rural. Furthermore, the proportion of ethnic minority group reached 17% for the entire province, while having only 15% for the seven coastal districts. Generally, areas with higher population densities are expected to be more sensitive to coastal impacts resulting from future sea-level rise. Moreover, specific groups of people are more sensitive than other groups to climate change impacts; for example, the impacts are likely to affect rural people more severely than urban people; women are often more at risk than men, etc., which is described greater detail in chapter 4, sub-section 4.3.2.1. A strong relationship between population density and vulnerability has been reported in the literature chapter (see details in chapter 2 section 2.6, and appendix 1). The population density variable was, therefore, considered as the most important in representing the societal factors sub-component. This was followed by the proportion of rural people variable, and then the proportion of ethnic minorities. The least important was the proportion of female people variable, in representing the societal factors sub-component.

5.4.1.2 Aggregation of societal factors sensitivity sub-component

Figure 5.9 presents GIS-AHP mapping of the societal factors sub-component of the study area. In Figure 5.9, the left hand side a) displays maps of classified variables used in the analysis, whereas the right hand side b) visualises the map of reclassified the societal factors sub-component.

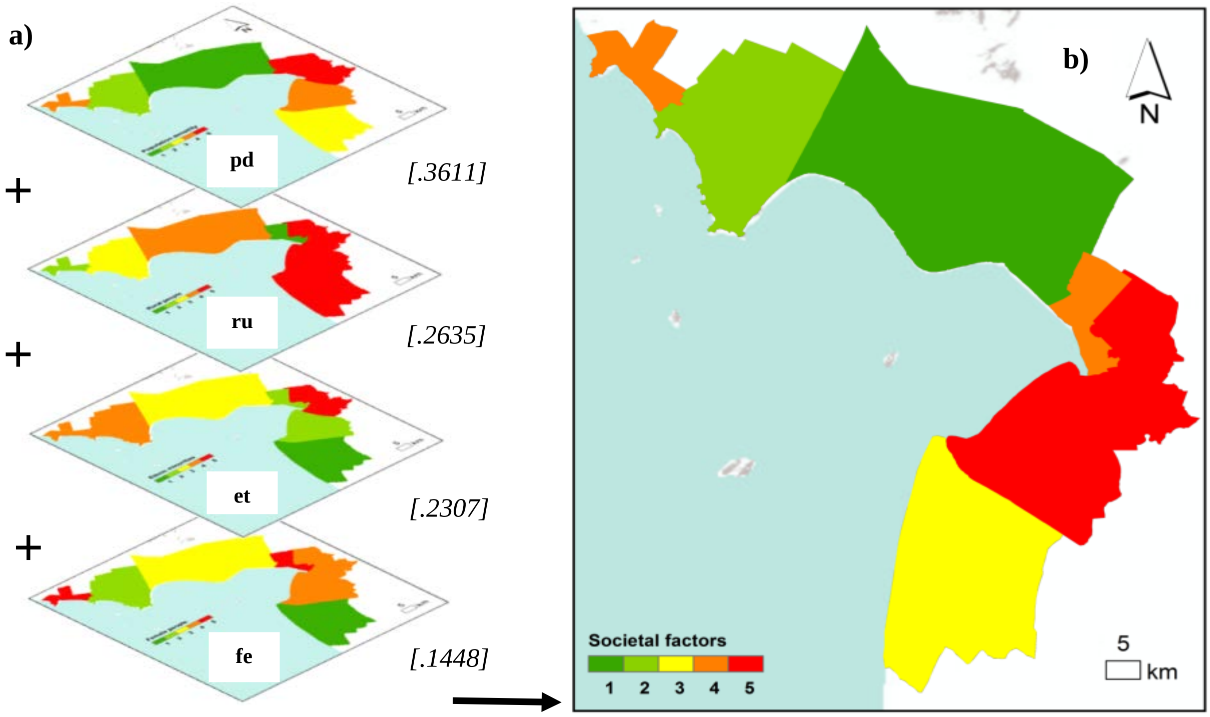


Figure 5.9 GIS-AHP mapping of societal factors sub-component: a) aggregate of classified variables: population density [pd], rural people [ru], ethnic minorities group [et], and female people [fe]; and b) reclassified societal sub-component [SF].

Note: as described in Figure 5.1. Numbers in square brackets are presented together with variables indicating relative weights of those variables, obtained by AHP.

Figure 5.9b indicated two districts An Bien, and Chau Thanh experienced the most sensitive areas (shaded red), while Hon Dat experienced the least sensitive (shaded dark green). Contrary to expectations, this Figure also indicated that urban areas, comprising Rach Gia and Ha Tien, seem less sensitive than rural areas in terms of societal factors sensitivity. A possible explanation for these results may be that input data are only available at an entire district level. To examine this, scale-based approaches to the coastal vulnerability assessment will be discussed later in this chapter to see whether or not they influence the mapping outcome. Three different scale-based approaches, using population density will be demonstrated in order to represent the scale-based sensitivities in sub-section 5.4.4.2. The analyses of the coastal vulnerability for a settlement scale will be provided in chapter 6, sub-section 6.4.3.4.

Seven districts were ranked in the study area based on the areas representing very high to high sensitivity of the four variables, respectively, in representing the societal factors sub-component, that are summarised in Table 5.14.

Table 5.14 Overall aggregated rankings from four variables: population density, rural people, ethnic group, and female people in representing societal factors sensitivity sub-component for each district.

Rank	Population density	Rural people	Ethnic group	Female people	*Societal factors*
1	Hon Dat	Rach Gia	An Minh	An Minh	*Hon Dat*
2	Kien Luong	Ha Tien	Rach Gia	Kien Luong	*Kien Luong*
3	An Minh	Kien Luong	An Bien	Hon Dat	*An Minh*
4	An Bien	Hon Dat	Hon Dat	An Bien	*Ha Tien*
5	Ha Tien	Chau Thanh	Ha Tien	Chau Thanh	*Rach Gia*
6	Chau Thanh	An Bien	Kien Luong	Ha Tien	*Chau Thanh*
7	Rach Gia	An Minh	Chau Thanh	Rach Gia	*An Bien*

Note: as described in Table 5.12.

As seen in Table 5.14, the rankings in societal factors sub-component seem to reflect their rankings using the population density variable. A probable explanation for this is that the population density variable was assigned the most importance, compared to the other three variables. An Bien appears area the most sensitive (ranked at 7) due to moderate [pd] (309 inhabitants/ km^2, in a range of 164 - 2 246; ranked at 4), a large proportion of rural people (at 91%, ~112 650 rural people, in a range of 7 - 94%; ranked at 6), a small proportion of ethnic group (at 11%, ~13 617 ethnic people, in a range of 2 - 38%; ranked at 3), and a large proportion of female people (49.49%, ~61 266 females, in a range of 48.98 - 50.88%; ranked at 4). Similarly, Chau Thanh appeared the second highest sensitive area (ranked at 6) due to high [pd] 531 inhabitants/ km^2 (ranked at 6), a large proportion of rural people (at 86%, ~130 342 rural people; ranked at 5), and the largest proportion of ethnic group (at 38%, ~57 593 ethnic people; ranked at 7), and a large proportion of female people (at 50.22%, ~76 108 females; ranked at 5). On the other hand, Hon Dat appeared the area least sensitive (ranked at 1) due to the lowest population density 164 inhabitants/ km^2 (ranked at 1), a moderate proportion of rural people (at 82%, ~139 773 rural people; ranked at 4), and a moderate proportion of ethnic minorities (at 14%, ~23 864 ethnic people; ranked at 4), and a fairly small proportion of female people (at 49.18%, ~83 830 females; ranked at 3) (see chapter 4, sub-section 4.5.3.2). However, one discrepancy was the ranking in the sub-component for An Bien. A possible explanation for this result may be due to data being available only at entire district level.

5.4.2 Mapping of the landuse factors sensitivity sub-component

5.4.2.1 Overview

As described in chapter 4, sub-section 4.5.3.3a, Kien Giang generally has a greater proportion of agricultural land, while having less non-agricultural land and unused land compared to

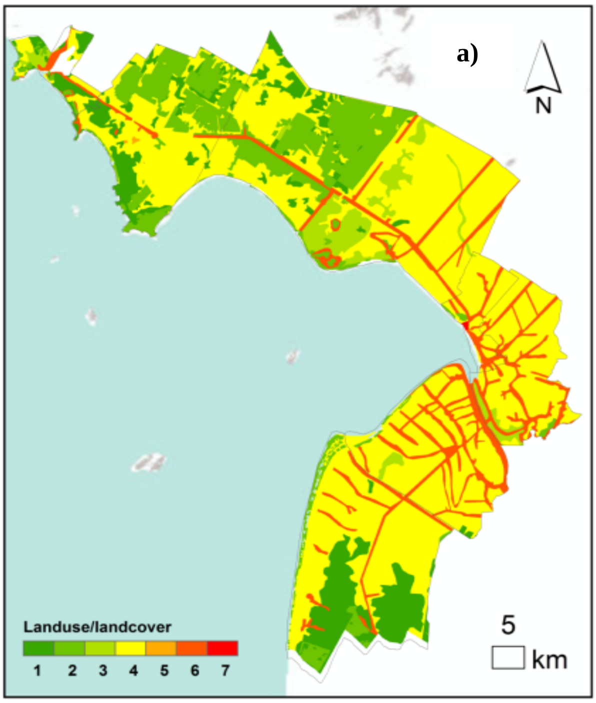
average proportions for the delta. Objectives of this sub-section are two-fold. The first objective is to evaluate landuse sensitivity for the study area. The second objective is to use those sub-components in the aggregate of the sensitivity study. A map showing the landuse sensitivity sub-component for the study area is presented in Figure 5.10b. The sub-component map was reclassified into 7 categories by using Jenks, and mapped using 3 levels from low to high, shaded as for the landuse sensitivity sub-component, with proportions of the study area reported in Table 5.15.

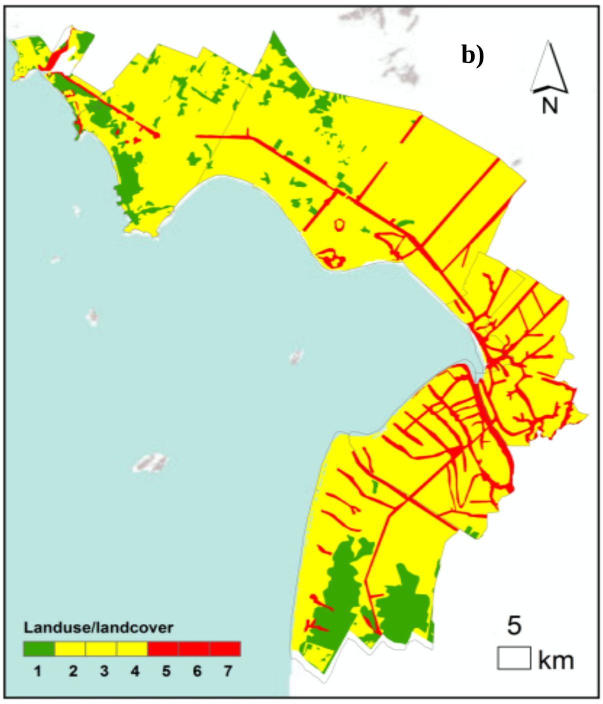
5.4.2.2 Aggregation of landuse sensitivity sub-component

As described in greater detail in chapter 4, sub-section 4.5.3.3 (see Appendices 4 and 9), the landuse sensitivity sub-variable, and variable were based on the landuse map, respectively. Eleven sub-categories of a map of landuse were classified into 7 sub-classes, and then were reclassified into 3 main categories assigning as the three classes (see Table 5.1). These are:

- *Unused land* consists of the bare land.
- *Agricultural land* consists of forest land, perennial industrial plant land, and perennial fruits and orchard land, annual crops in the plain-field, salt pond land, paddy field, and fishery farm land.
- *Non-agricultural land* consists of specially used land, rural and urban land, it is largely for settlements and roads etc.,.

In Figure 5.10, the left hand side a) presents the map of classified 7 sub-classed, whereas the right hand side b) displays the map of reclassified 3 classes, in terms of representing the landuse sensitivity sub-component. The non-agricultural land variable was considered the most important, followed by agricultural land variable, whereas unused land was the least significant, in representing the landuse factors sensitivity. Densely populated settlements associated with urbanisation (with a high road density) are most at risk under climate change impacts (areas shaded red). Table 5.15 presents proportions of the study area classed as low to high landuse sensitivity.





The unused land	~ 1	*The used land*	~ 1: low sensitivity
Forests and perennial industrial plants, fruits, and orchards land	~ 2	*The agricultural land*	~ 2: moderate sensitivity
Other annual crops, except rice, and salt ponds land	~ 3		
Rice field and fishery farming land	~ 4		
Specially used land	~ 5	*The non- agricultural land*	~ 3: high sensitivity
Rural area	~ 6		
Urban area	~ 7		

Figure 5.10 A map of landuse sub-component study: a) classifed into seven sub-classes; and b) reclassified into 3 classes in representing landuse sub-component [LU].

Note: 11 categories of landuse, assigned as sub-variables, were classified into 7 sub-classes (see Table 5.1, and Appendix 4); And then, these sub-classes were reclassified into 3 main classes, assigned as variables, from low sensitivity shaded dark green, moderate sensitivity shaded yellow, and high sensitivity shaded red (see Table 5.15).

Table 5.15 Proportions of the study area classed as low to high in representing landuse factors sensitivity.

Coastal district	Landuse , % of area		
	Low 1	Moderate 2 – 4	High 5 – 7
An Bien	0.5	75.8	23.7
An Minh	29.2	63.8	7.0
Chau Thanh	0.0	77.7	22.3
Hon Dat	5.4	87.5	7.1
Ha Tien	32.1	53.6	14.3
Kien Luong	17.4	80.4	2.3
Rach Gia	0.0	75.8	24.2
Seven coastal districts	*24.0*	*53.2*	*22.8*

Note: The sub-component was classified into a range of 1 - 7, and then reclassified into 3 classes: a value of 1 representing low sensitivity; values of 2, 3, and 4 representing moderate sensitivity; and values of 5, 6, and 7 representing high sensitivity.

Table 5.15 shows that only small proportions of the area were either bare land, considered low sensitivity (shaded dark green) to account for 24% (~72 000 ha), or non-agricultural land, considered high sensitivity (shaded red) to account for 22.8% (~68 400 ha). On the other hand, the largest proportion of agricultural land (shaded yellow) was 53.2% representing moderate sensitivity (see Figure 5.10b). This land is mainly used for rice cultivation, shrimp farmings, and forest activities. Rach Gia appeared the most sensitive area (i.e., a city), due to the largest proportion representing high [LU] (24.2%, ~2 500 ha), together with a large proportion representing moderate [LU] (75.8%, ~7 850 ha). On the other hand, Kien Luong appears the least sensitive area, due to the least proportion representing high [LU] (only 2.3%, ~1 068 ha), and a large proportion representing moderate [LU] (80.4%, ~38 000 ha), and a fairly large proportion representing low [LU] (17.4%, ~8 210 ha). There are several possible explanations for these results obtained. Rach Gia is the densely populated city, and relatively well developed and accounted a large proportion of urban area, compared to other districts, with little available unused land in Rach Gia. By contrast, Kien Luong is one of districts that relies heavily on the agricultural activities, having a large agricultural land, together with the bare land, (i.e., hills and mountains) scattered along the coast.

5.4.3 Mapping of the sensitivity component

Figure 5.11 presents GIS-AHP mapping of the sensitivity study. In Figure 5.11, the left hand side a) presents maps of reclassified sub-components used in the analysis, whereas the right hand side b) displays the sensitivity levels map. The sensitivity component map was reclassified into 9 categories by using Jenks, and mapped using 5 levels from very low to very high, shaded as for the component, with proportions of the study area reported in Table 5.16. Relative weights of aggregated sub-components using AHP, were obtained simultaneously (see details in Appendix 12b).

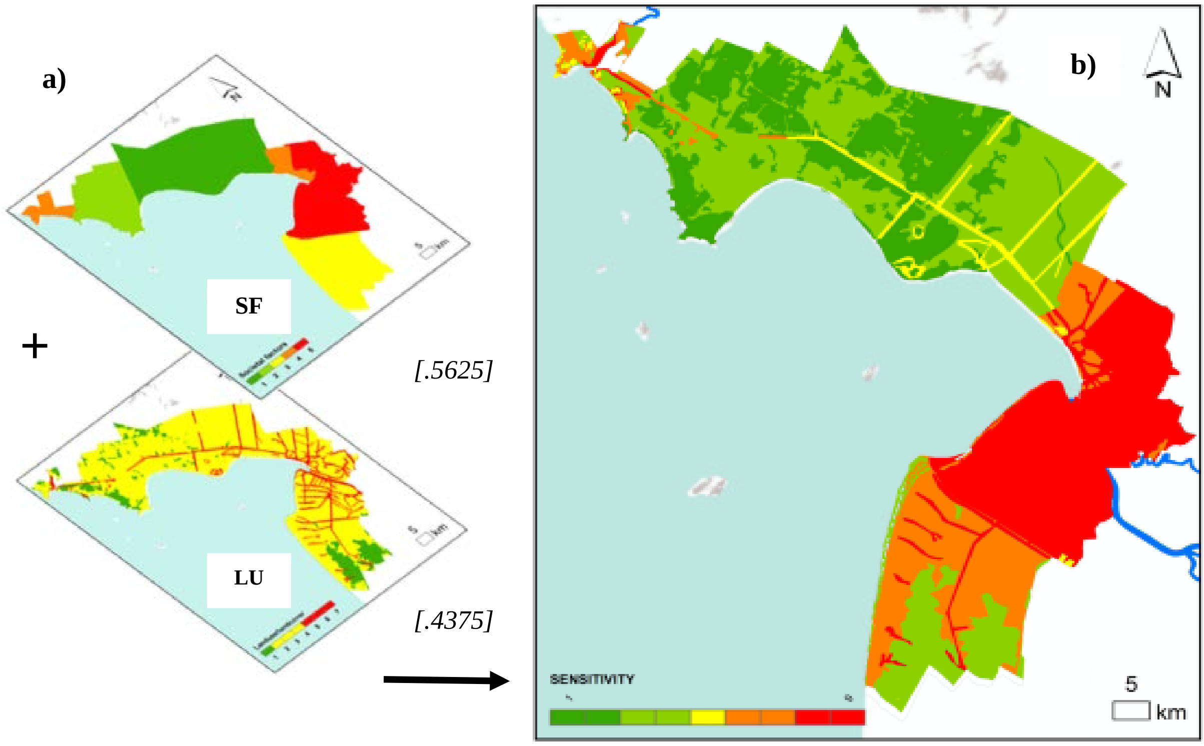


Figure 5.11 GIS-AHP mapping of sensitivity component: a) aggregate of reclassified sub-components: societal factors [SF], landuse [LU]; and b) reclassified sensitivity component [S].

Note: As described in Figure 5.1. Numbers in square brackets are presented together with sub-components indicating relative weights of those sub-components, obtained by AHP. As [SF] and [LU] presented in Figures 5.9 and 5.10, respectively.

Table 5.16 Proportions of the study area classed as very low to very high in representing sensitivity.

Coastal district	Sensitivity component using AHP , % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6 - 7	Very high 8 – 9
An Bien	0.0	0.0	0.5	1.2	98.2
An Minh	0.0	36.4	0.0	56.6	7.0
Chau Thanh	0.0	0.0	0.0	0.9	99.1
Hon Dat	36.3	56.6	7.1	0.0	0.0
Ha Tien	0.0	32.1	10.8	42.8	14.3
Kien Luong	51.3	46.4	0.0	2.3	0.0
Rach Gia	0.0	0.0	2.6	73.0	24.4
7 districts	*21.0*	*35.4*	*3.0*	*15.4*	*25.2*

Note: See details of reclassifying values of results using Jenks in Figure 5.1.

Figure 5.11b indicates that An Bien and Chau Thanh appear to be the most sensitive areas (mostly shaded red), while Hon Dat and Kien Luong appeared the least sensitive areas (dominantly areas shaded green). Moreover, Table 5.16 indicated the moderate proportion of area representing very high to high sensitivity (shaded red and orange) (40.6%, ~121 800 ha) (see Figure 5.11). Specifically, the largest proportion of this was 99.1% in Chau Thanh,

followed by 98.2% in An Bien. On the other hand, there was a small proportion of only 2.3% in Kien Luong. The least proportion was in Hon Dat (0%).

5.4.4 Discussion

5.4.4.1 Coastal sensitivity study

Results for the sensitivity obtained for the study area, are relative values; however, the large proportion of area representing very high to high sensitivity (nearly 41%) indicates the study area is expected to be relatively sensitive. These include about 25% (~75 700 ha) representing very high [S], comprising almost all of Chau Thanh (99%, ~28 300 ha) and An Bien (98%, ~39 300 ha), together with nearly 16% (~44 900 ha) representing high [S] (see Table 5.16). Moreover, "*who*" is not spatially very accurate due to the limitations of data available in representing the societal factors (at an entire district level) (see Figure 5.9). Most of input data derived from the Kien Giang Statistical Office 2012, used in the aggregate of sensitivity component, were at a given time (i.e., mostly in 2011) which may influence the outcome. The societal factors [SF] have changed over time, thus, different chosen times of input data may obtain different outcomes. The sensitivity outcome [S] is likely to be more changeable, compared to the exposure outcome [E], involving physical factors. Results for the sensitivity study should therefore be interpreted with caution, particularly areas shaded red (see Figure 5.11). It seems that aggregate map of [S] in b) closely resembles district map of societal data [SF] in a), and even including [LU] for this analysis that has led to some variation within districts. There appears to be the modifications in areas in Ha Tien and An Minh, especially to unbounded areas between Kien Luong and Hon Dat. In fact, the interaction of detailed spatial evaluations and societal factors increases the accuracy of the results and will remain challenging for science. Scale-based approaches, especially to using accessible data about the population density variable in representing [S], therefore, will be further discussed in the following sub-section 5.4.4.2.

Overall aggregated rankings for each district in representing coastal sensitivity are summarised in Table 5.17. The rankings of [S] closely reflect rankings of [SF], because [SF] was assigned more importance than [LU], and because of the data of [SF] was obtained only at district level. Chau Thanh appeared to have the largest proportion representing very high to high [S] (ranked at 7), due to high [SF] (ranked at 6), and a large proportion representing high [LU] (ranked at 5). On the other hand, Hon Dat appeared to have the least proportion representing very high to high [S] (ranked at 1), due to the lowest ranking of [SF] (ranked at

1), and a moderate proportion representing high [LU] (ranked at 4). However, there was a discrepancy in the rankings of two sub-components representing [S] for Chau Thanh and An Minh.

Table 5.17 Overall aggregated rankings for two sub-components: societal factors, and landuse factors in representing sensitivity component for each district.

Rank	Societal factors	Landuse	*Sensitivity*
1	Hon Dat	Kien Luong	*Hon Dat*
2	Kien Luong	An Minh	*Kien Luong*
3	An Minh	Ha Tien	*Ha Tien*
4	Ha Tien	Hon Dat	*An Minh*
5	Rach Gia	Chau Thanh	*Rach Gia*
6	Chau Thanh	An Bien	*An Bien*
7	**An Bien**	**Rach Gia**	***Chau Thanh***

Note: as described in Table 5.12.

The weight value of the sensitivity study is summarised in equations as follows. The consistency ratios (CR) obtained were acceptable, according to the procedures of Saaty (1980; 1994) (see Appendix 15).

Layer$_S$ = 0.5625 * layer$_{SF}$ + 0.4375 * layer$_{LU}$ **[Equation 5.2[9]]**

⇔ **Layer**$_S$ = 0.5625 * [0.3611 * layer$_{pd}$ + 0.2635 * layer$_{ru}$ + 0.2307 * layer$_{et}$ + 0.1448 * layer$_{fe}$] + 0.4375 * layer$_{LU}$ **[Equation 5.2.1[10]]**

⇔ **Layer**$_S$ = [0.2031 * layer$_{pd}$ + 0.1482 * layer$_{ru}$ + 0.1298 * layer$_{et}$ + 0.0815 * layer$_{fe}$] + 0.4375 * layer$_{LU}$ **[Equation 5.2.2]**

Note: Abbreviation of variables, sub-components constituent to the sensitivity, and relative weights of those variables, and sub-components, obtained by AHP as presented in Figures 5.9 to 5.11. See a summary of those relative weights in Appendix 15.

Similar to Equations presented in the previous section representing the exposure, the results in Equations 5.2 summarise the relative weights of two layers of sub-components: [SF], and [LU] obtained in order to represent the sensitivity component [S] (see Figure 5.11). The results in Equation 5.2.1 indicate that relative weights of layers of two sub-components, comprising those of four layers variables: [pd], [ru], [et], and [fe], in mapping [SF], and those of three layers: classes non-agricultural land, agricultural land, and unused land, in mapping [LU] were aggregated to obtain the map of [S] (see Figures 5.9, and 5.10). A summary of those relative weights of variables, and landuse sub-component in mapping the sensitivity is

[9] See Figure 5.11a.
[10] See Figures 5.9a and 5.11a.

shown in Equation 5.2.2. The societal sensitivity was considered more important than the landuse sensitivity in order to represent overall sensitivity. The relative weight of [SF] obtained by AHP, therefore, was 0.5625, whereas the relative weight of [LU] was 0.4375.

5.4.4.2 Evaluation of the effect of scale of input data

Figure 5.12 presents an evaluation of the effect of the scale at which input data is available, and its influence on the sensitivity outcomes. In Figure 5.12, the left hand side a) presents the map of the sensitivity obtained by using the 2.5 arc-minute grid cells of population density variable [pd] - at the global scale from Center for International Earth Science Information Network (CIESIN) - Columbia University, and Centro Internacional de Agricultura Tropical (CIAT) (2005) - version 3 (GPWv3), the estimate for the year 2010 was used in the analysis, assigned as [SF]. The middle b) shows the map of sensitivity obtained in this study ([pd] and three other societal variables at an entire district level (see the previous sub-section). The right hand side c) displays the map of sensitivity obtained by using the population density data [pd] within the district level, comprising data within a pilot GIS database (undated, MARD) where buildings, such as households, centre malls, or settlements are digitised as polygons. Two variables: the urban population density and the rural population density, were used to generate the aggregated sub-component [SF]. The maps of the sensitivity were reclassified into 9 categories by using Jenks, and mapped into 5 levels from very low to very high, shaded as for [S], with proportions reported in Table 5.18 (see details in Appendix 17).

The objectives of this sub-section are two-fold. The first objective is to evaluate the effect of the scale at which input data is available (e.g., the population density variable) in mapping the sensitivity. The second objective is to use those sensitivity outcomes in evaluation the aggregated potential impacts that will be provided later in this chapter (sub-section 5.5.3.2), and the final vulnerability (see chapter 6, sub-section 6.4.3.2).

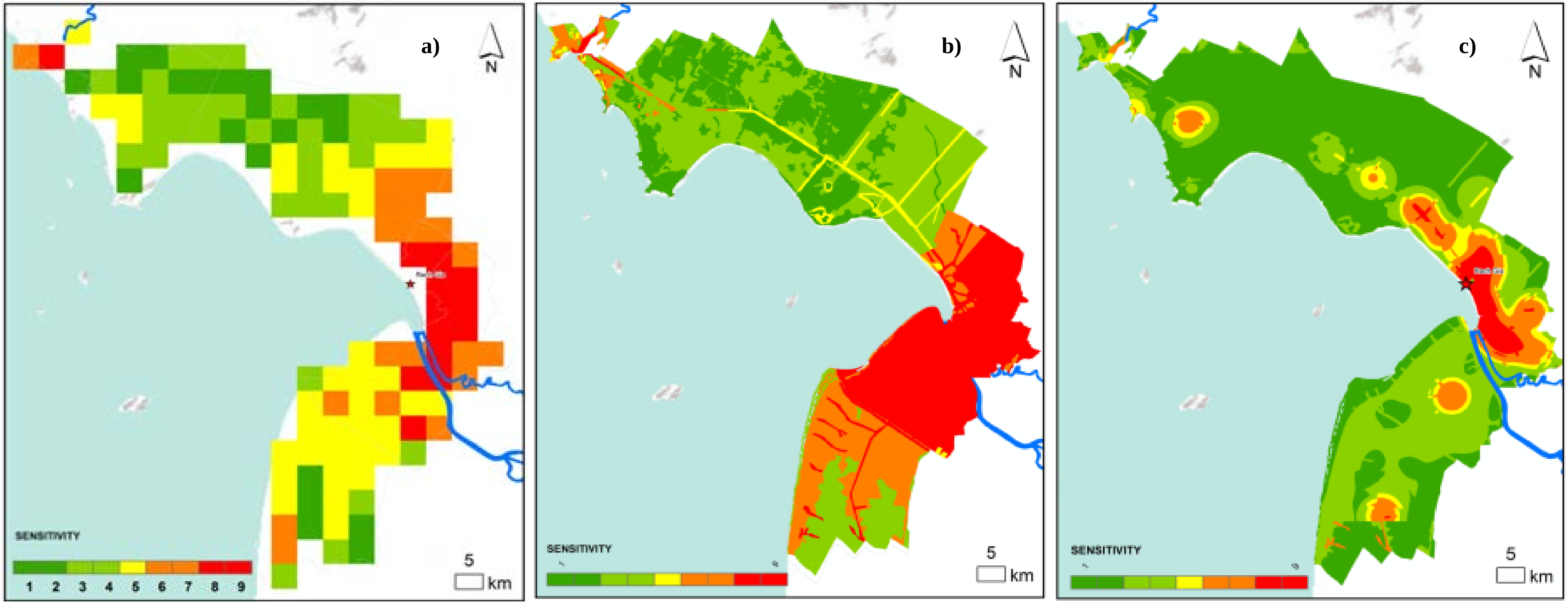


Figure 5.12 Evaluation of the effect of scale of input data in order to represent the sensitivity component: a) the sensitivity obtained by using the population density at global scale[11]; b) the sensitivity obtained by using the population density at an entire district level[12]; and c) the sensitivity obtained by using the population density within district level[13].

Note: As described in Figure 5.1; And a) and c) see details in Appendix 17, whereas b) as presented in Figure 5.11b.

[11] Accessible [pd] at global scale. As see Appendix 17.
[12] Accessible [pd] at an entire district level. As see Figure 5.11b.
[13] Accessible [pd] within district level. As see Appendix 17.

In fact, there are major population magnets within the Kien Giang province: the city of Rach Gia (on the coast in the centre of the province), and Ha Tien (at the northern tip of the Cambodian border) (see Figure 5.12, the left hand side a), and the right hand side c), respectively). Particularly in Figure 5.12c, densely populated areas seem to be very high, and high sensitivity (shaded red and orange). Rach Gia appears to be the district most sensitive, with a large proportion of area shaded red. Half the area of Chau Thanh appears very high to high sensitivity (shaded red and orange). Some high sensitivity areas occurred in Ha Tien, Hon Dat, Kien Luong, An Bien, and An Minh that may be settlement areas.

Table 5.18 A comparison of proportions of the study area in representing evaluating the sensitivity, obtained from scale-based approaches of the population density input data.

Coastal district	Sensitivity components using AHP, respectively , % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6 - 7	Very high 8 – 9
[S] in a)[7]	16.9	26.6	29.8	16.1	10.5
[S] in b)[8]	21.0	35.4	3.0	15.4	25.2
[S] in c)[9]	53.6	30.1	5.1	7.7	3.5

Note: See details of reclassifying values of results using Jenks in Figure 5.1.

Table 5.18 indicates that a large proportion of the study area (26.6%) representing very high to high sensitivity if the global gridded population density variable (at 2.5 arc-minute grid cells) was used in the aggregate of sensitivity, compared with a larger proportion, up to 40.6%, if [pd] data is only available at an entire district level (see details in sub-section 5.4.4.1), and the least proportion, only 11.2%, if [pd] data is accessible within district level. Particularly, proportions assigned as very high sensitivity (shaded red) were markedly decreased from 25.2% in b), and 10.5% in a) to only 3.5% in c) (see Figure 5.12). Therefore, it is clear that the scale of available input data used in the aggregate of sensitivity can influence the outcomes. This is intended to help coastal managers, policy makers, and scientists in identifying the scale at which input data is most suitable for the coastal assessment to be undertaken. The information gained from a finer scale is useful as a basis for conducting more accurate and detailed local studies. If population density data were accessible for input within the district level it would be expected to produce a finer scale for the analysis. This data, however, could not be used instead of district data, because little is available and is time consuming to calibrate (e.g., overlaying this population density layer into Google Earth satellite images with 3D Buildings, and then digitising infrastructure, such as focusing on houses or high buildings). In any case, other societal data are not available for analysis at this finer scale. These findings further support the evaluations of Cutter el al.

(2003) who address the construction of an index of social vulnerability to environmental hazards.

5.5. Potential impacts of climate change, particularly sea-level rise

Differences in exposure to the various direct effects of climate change and different sensitivities to these direct effects lead to different potential impacts on the system of interest. When integrated with sensitivity, the result allows identification of geographical areas where potential impacts are likely to be most pronounced. Potential impacts, as used here, refer to an aggregate of the two components: exposure, and sensitivity, before adaptive capacity (or the ability of a system to manage risk to prevent potential impacts) is considered.

The exposure component was judged to have an extremely high influence, and was assigned a priority of [9], while the sensitivity component was judged to have a moderate influence, and was assigned a priority of [5], in representing potential impacts. This is because of several reasons:

- Exposure is considered a higher priority in terms of vulnerability than sensitivity because these physical factors that can not really be changed (i.e., seawater incursion, the flood risk, and erosion are naturally occurirng), whereas sensitivity could be changed (i.e., how many people live in particular areas, and the type of landuse).
- The study area is expected to be highly exposed to existing impacts, such as seawater incursion and flood depth, together with moderate loss of mangroves characterising the coastal fringe of each district. The fact that 69% of the area indicates very high to high exposure in the analysis is relative value the specifics of which may be a result of the apportioning of natural breaks by the Jenks algorithm, but it produces a realistic ranking of areas in terms of their exposure (see section 5.3).
- The study area seems to be moderately sensitive in terms of the societal and landuse sensitivity factors. The societal factors of the study area, compared to the whole province, indicate greater sensitivity characterised by the higher proportion of population density. In addition to this, landuse factors of the study area were more sensitive in terms of non-agricultural land because of its fairly high proportion. Similarly, nearly 41% of area indicating very high to high sensitivity seems to be realisable (see section 5.4).

5.5.1 Overview

The analyses from the previous sections 5.3 and 5.4 showed a large proportion of area representing very high to high exposure (69%, ~207 000 ha), together with a moderate proportion representing very high to high sensitive (41%, ~123 000 ha). The study area, thus, is expected to experience relatively high potential impacts. The potential impacts map was reclassified into 9 categories by using Jenks, and mapped using 5 levels from very low to very high, shaded as for potential impacts, with proportions reported in Table 5.19. Relative weights of components for aggregate using AHP were obtained simultaneously (see details in Appendix 13).

5.5.2 Aggregation of exposure and sensitivity components

Two first components, exposure and sensitivity, were used in the aggregate of potential impacts in the study area (see Figure 5.13). Figure 5.13a presents the reclassified components that were used in the aggregate of potential impacts, shown in Figure 5.13b.

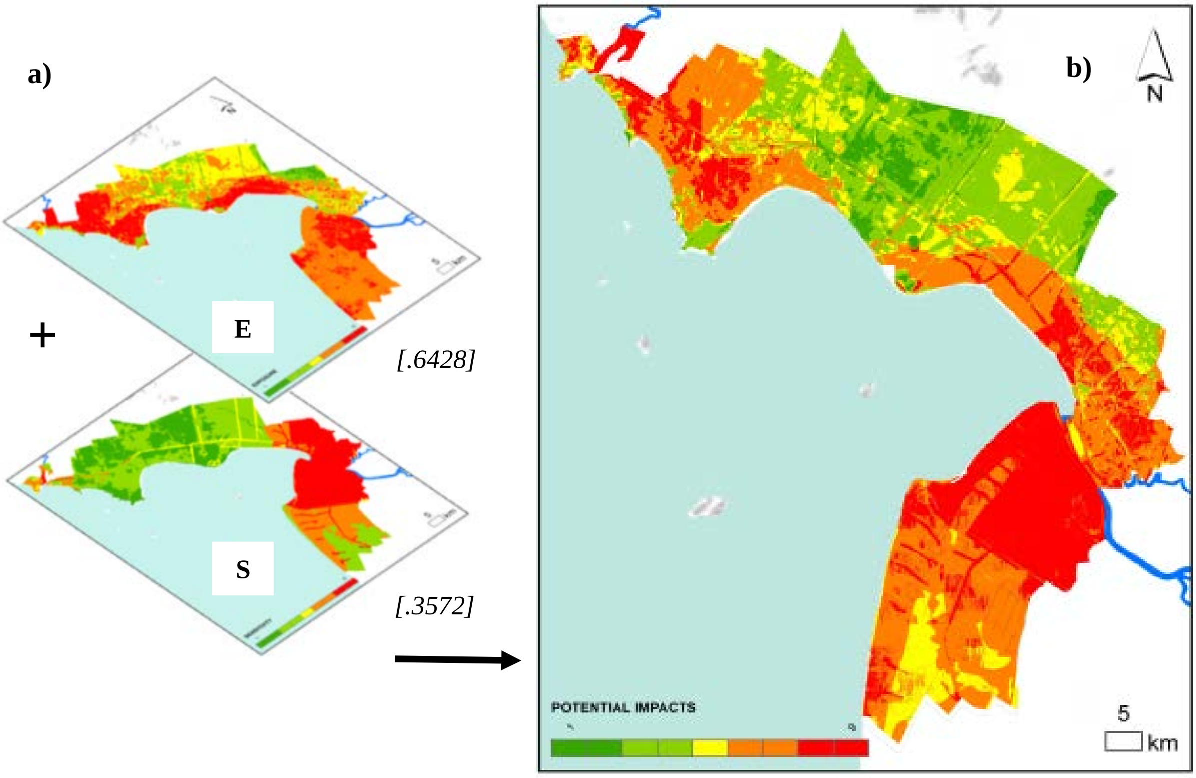


Figure 5.13 GIS-AHP mapping of potential impacts study: a) aggregate of reclassified components: exposure [E], and sensitivity [S]; and b) reclassified potential impacts [PI].

Note: As described in Figure 5.1. Numbers in brackets are presented together with sub-components indicating relative weights of those sub-components, obtained by AHP. As [E], and [S] presented in Figures 5.7c, and 5.11b, respectively.

Table 5.19 Proportions of the study area classed as very low to very high in representing potential impacts.

Coastal district	Potential impacts using AHP , % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6 - 7	Very high 8 – 9
An Bien	0.00	0.02	0.05	7.68	92.23
An Minh	0.00	0.13	19.37	62.60	17.90
Chau Thanh	0.03	12.55	13.70	49.74	23.98
Hon Dat	15.34	49.26	15.47	18.16	1.77
Ha Tien	0.25	7.16	14.19	25.35	53.05
Kien Luong	1.09	17.59	14.23	49.08	18.00
Rach Gia	1.36	21.68	10.51	27.70	38.76
7 districts	*5.7*	*22.49*	*13.64*	*34.02*	*24.15*

Note: See details of reclassifying values of results using Jenks in Figure 5.1.

Figure 5.13 shows that the map of the potential impacts is broadly similar to the exposure map. Table 5.19 indicates that a major proportion of area representing very high to high [PI] was 58% (~174 500 ha), whereas the remainder is either moderate of 13.64% (~40 924 ha), or low of 22.49% (~67 470 ha), and very low of only 5.7% (~17 110 ha). An Bien appeared to be the area having the largest proportion representing very high to high [PI] (99.91%, ~40 000 ha), while the least proportion was only 19.93% (~20 720 ha) in Hon Dat.

The weight value of the potential impacts study is summarised in equations as follows. The consistency ratios (CR) obtained were acceptable according to the procedures of Saaty (1980; 1994) (see Appendix 15).

$\mathbf{Layer_{PI}} = \mathbf{0.6428} * \text{layer}_E + \mathbf{0.3572} * \text{layer}_S$ **[Equation 5.3[14]]**

⇔ $\mathbf{Layer_{PI}} = 0.6428 * [0.5185 * \text{layer}_{SI} + 0.3975 * \text{layer}_{FR} + 0.0841 * \text{layer}_{SC}] + 0.3572 * [0.5625 * \text{layer}_{SF} + 0.4375 * \text{layer}_{LU}]$ **[Equation 5.3.1]**

⇔ $\mathbf{Layer_{PI}} = [0.3333 * \text{layer}_{SI} + 0.2555 * \text{layer}_{FR} + 0.0540 * \text{layer}_{SC}] + [0.2009 * \text{layer}_{SF} + 0.1563 * \text{layer}_{LU}]$ **[Equation 5.3.2]**

Note: Abbreviation of two components constituent to potential impacts, and relative weights of those components, obtained by AHP as presented in Figure 5.13. See details in Equations in sub-sections 5.3.5.1 for layer_E, and 5.4.4.1 for layer_S. See a summary of those relative weights in Appendix 15.

Similar to Equations presented in the previous sections, representing the exposure and sensitivity, the results in Equations 5.3 summarise the relative weights of two key layers of components: [E], and [S] obtained in order to represent the potential impacts [PI] (see Figure

[14] See Figure 5.13.

5.13). The results in Equations 5.3.1 and 5.3.2 indicate that the relative weight value of the mapping [PI] is a sum of the relative weights of layers of two components, comprising those of 3 layers sub-components: [SI], [FR], and [SC], in mapping [E], and those of 2 layers sub-components: [SF] and [LU], in mapping [S]. The exposure was considered to be more important than the sensitivity in order to represent potential impacts. The relative weight of [E] obtained by AHP, therefore, was 0.6428, whereas the relative weight of [S] was 0.3572.

5.5.3 Discussion

5.5.3.1 Coastal potential impacts study

This study was the first attempt to rigorously assess potential impacts at a local scale by using the Spatial Analyst tools and the analytical hierarchy process tool, extensions to ArcGIS. It considered the 11 sub-variables and 13 variables into 5 sub-components of 2 components, respectively that may influence the exposure, and sensitivity of the study area to the impacts of coastal hazards and sea-level rise. The large proportion representing very high to high [PI] (about 58%, ~174 500 ha) indicates the study area is expected to experience relatively high impacts. These include 24.15% of area (~74 000 ha) representing very high [PI], comprising 92.2% (~36 920 ha) in An Bien, 17.9% (~10 570 ha) in An Minh, 18% (~8 510 ha) in Kien Luong, 24% (~6 850 ha) in Chau Thanh, 53.1% (~5 280 ha) in Ha Tien, 38.8% (~4 000 ha) in Rach Gia, and only 1.8% (~1 840 ha) in Hon Dat, together with 34% (~97 000 ha) representing high [PI] (see Table 5.19). Figure 5.14 gives a summary of proportions of the study area representing very high to high exposure on the left hand side a), sensitivity in the middle b), and combined potential impacts on the right hand side c).

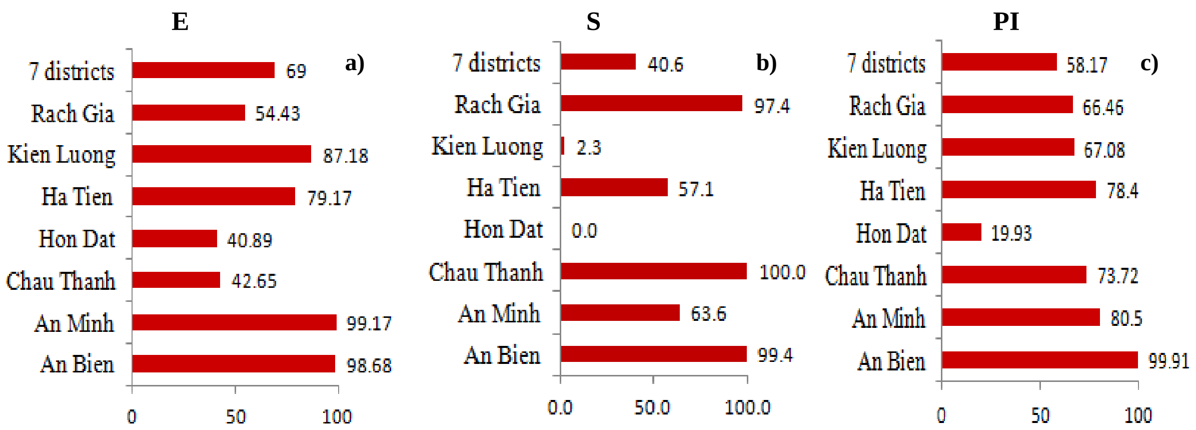
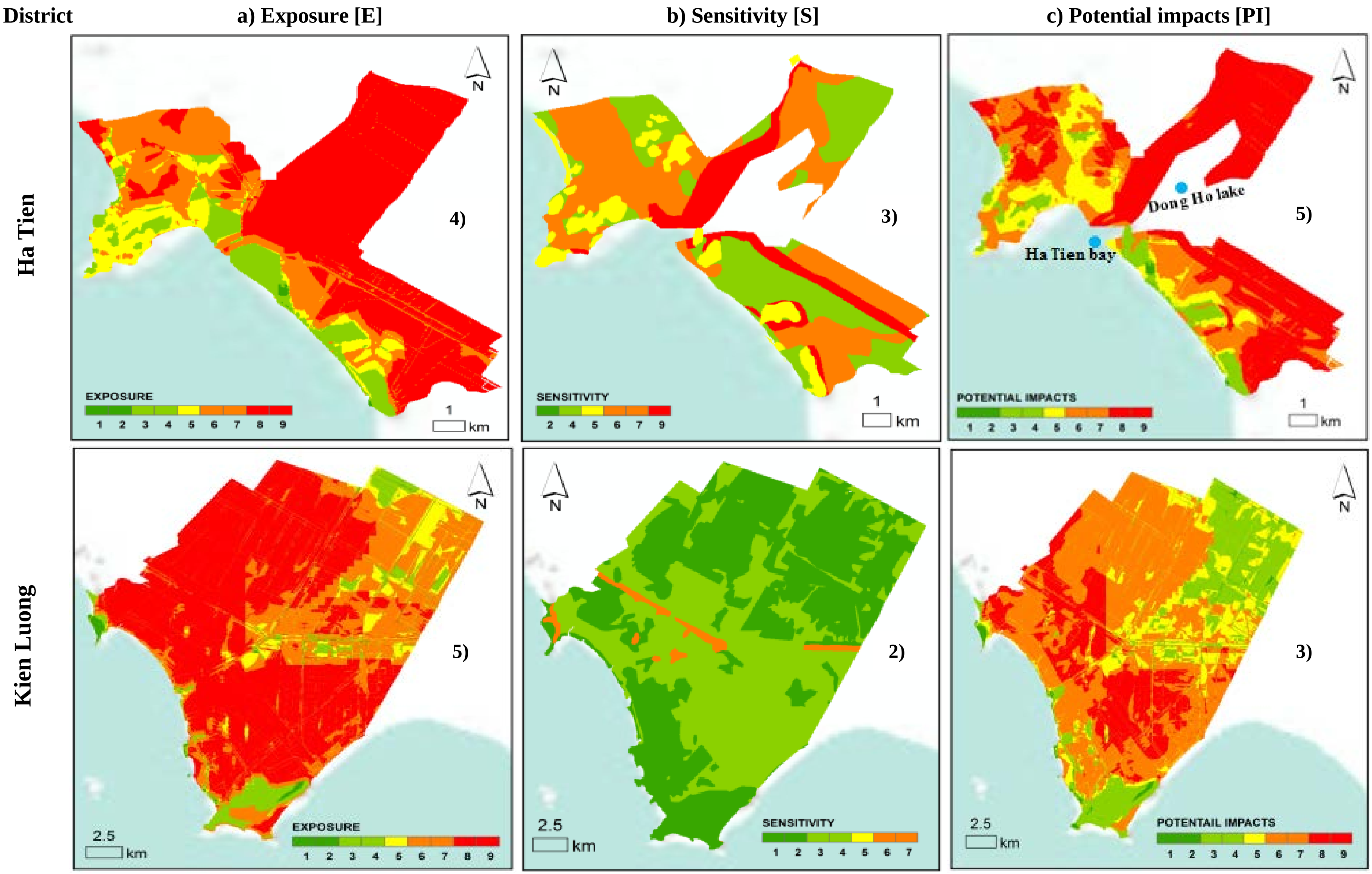


Figure 5.14 Proportions of the study area within seven districts indicating very high to high: in terms of a) exposure; b) sensitivity; and c) combined potential impacts.

Note: Exposure in a), sensitivity in b), and combined potential impacts in c) see Tables 5.11, 5.16, and 5.19, respectively.

As seen in Figure 5.14, An Minh (~99.2% of area), An Bien (~98.7%), and Kien Luong (~87.2%) appear to be characterised by very high to high exposure, while Chau Thanh (100%), An Bien (99.4%), and Rach Gia (97.4%) appear to have proportions indicating very high to high sensitivity. An Bien (~99.9%), An Minh (~80.5%), and Ha Tien (~78.4%) have the greatest proportion subject to very high to high potential impacts. Furthermore, aggregated rankings for each district, based on proportions of high to very high in measuring the exposure, sensitivity, and combined potential impacts, were summarised and illustrated in Figure 5.15. One discrepancy was the high potential impacts ranking for Ha Tien (ranked at 5). This was a result of aggregate of moderate exposure (ranked at 4), and relatively low sensitivity (ranked at 3) (see Appendix 14). It can therefore be concluded that overall aggregated rankings of potential impacts for seven coastal districts were from moderate (the least for Hon Dat) to high (for other districts) and very high (the highest for An Bien). Again, results in the exposure, sensitivity, and combined potential impacts obtained (% of area) are shown by Jenks, and they are relative values, but they are realistic and appear meaningful. Those areas identified and visualised as at risk reflect patterns in the landscape relatively representing [E], [S], and [PI] and the maps may be useful to make decisions.

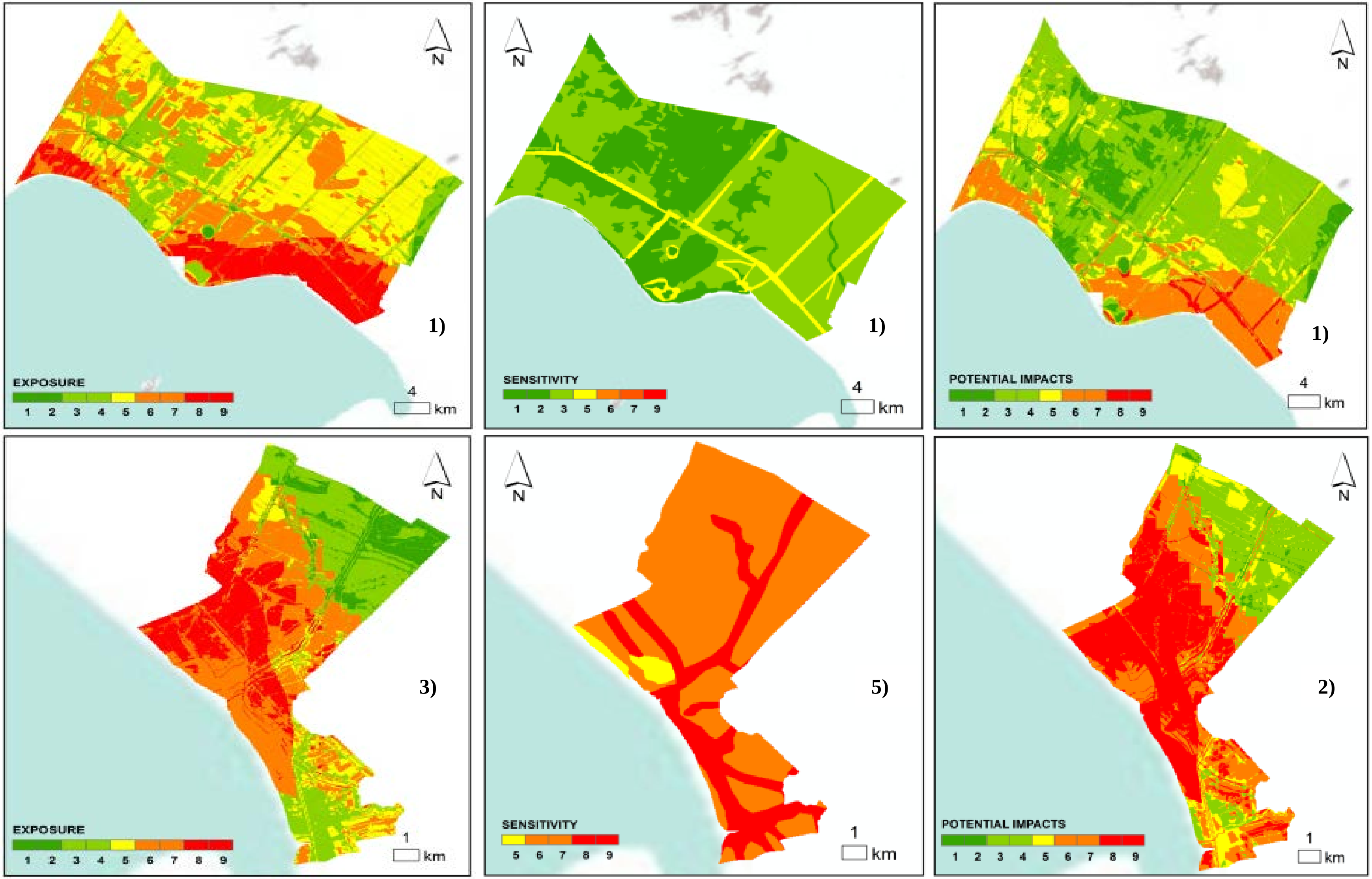
Figure 5.15 visualises maps obtained using AHP for exposure in a), sensitivity in b), and combined potential impacts in c) for each of the seven coastal district respectively, extracted from the maps of exposure, sensitivity, and potential impacts levels for the study area. An Minh and An Bien are the areas regarded as most exposed, though some sections of their shorelines are less so (i.e., they are accreting). There is more variability in the maps of the sensitivity. Several sensitivity maps, such as Chau Thanh and An Bien, appear almost entirely red because of availability of societal data only at entire district, whereas in other districts this is a function of landuse (e.g., roads are shaded orange in Kien Luong, shaded yellow in Hon Dat, and shaded red in An Minh; or settlement areas parallel roads shaded red in Rach Gia, and Ha Tien). These maps give policy makers or planners, especially local authorities (at provincial, or district level), and communities, a generalised overview of potential impacts of climate change, which areas or patterns are likely to be most at risk, related to seawater incursion, flood risk, shoreline erosion and human effects.


District
a) Exposure [E]
b) Sensitivity [S]
c) Potential impacts [PI]
Ha Tien
Kien Luong
N
4)
3)
5)
2)
Dong Ho lake
Ha Tien bay
EXPOSURE
SENSITIVITY
POTENTIAL IMPACTS
POTENTAIL IMPACTS
1 2 3 4 5 6 7 8 9
2 4 5 6 7 9
1 2 3 4 5 6 7
1 km
2.5 km

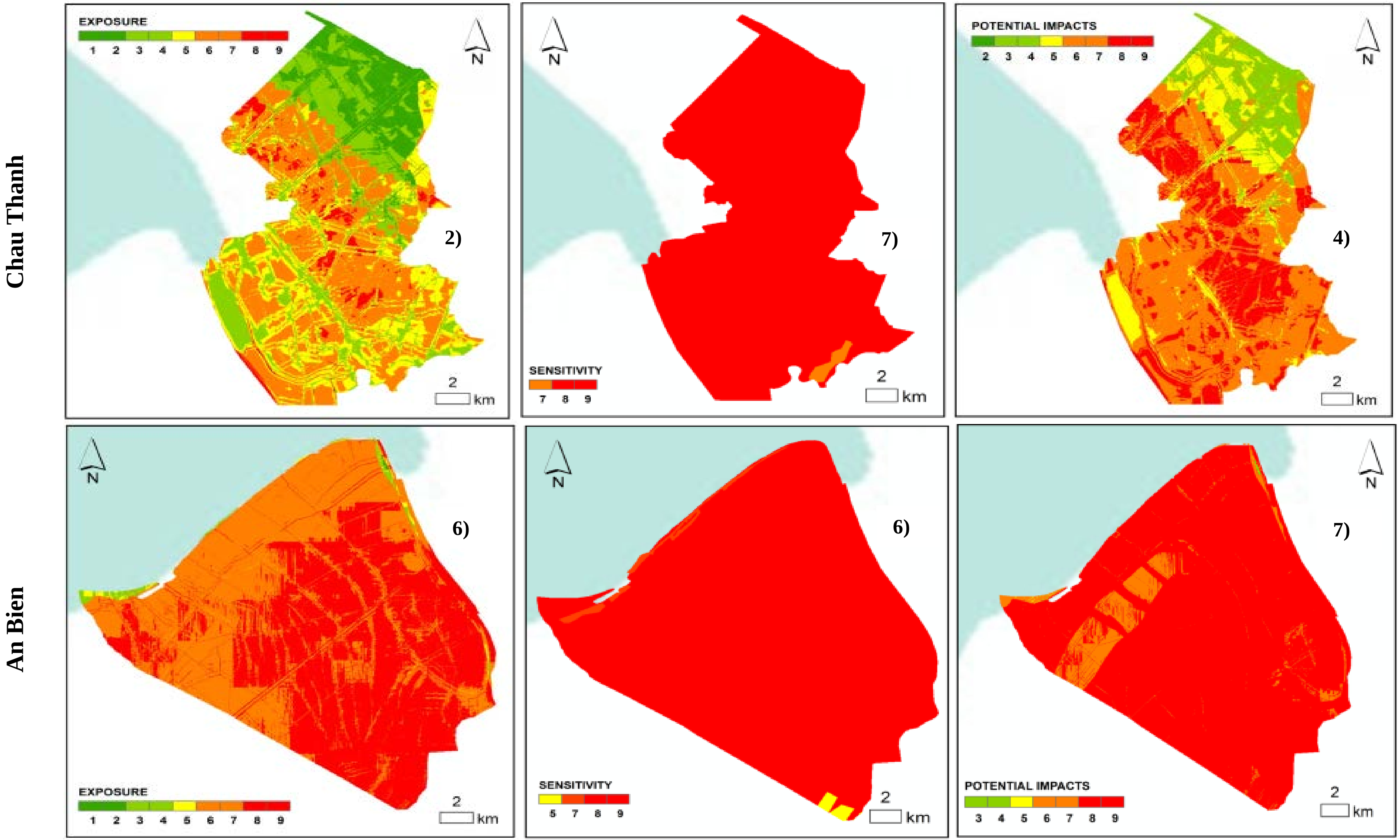
District | **a) Exposure [E]** | **b) Sensitivity [S]** | **c) Potential impacts [PI]**

Hon Dat

Rach Gia



District **a) Exposure [E]** **b) Sensitivity [S]** **c) Potential impacts [PI]**



District **a) Exposure [E]** **b) Sensitivity [S]** **c) Potential impacts [PI]**

An Minh

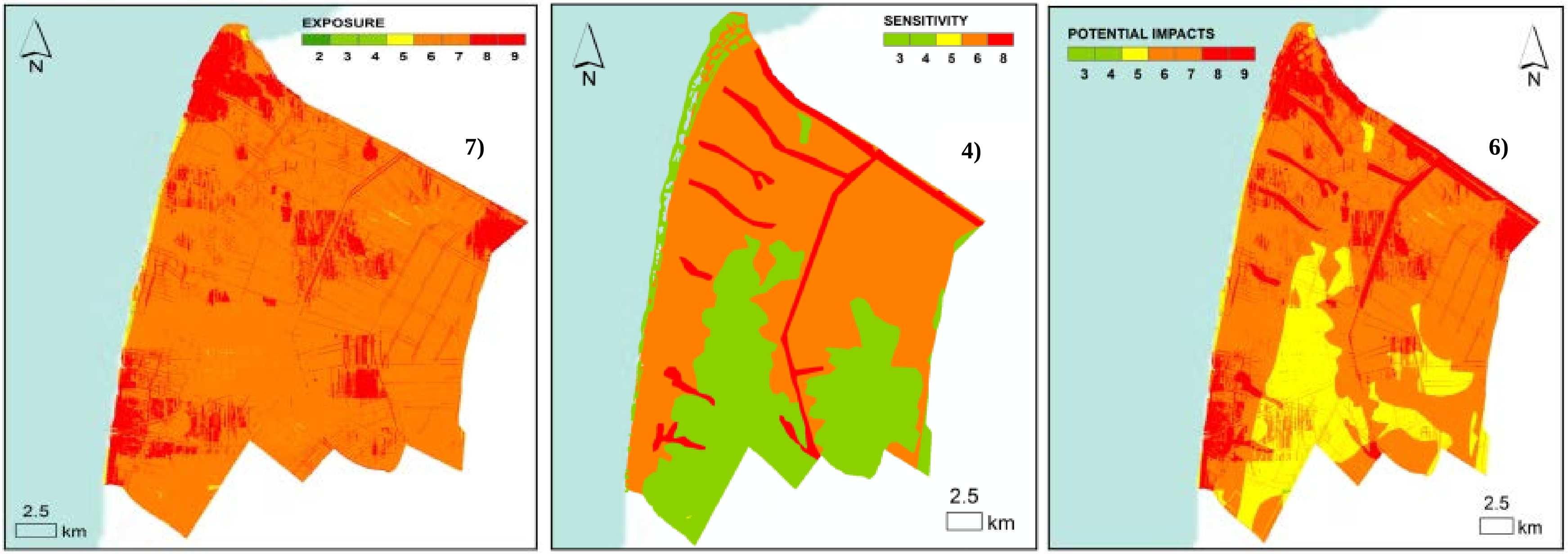


Figure 5.15 GIS-AHP mapping of: a) exposure[15], b) sensitivity[16], and c) combined potential impacts[17] for each district, comprising Ha Tien, Kien Luong, Hon Dat, Rach Gia, Chau Thanh, An Bien, and An Minh.

Note: Numbers are in each map that indicating overall aggregated rankings of each coastal district in representing exposure, sensitivity, and potential impacts, respectively.

[15] Extracted from the exposure map in Figure 5.7c.
[16] Extracted from the sensitivity map in Figure 5.11b.
[17] Extracted from the potential impacts map in Figure 5.13b.

In summary, pair-wise comparisons between exposure, and sensitivity were undertaken in order to represent the potential impacts for the study area. The relative weight of exposure was 0.6428, while the relative weight of sensitivity was 0.3572 (see a summary in Appendix 15). Although the assessment met the consistency criteria used in AHP; however, it is important to bear in mind that their possible subjective nature of some of the judgements can influence the outcomes.

5.5.3.2 Evaluation of potential impacts outcome

A comparison was undertaken to illustrate how more detail societal data might provide improved outcomes. Figure 5.16 presents GIS-AHP mapping of potential impacts for the study area. In Figure 5.16, the left hand side a) shows the map of [PI] obtained for an entire district level, whereas the right hand side b) displays the map of those within district level. The [PI] was reclassified into 9 categories by using Jenks, mapped into 5 levels from very low to very high, shaded as for [PI], with proportions reported in Table 5.20.

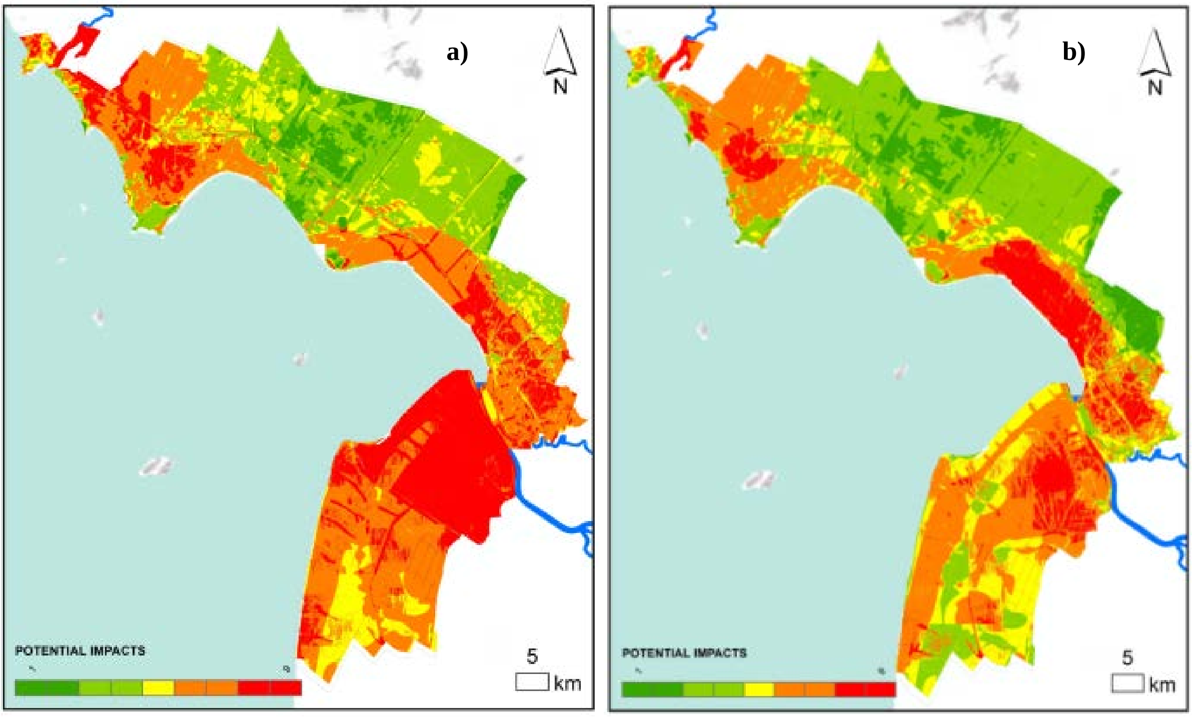


Figure 5.16 GIS-AHP mapping of potential impacts outcomes: a) potential impacts for an entire district level[18]; and b) potential impacts within district level[19].

Note: Potential impacts for the study area in a) as presented in Figure 5.13b; and evaluated potential impacts outcome in b) see Appendix 18.

[18] The map of potential impacts for an entire district level. As see Figure 5.13b.
[19] The map of potential impacts within district level. As see Appendix 18.

Table 5.20 A comparison of proportions of the study area classed as very low to very high in representing potential impacts outcomes.

Coastal district	Potential impacts using AHP, respectively , % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6 - 7	Very high 8 – 9
[PI] in a)[18]	5.7	22.49	13.64	34.02	24.15
[PI] in b)[19]	8.36	29.5	16.67	33.22	12.26

Note: Potential impacts for the study area in a) as presented in Table 5.19.

As seen in Table 5.20, a large proportion of area representing very high to high potential impacts was 58% (~174 500 ha) in a), while a lesser proportion was 45.5% (~129 710 ha) in b). There was also a marked reduction of proportion, particularly in representing very high potential impacts from 24.15% (~73 980 ha) in a) to only 12.26% (~34 970 ha) in b). Therefore, different scale-based approaches of input data can produce different outcomes. Interestingly, the map of potential impacts within district level (see Figure 5.16b) shows a pattern similar to the map of sensitivity using finer scale input data for the population density variable (see Figures 5.12). It also seems that areas shaded red seem to be coastal settlements considered as most likely at risk under very high potential impacts as other areas. A finer scale such as a settlement scale for the coastal vulnerability assessment needs to be explored further, and will be described in the next chapter, sub-section 6.4.3.4.

It can therefore be concluded that the study area is relatively highly exposed to potential impacts with a large proportion of area representing very high to high potential impacts obtained from different scale-based approaches. However, it is important to keep in mind that in view of the weighting methods, the outcomes representing very high potential impacts (hotspots or areas) depend on subjective judgements. All of these numbers are of course relative, characterised by specific sites. By changing thresholds (classification for variables, see chapter 5 Table 5.1), or priorities of variables in pair-wise comparisons (see chapter 5, sub-section 5.3.5.2), or reclassification for sub-components, exposure and sensitivity components by using Jenks, scaled from a fundamental range of 1 to 9 into 5 levels), different values would result. Furthermore, scale-based approaches can influence the outcomes somewhat (see chapter 5, sub-section 5.4.4.2, and chapter 6, sub-sections 6.3.5.2, and 6.4.3.2). The map of potential impacts levels shown in Figure 5.16, when augmented with supporting text, can offer an overview of nature, human impacts, and the extent of problems that are likely to result from a relative rise in sea level along the coast.

5.6 Summary of this chapter

This chapter aimed to examine potential impacts comprising exposure to seawater incursion, flood risk, shoreline erosion caused by climate change, particularly sea-level rise, as well as sensitivity because of human effects in the study area. It did this by the aggregation of eleven sub-variables, and thirteen variables into five sub-components of two components, exposure, and sensitivity (see Table 5.1), using GIS and AHP.

Each variable was classified into a range from 1 up to 9 (maximum), where applicable and mapped at a scale of one to five, where level one was for very low exposure and sensitivity, and level five was for very high exposure and sensitivity. The level for each variable was assigned within integer raster pixels using three criteria. First, weighted values from pair-wise comparison obtained for each raster variable using AHP. Second, break values for each sub-component, and two key components exposure and sensitivity were used, reclassified into 9 classes. Third, each variable was scaled into 5 levels, level one shaded red, while level 5 shaded dark green. This enabled identification and prioritisation of the hotspots or areas of the study area that have the most potential to be affected, related to seawater incursion, flood risk, shoreline erosion, exacerbated by relative sea-level rise, as well as human factors.

The results from coastal exposure showed that the study area is expected to be relatively highly exposed to seawater incursion, flood risk, and shoreline change with approximately 69% of area representing very high to high exposure. An Minh appears to have the greatest exposure, due to the considerable threat of seawater incursion, although it is the least exposed to flood risk, and experiences accretion along some of the coast. Hon Dat appears to be the least exposed due to the least exposure to seawater incursion, although it is exposed to flooding, and had the highest rates of erosion.

AHP is a multi-criteria decision making method, combining quantitative and qualitative data that is based on pair-wise comparisons. It allows decision makers to select the best alternative within feasible alternatives under diverse priorities. The change in priorities of variables was also undertaken to indicate that this can somewhat influence the outcomes, although AHP allows a check for inconsistency in subjective judgments after the method followed by Saaty (1980; 1994) (see sub-section 5.3.5.2).

Due to limitations of data available in representing societal factors, most available only at an entire district level, it has not enabled identification of spatial variations in human sensitivity for the study area. The study area is expected to be moderate sensitivity with nearly 41% of area representing very high to high sensitive. However, input data of societal factors obtained, might be changeable over time, thus, this can influence the map of sensitivity. Additionally, different scale-based approaches of input data have been undertaken that indicate their influence on the outcomes (see sub-section 5.4.4.2). This is meant to help coastal managers, policy makers, and scientists in identifying the scale-based approach characteristics most suitable for the coastal assessment to be undertaken. Coastal settlements are possibly most at risk under very high potential impacts and may require further coastal vulnerability assessments.

In summary, taken together the results from aggregating the first two components, exposure and sensitivity, showed that a large proportion of area has very high to high potential impacts (58%). An Bien appears the area the most likely to experience potential impacts, while Hon Dat appears the area with the least potential impacts. Due to changing social factors input data over time and space, sensitivity outcomes obtained have changed, thus the potential impacts outcomes can be influenced. Despite these, the maps and data presented in this study can provide an indication of the geographical pattern of physical changes most likely to occur as sea level continues to rise. It provides a preliminary tool for coastal managers to undertake more site-specific assessments at the most threatened hotspots or areas densely populated, generally with a large rural population and high numbers of ethnic households with limited availability of agricultural land. The next chapter will examine adaptive capacity that aims to assess the ability to manage the potential impacts. The adaptive capacity will be combined with the potential impacts to provide an assessment of the final coastal vulnerability for the study area.

Chapter Six

Adaptive capacity component and coastal vulnerability assessment

6.1 Aims of this chapter

The aim of this chapter is to assess the vulnerability levels of the study area. This involved an examination of the ability of policy makers or communities to manage potential impacts. As mentioned in chapter 5, results of exposure and sensitivity were used in the aggregate of the potential impacts. The chapter is structured as follows. Section 6.2 introduces several steps involved in representing the vulnerability levels. Sub-sections 6.3.1 to 6.3.5 present and discuss the mapping of the adaptive capacity component by aggregating three sub-components, comprising socioeconomic, technological, and infrastructure capabilities. The output was scaled to a range of five levels, namely: very low, low, moderate, high, and very high, based on their ability to manage, in which an area of very low adaptive capacity can scarcely reduce the impacts, and remains vulnerable. Sub-sections 6.4.1, and 6.4.2 present mapping of the vulnerability levels by aggregating the three key components: exposure, sensitivity, and adaptive capacity. The final vulnerability map indicates hotspots, and areas together with *"who, and what"* is most likely to be vulnerable. A system is anticipated to be vulnerable if it is highly exposed, and sensitive to the impacts, and has a low capability to cope with those impacts. Sub-section 6.4.3 discusses mapping of the vulnerability levels. The results to be presented include the final coastal vulnerability study in sub-section 6.4.3.1, and evaluating vulnerability outcomes obtained according to scale-based approaches of input data in sub-section 6.4.3.2. Sub-section 6.4.3.3 presents ArcGIS ModelBuilders with weighted overlay applied to mapping the vulnerability levels, and compared to maps of the final vulnerability obtained, using AHP. Sub-section 6.4.3.4 presents analyses of the coastal vulnerability at a settlement scale. A summary of this chapter is presented in section 6.5.

6.2 Introduction

Vulnerability based on the definition proposed by IPCC AR4 (2007), is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. It highlights the fact that the first two components, exposure and sensitivity, dictate the potential of a system or process to be affected by impacts; whereas

the third, adaptive capacity, refers to the ability of the system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. As mentioned in chapter 3, it involves several steps in order to estimate the vulnerability levels for the study area. These include:

- Organise the hierarchical structure from thirteen sub-variables into nine variables used in three sub-components of the adaptive capacity component (see Figure 3.3).
- Classify these sub-variables and variables prior to their aggregation (see Table 3.14).
- Reclassify these sub-components to be used in the aggregate adaptive capacity component.
- Reclassify the adaptive capacity component to be used in the aggregation of the three key components (E, S, and A) for generating a final map of coastal vulnerability. This involved pair-wise comparisons of sub-variables, variables, sub-components, and components, following the fundamental AHP rule scale, originally developed by Saaty (1980). Simultaneously, relative weights of these variables, sub-components, and components were obtained, based on their initial prioritisations.

6.3 Adaptive capacity component

Adaptive capacity incorporates the system's potential to adjust to climate variations, including the ability to learn from experience or information, and hence to reduce somewhat its sensitivity. Estimates of adaptive capacity, therefore, enable policy makers and other stakeholders, such as farmers, to adopt suitable strategies in order to enhance the adaptive capacity or resilience of the system to respond to the impacts of climate change. Actions related to building adaptive capacity may involve using climate change knowledge, building awareness of potential impacts, maintaining well-being, protecting property or land, or maintaining economic growth (Adger et al., 2005). "*Who, and what*" with appropriate adaptive capacity information, thus, were used to represent the adaptive capacity. The adaptive capacity component, as used here, refers to three sub-components: socioeconomic, technological, and infrastructure capability.

The socioeconomic sub-component, in terms of representing the adaptive capacity component, was judged to have a very high effect on managing impacts, therefore, being able to reduce the vulnerability. The socioeconomic sub-component was considered the most important and assigned a priority of [9]. This was followed by the technological sub-component, because it has relatively strong effects on managing impacts, and assigned was a

priority of [5.4]. The least was the infrastructure sub-component, considered similar to the technological sub-component, and assigned a priority of [5]. Reasons include:

- Socioeconomic capability prepares a society to better cope with the impacts, reflecting a greater level of development in any society, in terms of income, quality of education, and health services, etc.
- Technological capability, as used here, refers to the capacities of irrigation and drainage, and electricity, while infrastructure capability refers to the capacities of road, communication access, and households having solid houses in order to cope with the impacts. These capabilities play crucial roles in development; however, livelihoods of most local people rely on agricultural activities. Therefore, from an agricultural viewpoint, the technological sub-component is considered slightly more important than the infrastructure sub-component.

Table 6.1 summarises adaptive capacity variables together with the relative directions of their effects on potential impacts, which is described in detail in Table 3.14. The arrows indicate the direction of effects of adaptive capacity variables on the impacts (i.e., higher income can reduce impacts (↓) because people can afford to take action, while a higher poverty ratio may increase impacts (↑)).

Table 6.1 Adaptive capacity component, and the direction of its effects on the impact in this study.

No	Component/ sub-component/ Variable	The direction of the effects on the impacts	No	Component/ sub-component/ Variable	The direction of the effects on the impacts
A	**Adaptive capacity**				
A1	*Socioeconomic capability*		A2	*Technological capability*	
	Income, GDP/capita	↓		Irrigation & drainage capability	↓
	Education	↓		Canal capability	↓
	Pupils/ primary & secondary school	↓		Sea dyke capability	↓
	Pupils/ teacher at primary & secondary school	↑		River density	↑
	Kids/ kindergarten	↓		River embankment capability	↓
	Kids/ teacher at kindergarten	↑		Sluice gate density	↓
	Health services	↓		Electricity density	↓
	Inhabitants/ establishment	↑		Voltage power line density	↓
	Inhabitants/ health staff	↑		Transformer station density	↓
	Poverty ratio, %	↑			
A3	*Infrastructure capability*				
	% household having solid house	↓			
	Road density (radius)	↓			
	Inhabitants/ fixed-line telephone subscriber	↑			

Note: An arrow (↑) indicates the ability to increase the impacts; an arrow (↓) indicates the ability to reduce the impacts.

6.3.1 Mapping the socioeconomic sub-component

The socioeconomic sub-component, as used here, refers to the aggregate of four variables. They include income, poverty ratio, health services and education system. However, these variables were obtained using statistical datasets at an entire district level. Objectives of this sub-section are two-fold. The first objective is to evaluate socioeconomic capability for the study area. The second objective is to aggregate these sub-components for use in the adaptive capacity. A map showing the socioeconomic sub-component for the study area is presented in Figure 6.1c. This sub-component map was reclassified into 9 categories by using Jenks, and mapped using 5 levels from very low to very high, shaded as for the sub-component, with proportions of the study area reported in Table 6.2. Relative weights of sub-variables, and variables of the aggregate using AHP, were obtained simultaneously (see Appendices 19a).

6.3.1.1 Overview

According to the Kien Giang district Survey 2011, the average income for the study area (at US$ 949) was slightly lower than the income for the entire province (at US$ 972). However, only 6.6% of the households in the study area fall into this category considered poor compared to the poverty ratio for the entire province (at 7.2%). Furthermore, based on statistical datasets obtained from the Kien Giang Statistical Office 2012, education and health care services in the study area were slightly improved, compared with the entire province (see greater detail in chapter 4, sub-section 4.5.3.4). In terms of representing the sub-component, the income variable was thus considered the most important. This was followed by the education system variable, and then by the health services variable, whereas the least important variable was the poverty ratio.

6.3.1.2 Aggregation of the socioeconomic sub-component

Figure 6.1 presents GIS-AHP mapping of the socioeconomic sub-component. Figure 6.1a presents six classified sub-variables, comprising four layers, namely pupils per primary and secondary school, and per teacher, together with kids per kindergarten, and per teacher. These were used in the aggregate of the education variable, and two layers of inhabitants per health establishment, and per health staff were used in the aggregate of the health services variable. Pupils per primary and secondary school was considered the most important sub-variable, in terms of representing the education variable. This was followed by pupils per teacher at primary and secondary school, and then by kids per kindergarten. The least important sub-variable was the kids per teacher at kindergarten. On the other hand, the inhabitants per health

establishment sub-variable was considered more important than the inhabitants per health staff, in terms of representing the health services variable. Figure 6.1b presents four classified variables, comprising income, education, health services, and poverty ratio used in the aggregate of the socioeconomic sub-component, whereas a map of aggregated socioeconomic adaptive capacity levels is shown in Figure 6.1c.

In Figure 6.1, the middle b) shows An Minh to be the least able to adapt to reduce potential impacts, while Rach Gia appears the most adaptable in terms of income capability [in]. This reflects the greater wealth in the urban area but mapping is limited, because input data is only available at entire district level (see Appendix 19a.3). Ha Tien, Hon Dat, and An Minh appear to have the lowest capabilities, while An Bien appears the highest in terms of education capability [ed] (see Appendix 19a.1). Ha Tien and An Minh appear to have the lowest capabilities, while Rach Gia appears the highest in terms of health services capability [he] (see Appendix 19a.2). An Minh, An Bien, and Chau Thanh have the highest poverty ratios [po], while Kien Luong appears the lowest (see Appendix 19a.3). As a result, the right hand side c) shows that Hon Dat and An Minh appeared areas the least adaptable to manage potential impacts, whereas Rach Gia appears the most adaptable, in representing the socioeconomic sub-component.

Table 6.2 gives a summary of overall aggregated rankings from the four variables: income, education, health services, and poverty ratio, obtained from the socioeconomic sub-component for each district.

Table 6.2 Overall aggregated rankings from four variables: income, education, health, and poverty ratio in representing the socioeconomic sub-component for each district.

Rank	Income	Education	Health	Poverty ratio	*Socioeconomic*
1	Rach Gia	An Bien	Rach Gia	Kien Luong	*Rach Gia*
2	Ha Tien	Rach Gia	Chau Thanh	Rach Gia	*Kien Luong*
3	Kien Luong	Chau Thanh	An Bien	Ha Tien	*An Bien*
4	Hon Dat	Kien Luong	Kien Luong	Hon Dat	*Ha Tien*
5	Chau Thanh	Ha Tien	Hon Dat	Chau Thanh	*Chau Thanh*
6	An Bien	Hon Dat	Ha Tien	An Minh	*Hon Dat*
7	**An Minh**	**An Minh**	**An Minh**	**An Bien**	***An Minh***

Note: A value of 7 indicates the least rank within seven districts, while a value of 1 indicates the highest rank in representing the socioeconomic sub-component; The colour indicates districts adaptability to the impacts, with red, yellow, and green colours in representing low, moderate, and high adaptability, respectively.

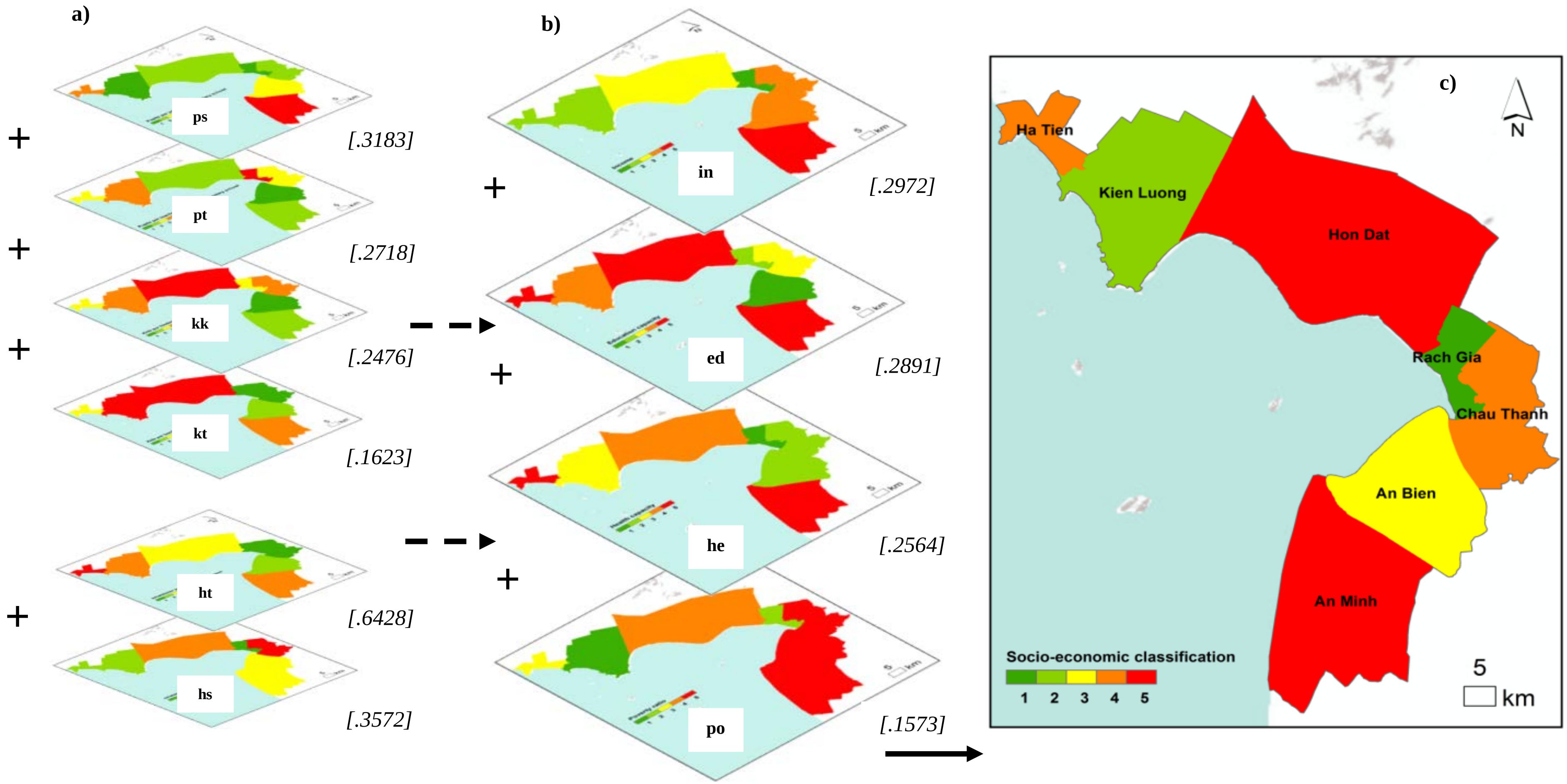


Figure 6.1 GIS-AHP mapping of the socioeconomic sub-component: a) aggregate of classified sub-variables: pupils per primary and secondary school [ps], and per teacher [pt], kids per kindergarten [kk], and per teacher [kt], inhabitants per health establishment [ht], and per health staff [hs]; b) aggregate of classified variables: income [in], education [ed], health [he], and poverty [po]; and c) reclassified socioeconomic sub-component .

Note: The sub-component was reclassified in a range of 1 – 5 by using Jenks: a value of 1 representing very high adaptability as indicated by shaded dark green; a value of 2 representing high adaptability as indicated by shaded green; a value of 3 representing moderate adaptability as indicated by shaded yellow; a value of 4 representing low adaptability as indicated by shaded orange; and finally, a value of 5 representing very low adaptability as indicated by shaded red. Numbers in square brackets are presented together with sub-variables, and variables indicating relative weights of those sub-variables, and variables, simultaneously obtained by AHP.

Table 6.2 shows that An Minh appears the least adaptable (ranked at 7) because of the lowest value of income (698 $US/capita, in a range up to 1 480), the lowest capabilities of education and health services, and the second highest poverty ratio (ranked at 6; 13%, in a range of 1 - 15%, ~15 106 poor people; see Appendix 9d.1). Hon Dat appears the second lowest adaptable (ranked at 6) because of a moderate value of income (808 $US/capita, in a range of 698 - 1 480), the second lowest capability of education, the third lowest capability of health services, and the fourth highest value of the poverty ratio (6%, ~10 345 poor people). On the other hand, Rach Gia appeared the most adaptable to the impacts (ranked at 1) because of the highest value of income (1 480 $US/capita), the second highest capability of education, the highest capability of health services, and the second lowest value of the poverty ratio (only 2%, ~4 687 poor people). Urban population is definitely better able to adapt than rural population.

The weight value of the socioeconomic sub-component obtained is summarised in equations as follows. The consistency ratios (CR) were acceptable in the way demonstrated by Saaty (1980; 1994). The results in Equations 6.1 summarise relative weights of four layers assigning four variables [in], [ed], [he], and [po] obtained in this analysis (see Figure 6.1c). Moreover, the results in Equations 6.1.1 and 6.1.2 show relative weights of the layer of [in], relative weights of four layers sub-variables: [ps], [pt], [kk], and [kt] in mapping [ed], relative weights of two [ht], and [hs] in mapping [he], and the layer of [po], which were aggregated to obtain the relative weight of [SO].

$$\textbf{Layer}_{SO} = 0.2972 * layer_{in} + 0.2891 * layer_{ed} + 0.2564 * layer_{he} + 0.1573 * layer_{po}$$

[Equation 6.1[20]]

$$\Leftrightarrow \textbf{Layer}_{SO} = 0.2972 * layer_{in} + 0.2891 * [0.3183 * layer_{ps} + 0.2718 * layer_{pt} + 0.2476 * layer_{kk} + 0.1623 * layer_{kt}] + 0.2564 * [0.6428 * layer_{ht} + 0.3572 * layer_{hs}] + 0.1573 * layer_{po}$$

[Equation 6.1.1[21]]

$$\Leftrightarrow \textbf{Layer}_{SO} = 0.2972 * layer_{in} + [0.0920 * layer_{ps} + 0.0786 * layer_{pt} + 0.0716 * layer_{kk} + 0.0469 * layer_{kt}] + [0.1648 * layer_{ht} + 0.0916 * layer_{hs}] + 0.1573 * layer_{po}$$

[Equation 6.1.2]

Note: Abbreviation of sub-variables, and variables constituent to the socioeconomic sub-component, and relative weights of those sub-variables, and variables, obtained by AHP as presented in Figure 6.1. See a summary of those relative weights in Appendix 21.

[20] See Figure 6.1b.
[21] See Figure 6.1a, b.

As mentioned in the previous chapter, these equations have captured subjective judgements using AHP and GIS in the analysis into objective mathematics. The [in] is considered as the highest priority (its relative value obtained as 0.2972). This is followed by [ed] (0.2891), and then by [he] (0.2564). The least is [po] (0.1573). These relative values also may be useful to give a general idea for local authorities to set priorities or design response actions to climate change, particularly sea-level rise, within limitations of budget capacity.

6.3.2 Mapping the technological sub-component

The technological sub-component, as used here, involves the interaction between two variables: irrigation and drainage capabilities, and electricity capability. As mentioned in chapter 4, the Vietnamese Government puts special emphasis on rural production (both for export and national food security) and undertakes high investments for double or triple rice cropping particularly in the country's deltas and coastal plains. Therefore, water resources management in Vietnam is, to date, under strict state control and irrigation constitutes the dominant concern. Therefore, the irrigation and drainage capability variable was considered more important than the electricity capability variable, in representing the sub-component. The objectives of this sub-section are two-fold. The first objective is to evaluate the technological capability for the study area. The second objective is to aggregate these sub-components for use in the adaptive capacity. A map showing the technological adaptive capacity levels for the study area is presented in Figure 6.4. The sub-component map was reclassified into 9 categories by using Jenks, and mapping into 5 levels from very low to very high, shaded as for the sub-component, with proportions of the study area reported in Table 6.5. Relative weights of variables of the aggregate using AHP, were obtained simultaneously (see Appendices 19c.3 and 21).

6.3.2.1 Irrigation and drainage capability variable

The irrigation and drainage network, as used here, refers to facilities for taking advantage of water resources, mainly in agricultural and aquaculture activities in the study area that most local people rely heavily on. These comprise: canals, sea dykes, rivers, river embankments, and sluice gates. The agricultural output, particularly rice production, is markedly aided by the expansion and increased density of the irrigation and drainage. Furthermore, the development of an extensive irrigation network has made water available particularly in the dry season. The irrigation and drainage capability variable for the study area was based on a map of the irrigation and drainage network obtained from the database of the SIWRP (2010)

(chapter 4, Appendix 9d.3). A Kernel function was used to calculate the magnitude per unit area (searching within a radius of 5km) from point features, (i.e., from sluice gates) or polyline features, (i.e., from canals, or sea dykes), in order to concentrate on areas, which can be short of irrigation and drainage capability and can thus, find it difficult to adapt.

Figure 6.2a presents five maps of the sub-variables, capabilities of canals, sea dykes, rivers, river embankments, and sluice gates, respectively, used in the aggregate of the irrigation and drainage variable (see details in Appendix 19c.1). The canal capability sub-variable was considered the most important, followed by sea dyke capability, river capability, and river embankments capability sub-variables. The least important sub-variable was the sluice gate capability. As a result, a map of irrigation and drainage capability variable is shown in Figure 6.2b. Relative weights of sub-variables of aggregate using AHP, were obtained simultaneously (see Appendices 19c.1 and 21).

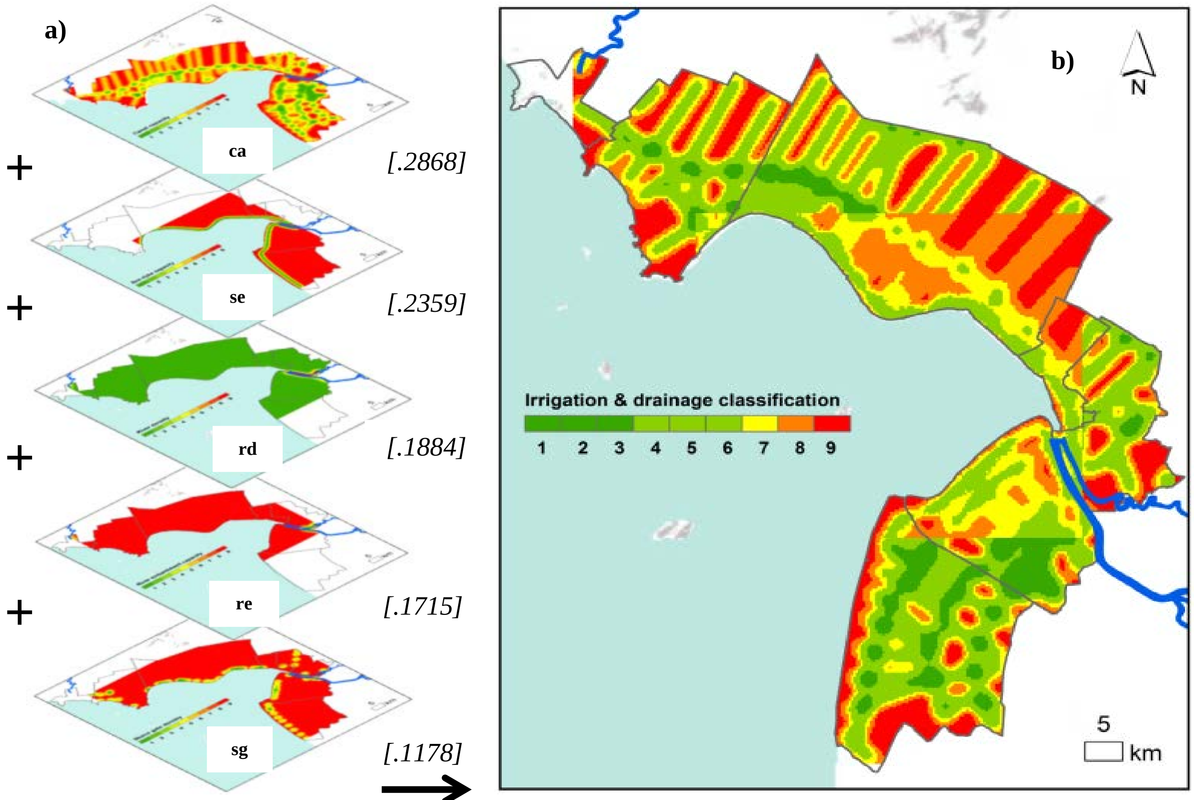


Figure 6.2 GIS-AHP mapping of irrigation and drainage capability study: a) aggregate of sub-variables: canal capability [ca], sea dyke capability [se], river density [ri], river embankment capability [re], and sluice gate capability [sg]; and b) reclassified irrigation and drainage variable [id].

Note: As described in Figure 6.1. Numbers in square brackets are presented together with sub-variables indicating relative weights of those sub-variables, simultaneously obtained by AHP. Data on the irrigation and drainage capability variable was unavailable for half the area of Ha Tien.

The map of irrigation and drainage capability on the right hand side b) of Figure 6.2 seems to reflect the map of canal capability on the left hand side a). This result may be explained by the fact that canal capability was considered the most important sub-variable, compared to other sub-variables in representing irrigation and drainage capability. In fact, the canal system in the study area combines an old, well-known and significant, Vinh Te Canal with a series of complicated 20-year canals (see chapter 4, sub-section 4.5.3.6a).

Table 6.3 gives a summary of proportions of the study area obtained from the irrigation and drainage capability variable. The results of the irrigation and drainage capability showed that 37.7% of area (~113 100 ha) is low to very low in terms of adaptability to manage the impacts, due to much shortage of irrigation and drainage network, while the majority of area was either high capability (34.7%, ~104 100 ha) or moderate capability (19.6%, ~58 800 ha).

Table 6.3 Proportions of the study area classed as very high to very low adaptability in terms of irrigation and drainage capability.

Coastal district	Irrigation and drainage capability using AHP, % of area				
	Very high 1 - 3	High 4 - 6	Moderate 7	Low 8	Very low 9
An Bien	15.3	32.1	30.9	17.5	4.2
An Minh	18.0	42.6	12.1	11.5	15.8
Chau Thanh	3.5	43.4	17.6	15.8	19.7
Hon Dat	3.6	29.2	20.8	29.2	17.2
Ha Tien*	0.1	24.0	18.2	19.3	38.4
Kien Luong	4.6	36.3	18.7	18.0	22.4
Rach Gia	0.3	33.3	21.1	25.2	20.1
7 districts	*8.1*	*34.7*	*19.6*	*20.6*	*17.1*

Note: The irrigation and drainage capability variable was reclassified in a range of 1 – 9 by using Jenks; (*): Data on the irrigation and drainage capability variable was unavailable for half the area of Ha Tien.

Table 6.3 also indicated that the largest proportion of area that has low to very low capacity to manage the impacts, being short of irrigation and drainage capability was 57.7% (~4 500 ha) in Ha Tien, while the least proportion was only 21.7% (~8 400 ha) in An Bien. There are several possible explanations for these results obtained for Ha Tien. Data on the irrigation and drainage was unavailable for half the area of Ha Tien which may be influencing the analysis of its capability. Ha Tien is a popular tourist site in the region because of its beautiful beaches and landscapes. Agriculture and aquaculture activities have not been prioritised in Ha Tien, therefore, its irrigation and drainage capability may be the least, compared to those of others districts. Surprisingly, the most interesting finding was that high irrigation and drainage capabilities are mainly distributed in rural areas, where agricultural, and aquaculture activities occur widely. Therefore, rural areas would seem to have higher capabilities to cope with

adverse effects, compared to those of urban areas, in terms of irrigation and drainage capability. Apart from these advantages, it is important to manage the irrigation and drainage network, particularly irrigation canals and sluice gates, as seawater incursion is considered most important in relation to exposure. The analyses in Table 6.3 also indicated that Rach Gia was one of the least adaptable districts (45.3%, ~4 370 ha). Again, it is important to keep in mind that results obtained for the analysis are relative values; they are influenced by subjective judgements, thresholds, and Jenks, but they look realistic.

6.3.2.2 Electricity capability variable

The electricity capability variable for the study area was based on the map of the electricity network, comprising voltage power line and transformer station data obtained from Tran et al. (2013) (see a map in Appendix 9d.3). As reviewed in chapter 4, the electricity network for the study area is a relatively modern and extensive power distribution system. Similar to representing irrigation and drainage capability in the previous sub-section, a Kernel function was also used to map areas that might be short of electricity capability, such as lower voltage or less power poles, that would hamper adaptation.

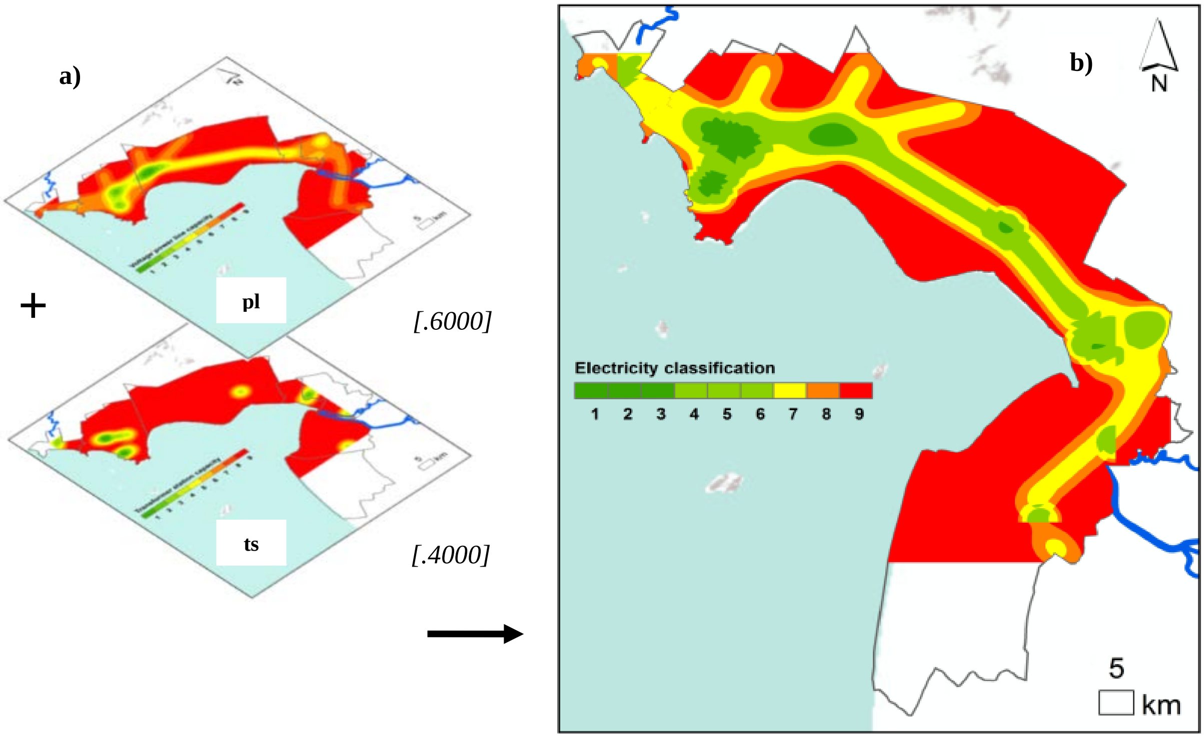


Figure 6.3 GIS-AHP mapping of electricity capability study: a) aggregate of sub-variables: voltage power line density [pl], and transformer station density [ts]; and b) reclassified electricity variable [ey].

Note: As described in Figure 6.1. Numbers in square brackets are presented together with sub-variables indicating relative weights of those sub-variables, simultaneously obtained by AHP. Data on the electricity capability variable was unavailable for half the area of An Minh, as well as half the area of Ha Tien.

In Figure 6.3, the left hand side a) presents two sub-variables: voltage power lines and transformer stations, which were used in the aggregate of the electricity capability variable (see details in Appendix 19c.2). The voltage power lines sub-variable was considered more important than the transformer stations in representing the variable. And the right hand side b) shows a map of the aggregated electricity capability variable. This Figure shows that half of the study area, shaded red, is not going to be as adaptable to potential impacts in terms of electricity capability. Proportions of the study area obtained from this variable are summarised in Table 6.4. Relative weights of sub-variables of the aggregate using AHP, were obtained simultaneously (see Appendices 19c.2 and 21).

Table 6.4 Proportions of the study area classed as very high to very low adaptability in terms of electricity capability.

Coastal district	Electricity capability using AHP, % of area				
	Very high 1 - 3	High 4 – 6	Moderate 7	Low 8	Very low 9
An Bien	0.0	1.6	11.5	14.2	72.6
An Minh*	0.0	0.0	0.3	2.4	97.3
Chau Thanh	0.4	19.5	31.4	16.4	28.5
Hon Dat	2.3	3.4	18.1	13.2	60.4
Ha Tien**	0.0	22.7	52.0	24.0	0.8
Kien Luong	10.6	16.5	23.3	13.3	30.3
Rach Gia	0.0	29.0	26.6	16.0	28.2
7 districts	*2.9*	*8.6*	*19.1*	*13.2*	*53.5*

Note: As presented in Table 6.3; Data on the electricity capability variable was unavailable for half the area of An Minh (*), as well as half the area of Ha Tien (**).

Table 6.4 shows that a major proportion of the area (66.7%, ~200 100 ha) is low to very low in terms of electricity adaptability, while a minor proportion is either very high (2.9%, ~8 700 ha), and high (8.6%, ~25 800 ha), or moderate capability (19.1%, ~57 300 ha). The electricity capability to manage the impacts, particularly outside the focal areas of 5 km from point features (i.e., from transformer station) or polyline features (i.e., from voltage power line) of of the study area, appears to be relatively low. Specifically, An Minh was the least adaptable district, with nearly 100% of area (~57 680 ha) low to very low capability to manage the impacts, while Ha Tien was the highest capability, with the least proportion being short of electricity capability (only 24.8%, ~1 950 ha). Kien Giang has a current relatively modern and extensive power distribution system, especially much stronger in the northern part, including Ha Tien and Kien Luong (having several industrial estates), and Rach Gia (a city), compared to those in the southern part, especially in An Minh and An Bien, as reviewed in chapter 4. Several power outages have occurred for a half or full day, particularly in the dry season, that

can threaten lectrical supply. These results, however, need to be treated with caution due to unavailable data for half the area of An Minh as well as half the area of Ha Tien.

6.3.2.3 Aggregation of technological sub-component

Figure 6.4a presents two variables, irrigation and drainage capabilities, and electricity capability, that were used in the aggregate of the technological sub-component (see details in Appendix 19c.3). The irrigation and drainage variable was considered more important than electricity, in representing the sub-component. As a result, a map of technological capability sub-component is presented in Figure 6.4b.

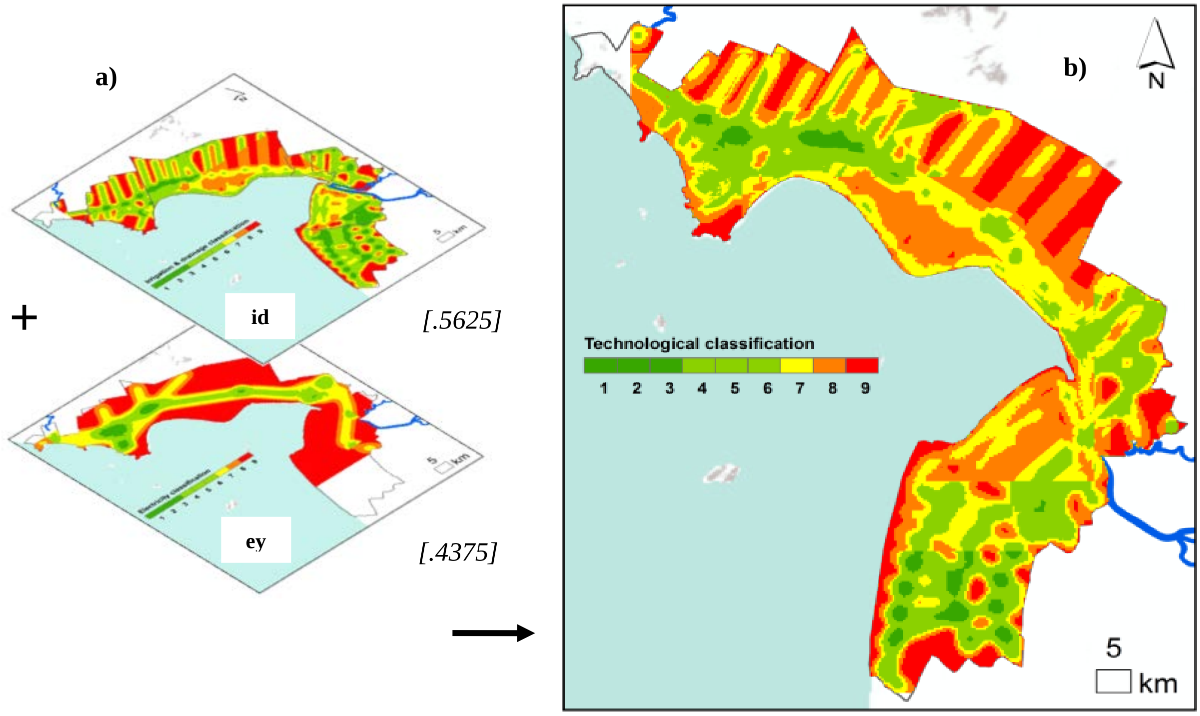


Figure 6.4 GIS-AHP mapping of technological sub-component study: a) aggregate of variables: irrigation and drainage [id], and electricity [ey]; and b) reclassified technological sub-component [TE].

Note: As described in Figure 6.1. The [id] and [ey] as presented in Figures 6.2b and 6.3b, respectively. Numbers in square brackets are presented together with variables indicating relative weights of those variables, simultaneously obtained by AHP; Data on the technological capability sub-component was unavailable for half the area of Ha Tien.

In Figure 6.4, the right hand side b) shows the map of technological capability that seems to reflect the map of irrigation and drainage capability on the left hand side a), which occurs because the irrigation and drainage capability was considered more important than the electricity capability. Generally, it highlighted the fact that the technological capability was relatively high making it possible to reduce the vulnerability. Figure 6.4b visualises a few parts of the study area with little technological capability, indicated by being shaded red, that

are not going to be as adaptable to potential impacts. Shaded red areas (very low adaptability), as used here, are most likely to be isolated areas (located over 5 km from the nearest service centre, making difficulty of access, such as by irrigation canal) that occurred along the gulf of Ha Tien, scattered in the hills and mountains of Ha Tien, and on the Kien Luong coast and mangrove fringes in An Minh, as well as in other rural areas that seem to have poor adaptability in terms of technological capability.

Table 6.5 gives a summary of proportions of the study area considered very high to very low in adaptability in terms of the technological sub-component. This table showed 13.2% of area (~39 600 ha) would experience very low technological capability, and with 28.9% (~86 700 ha) considered as low, while the remainder of area (57.9%) comprised 26.9% of moderate (~80 700 ha), 18.9% of high (~56 700 ha), and 3.2% of very high (~9 600 ha). Ha Tien was the least adaptable area, although this is influenced by unavailable data on the technological capability for half the area of Ha Tien (with 55.6% low to very low capability, ~4 350 ha), while An Minh was the most adaptable area (with only 30.7%, ~17 760 ha), in terms of technological capability.

Table 6.5 Proportions of the study area classed as very high to very low adaptability in terms of technological capability.

Coastal district	Technological capability using AHP, % of area				
	Very high 1 - 3	High 4 – 6	Moderate 7	Low 8	Very low 9
An Bien	0.4	10.1	28.6	42.3	4.2
An Minh	9.2	19.7	19.3	14.9	15.8
Chau Thanh	0.0	31.6	27.2	19.8	14.4
Hon Dat	1.9	13.8	30.6	36.2	14.9
Ha Tien*	0.0	24.5	20.6	43.3	12.3
Kien Luong	3.3	24.8	24.9	24.3	13.6
Rach Gia	0.0	23.8	39.8	27.1	11.4
7 districts	*3.2*	*18.9*	*26.9*	*28.9*	*13.2*

Note: As described in Table 6.3; (*): Data on the technological capability sub-component was unavailable for half the area of Ha Tien.

Figure 6.5 gives a summary of proportions of the study area indicating low to very low capacities in representing technological capability to manage potential impacts. In addition to this, Table 6.6 gives a summary of the rankings of the coastal technological capability of the study area according to proportions indicating low to very low adaptability to manage potential impacts.

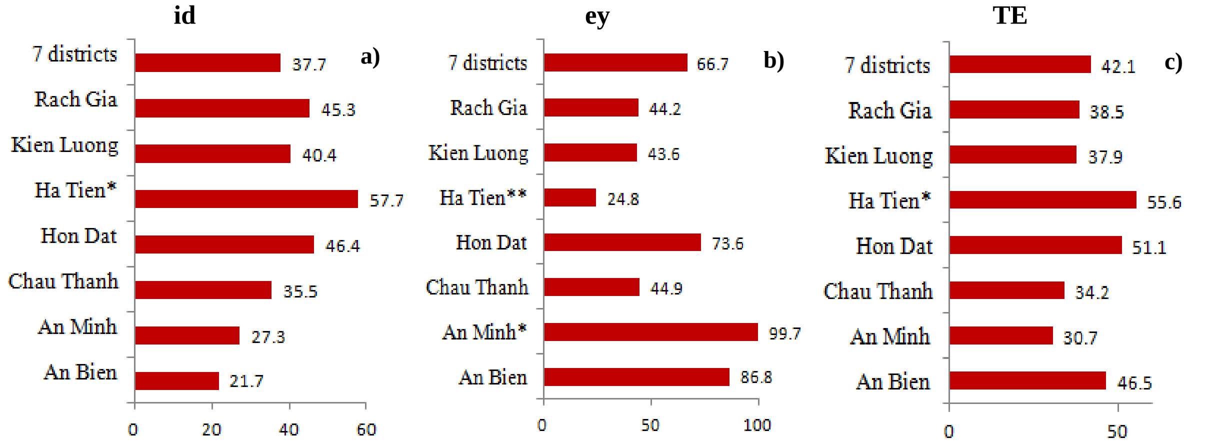


Figure 6.5 Proportions of the study area within seven districts indicating low to very low adapabilities to manage the impacts: in terms of capabilities of a) irrigation and drainage [id]; b) electricity [ey]; and c) technological [TE].
Note: [id], [ey], and [TE] as presented in Tables 6.3 to 6.5.

Table 6.6 Overall aggregated rankings from two variables of capabilities of irrigation and drainage and electricity in representing technological sub-component for each district.

Rank	Irrigation & drainage capability	Electricity capability	*Technological capability*
1	An Bien	Ha Tien	*An Minh*
2	An Minh	Kien Luong	*Chau Thanh*
3	Chau Thanh	Rach Gia	*Kien Luong*
4	Kien Luong	Chau Thanh	*Rach Gia*
5	Rach Gia	Hon Dat	*An Bien*
6	Hon Dat	An Bien	*Hon Dat*
7	**Ha Tien**	**An Minh**	***Ha Tien***

Note: As described in Table 6.2.

Figure 6.5a shows that Ha Tien was the least adaptable district (ranked at 7; 57.5% of area low to very low), while An Bien was the most adaptable district (ranked at 1; only 21.7%) in terms of irrigation and drainage capability (see rankings in Table 6.6). Figure 6.5b shows that An Minh was the least adaptable district (~99%), and Ha Tien was the most adaptable district (only 24.8%) in terms of electricity capability. As a result, Figure 6.5c shows that, Ha Tien was the least adaptable district (55.6%), while An Minh was the most adaptable district (only 30.7%) in terms of technological capability. However, a discrepancy was the rankings in the sub-components for An Minh and Chau Thanh. On the one hand, An Minh appeared to be the most adaptable district in terms of technological capability (ranked at 1) due to being the second highest in terms of irrigation and drainage adaptability (ranked at 2), and the least adaptable in terms of electricity (ranked at 7). On the other hand, Chau Thanh appeared to be the most adaptable district in terms of technological capability (ranked at 2) due to high adaptability in terms of irrigation and drainage (ranked at 3), and moderate adaptability in terms of electricity (ranked at 4). Therefore, rankings for other districts should be interpreted

with caution. Further contradictory findings, particularly in Ha Tien, indicating it to be less adaptable to potential impacts compared to rural areas, may be inaccurate because data was unavailable for half the area of Ha Tien.

The weight value of the technological sub-component is summarised in equations as follows. The consistency ratios (CR) obtained were acceptable according to the procedures of Saaty (1980; 1994).

$\mathbf{Layer_{TE}} = 0.5625 * layer_{id} + 0.4375 * layer_{ey}$ **[Equation 6.2[22]]**

⇔ $\mathbf{Layer_{TE}} = 0.5625 * [0.2868 * layer_{ca} + 0.2356 * layer_{se} + 0.1884 * layer_{ri} + 0.1715 * layer_{re} + 0.1178 * layer_{sg}] + 0.4375 * [0.6000 * layer_{pl} + 0.4000 * layer_{ts}]$ **[Equation 6.2.1[23]]**

⇔ $\mathbf{Layer_{TE}} = [0.1613 * layer_{ca} + 0.1325 * layer_{se} + 0.1060 * layer_{ri} + 0.0965 * layer_{re} + 0.0663 * layer_{sg}] + [0.2625 * layer_{pl} + 0.1750 * layer_{ts}]$ **[Equation 6.2.2]**

Note: Abbreviation of sub-variables, and variables constituent to the technological sub-component, and relative weights of those sub-variables, and variables, obtained by AHP as presented in Figures 6.2 to 6.4. See a summary of those relative weights in Appendix 21.

The results in Equations 6.2.1 and 6.2.2 show relative weights of mapping the technological sub-component being the sum of those five layers of sub-variables: [ca], [se], [ri], [re], and [sg] in mapping the irrigation and drainage capability variable, and those of two layers of sub-variables: [pl] and [ts] in mapping the electricity capability variable (see Figures 6.2 and 6.3). A summary of those relative weights in order to represent [TE] is presented in Equation 6.2. The [id] (its relative value obtained as 0.5625) is considered more important than the [ey] (its relative value obtained as 0.4375), in terms of [TE].

6.3.3 Mapping the infrastructure sub-component

The infrastructure capability, as used here, refers to three variables: house characteristics, road, and communication access. However, these data also are limited in that housing standards (percentages of households having solid houses), and communication access (inhabitants per fixed-line telephone subscriber) were only obtained at the scale of the entire district. In terms of representing infrastructure capability, the housing variable was regarded as the most important, followed by road capability and the least important variable was communication

[22] See Figure 6.4.
[23] See Figures 6.2 to 6.4.

access capability. Objectives of this sub-section are two-fold. The first objective is to evaluate the infrastructure capability. The second objective is to aggregate these sub-components for use in adaptive capacity. A map showing the infrastructure adaptive capacity levels for the study area is presented in Figure 6.7. The sub-component map was reclassified into 9 categories by using Jenks, and mapped into 5 levels from very low to very high, shaded as reported in Table 6.7. A summary of overall aggregated rankings for each district representing very low to low adaptability is shown in Table 6.8. Relative weights of variables of the aggregate using AHP, were obtained simultaneously (see Appendix 19b).

6.3.3.1 Road capability variable

The road capability variable for the study area was based on the map of road networks obtained from Tran et al. (2013) (see a map in Appendix 9d.2). A Kernel function was used in order to represent road capability, similar to that used in representing irrigation and drainage capability in sub-section 6.3.2.1. It also indicates the most isolated areas, as used here, located over 5 km from the nearest road, meaning greater difficulty of access. Figure 6.6 presents a map of the road capability variable.

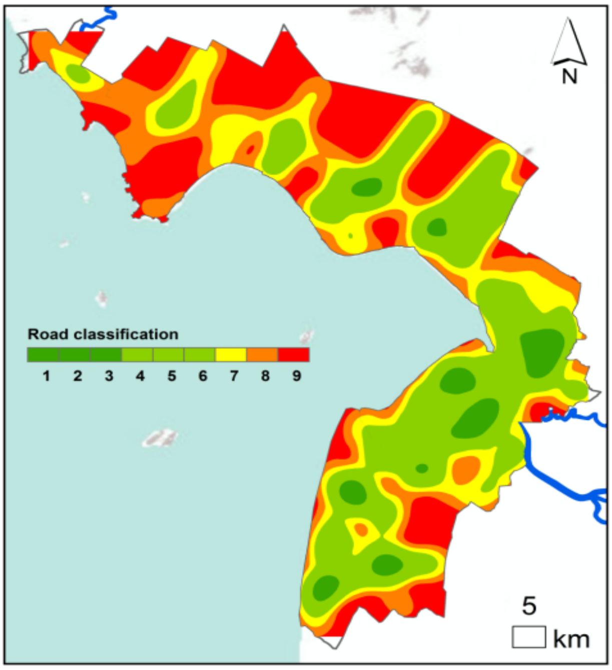


Figure 6.6 GIS mapping of the road capability variable [rd].

Note: as described in Figure 6.1.

As seen in Figure 6.6, the major proportion of area in terms of road capability was either very low, shaded red (accounted for 23.3%, ~69 900 ha) or low adaptability, shaded orange (18.6%, ~55 800 ha). It also indicated that roads in the study area were quite dense, and

relatively accessible. On the other hand, a small proportion (5.2%, ~15 600 ha), shaded dark green, indicated very high adaptability. These areas were largely main roads (very high densities) running through settlement areas. Road capabilities in Kien Luong, Hon Dat, and An Minh imply that these may be less adaptable than in other districts.

6.3.3.2 Aggregation of the infrastructure sub-component

Figure 6.7 presents GIS-AHP mapping of the infrastructure sub-component. In Figure 6.7, the left hand side a) presents three classified maps of variables for the analysis, whereas the right hand side b) displays the map of aggregated infrastructure adaptive capacity levels for the study area.

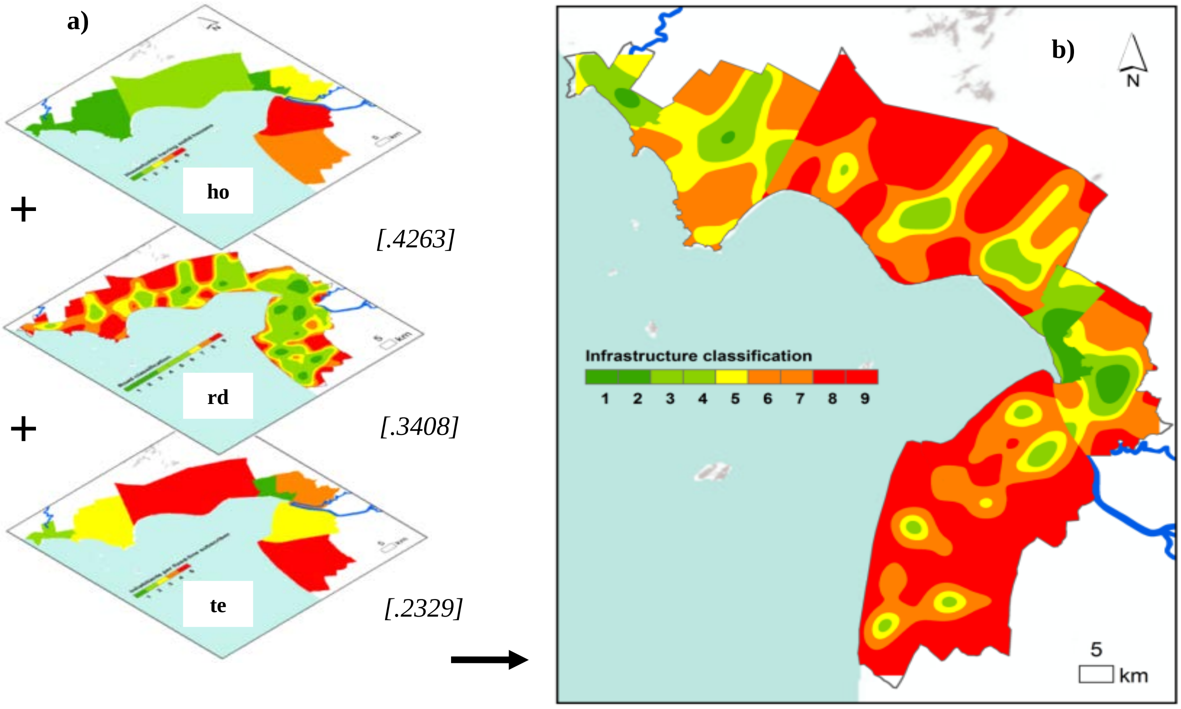


Figure 6.7 GIS-AHP mapping of infrastructure sub-component study: a) aggregate of variables: capacities of houses [ho], road [rd], and communication access [te]; and b) reclassified infrastructure sub-component [IN].

Note: As described in Figure 6.1. Numbers in square brackets are presented together with variables indicating relative weights of those variables, simultaneously obtained by AHP.

The results of the infrastructure sub-component revealed that the majority of the study area was considered as either low (32.2%, ~96 600 ha), or very low adaptability (39.5%, ~118 500 ha), while the minority was either very high (only 2.7%, ~8 100 ha), and high adaptability (11.3%, ~33 900 ha). An Minh appeared to have the largest proportion representing low to very low adaptability (98.4%, ~56 930 ha), while Rach Gia appeared to have the least proportion (0%) in terms of infrastructure capability (Table 6.7).

Table 6.7 Proportions of the study area classed as very high to very low adaptability in terms of infrastructure capability.

Coastal district	Infrastructure capability sub-component using AHP, % of area				
	Very high 1 - 2	High 3 - 4	Moderate 5	Low 6 - 7	Very low 8- 9
An Bien	0.0	4.4	9.0	35.0	51.6
An Minh	0.0	1.6	5.0	23.2	70.2
Chau Thanh	8.7	15.4	18.1	41.8	16.0
Hon Dat	0.0	6.5	12.8	33.1	47.6
Ha Tien	10.7	64.7	24.6	0.0	0.0
Kien Luong	0.7	20.9	32.0	46.4	0.0
Rach Gia	44.0	46.9	8.9	0.0	0.0
Seven coastal districts	*2.7*	*11.3*	*14.3*	*32.2*	*39.5*

Note: as described in Table 6.3.

Table 6.8 gives a summary of the rankings of the coastal infrastructure capability for the study area. An Minh, An Bien, and Hon Dat appeared to be the areas that are least adaptable. On the other hand, urban areas, such as Rach Gia and Ha Tien, have considerably higher percentages of households having solid structure, better road capabilities, and communication access, compared to rural areas; therefore, they may have stronger capacities to cope with potential impacts. However, one discrepancy was the ranking for Kien Luong. High adaptability is indicated for Kien Luong, ranked at 3, due to the highest percentages of households having solid houses (ranked at 1), the most isolated areas from road access (ranked at 7), and relatively high numbers of people who have access to fixed-line telephone subscriber services (ranked at 3). Another discrepancy was the ranking for An Minh. An Minh was ranked at 7 (the least adaptability district), due to low percentages of households having solid structures (ranked at 6), isolated areas from road access (ranked at 5), and low access to telephone services (ranked at 6). A possible explanation for this result may be the limitations of data with house and communication data available only at an entire district level.

Table 6.8 Overall aggregated rankings from the three variables capabilities of houses, road, and communication access in representing the infrastructure sub-component for each district.

Rank	Houses capability	Road capability	Communication access	*Infrastructure*
1	Kien Luong	Rach Gia	Rach Gia	*Rach Gia*
2	Rach Gia	Chau Thanh	Ha Tien	*Ha Tien*
3	Ha Tien	An Bien	Kien Luong	*Kien Luong*
4	Hon Dat	Ha Tien	An Bien	*Chau Thanh*
5	Chau Thanh	An Minh	Chau Thanh	*Hon Dat*
6	An Minh	Hon Dat	An Minh	*An Bien*
7	**An Bien**	**Kien Luong**	**Hon Dat**	***An Minh***

Note: as described in Table 6.2.

A summary of relative weights of the three variables related to houses, roads, and communication access, in order to represent the aggregated infrastructure sub-component

[IN], is presented in Equation 6.3 (see Figures 6.6 and 6.7). The consistency ratios (CR) were acceptable according to the procedures of Saaty (1980; 1994). The [ho] is considered with most priority (its relative value obtained as 0.4263). The second priority is [rd] (its relative value obtained as 0.3408). The least is [te] (its relative value obtained as 0.2329).

$$\textbf{Layer}_{\textbf{IN}} = 0.4263 * \text{layer}_{ho} + 0.3408 * \text{layer}_{rd} + 0.2329 * \text{layer}_{te}$$ **[Equation 6.3[24]]**

Note: Abbreviation of variables constituent to the infrastructure sub-component, and relative weights of those variables, obtained by AHP as presented in Figures 6.6, and 6.7. See a summary of those relative weights in Appendix 21.

6.3.4 Aggregation of the adaptive capacity component

Figure 6.8 presents GIS-AHP mapping of the adaptive capacity component. In Figure 6.8, the left hand side a) presents maps of the three sub-components capabilities: [SO], [TE], and [IN] for the analysis, whereas the right hand side b) presents the map of the adaptive capacity component for the study area. The adaptive capacity component map was reclassified into 9 categories by using Jenks, and mapped into 5 levels from very low to very high, shaded as for other components, with proportions of the study area reported in Table 6.9. Relative weights of sub-components, were obtained simultaneously (see details in Appendix 19d).

Table 6.9 Proportions of the study area classed as very high to very low adaptability in terms of adaptive capacity.

Coastal district	Adaptive capacity component using AHP, % of area				
	Very high 1 - 2	High 3 - 4	Moderate 5	Low 6 - 7	Very low 8 - 9
An Bien	0.0	5.8	9.4	60.5	24.4
An Minh	0.0	0.8	1.6	21.2	76.4
Chau Thanh	0.8	6.1	9.8	41.6	41.7
Hon Dat	0.0	0.1	0.3	14.1	85.4
Ha Tien*	0.0	2.8	29.9	67.3	0.0
Kien Luong	7.2	30.5	31.2	31.2	0.0
Rach Gia	75.0	24.7	0.1	0.2	0.1
Seven coastal districts	*3.7*	*7.2*	*8.2*	*27.8*	*53.1*

Note: As described in Table 6.3; (*): Data on adaptive capacity was unavailable for quarter of the area of Ha Tien.

[24] See Figure 6.7.

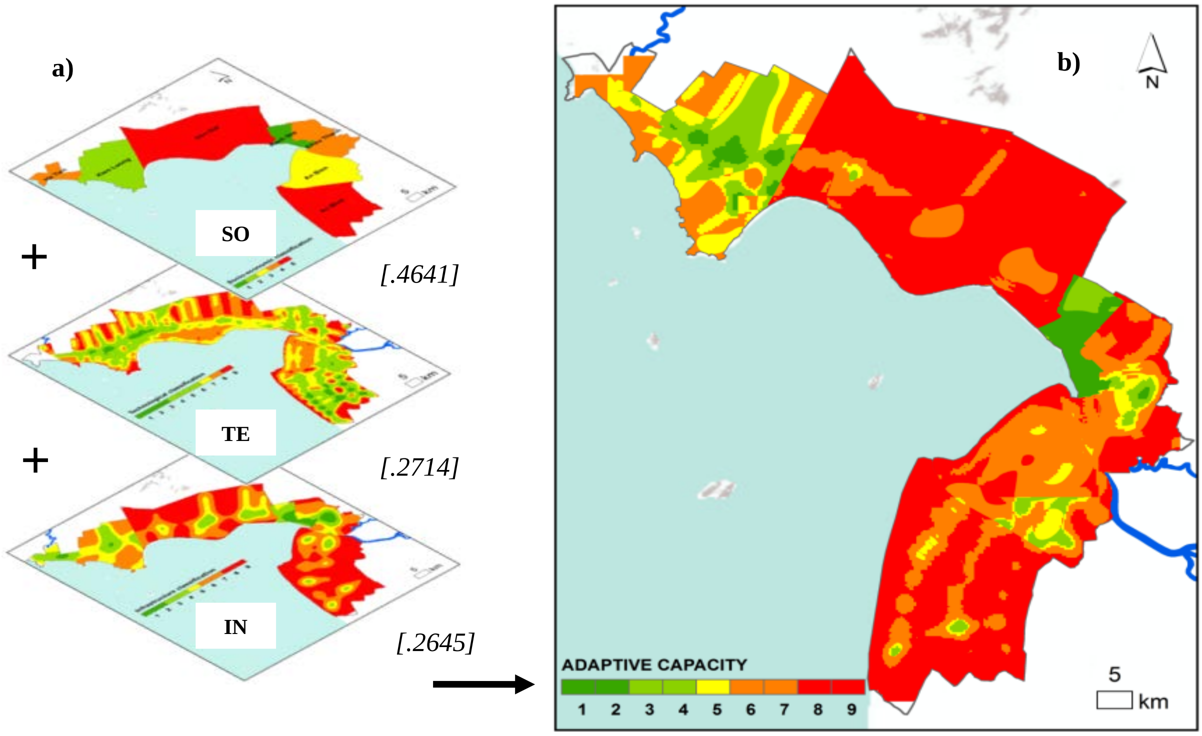


Figure 6.8 GIS-AHP mapping of adaptive capacity component study: a) aggregate of sub-components: capabilities of socioeconomic [SO], technological [TE], and infrastructure [IN]; and b) reclassified adaptive capacity component [A].

Note: As described in Figure 6.1. Numbers in square brackets are presented together with sub-components indicating relative weights of those sub-components, simultaneously obtained by AHP; [SO], [TE], and [IN] as presented in Figures 6.1b, 6.4b, and 6.7b, respectively.

The map of the adaptive capacity component on the right hand side b) of Figure 6.8 seems to closely reflect the map of the socioeconomic sub-component on the left hand side a), this is because [SO] was considered the most important sub-component, compared to the two others, in the aggregation. Hon Dat, and An Minh indicated by shaded red were areas shown to be least adaptable to potential impacts, while Rach Gia, Ha Tien, and Kien Luong indicated by shaded dark green were areas that are most adaptable, providing support for the idea that urban areas are expected to be more adaptable than rural areas. Kien Luong is an excpetion and may be inaccurate because socioeconomic data was available only at the scale of the entire district.

A major proportion of area representing low to very low adaptability to the impacts (~81%, 243 000 ha) indicated that the adaptive capacity for the study area is likely to be relatively low (see Table 6.9). Hon Dat appeared to have the largest proportion of area representing low to very low adaptability to the impacts (99.5%, ~103 180 ha), while Rach Gia appeared to have the least proportion (only 0.3%, ~29 ha). These results also indicate that the study area is

expected to be relatively vulnerable due to relatively low adaptive capacity to manage relatively high potential impacts (addressed in the previous chapter, sub-section 5.5.3.1).

6.3.5 Discussion

6.3.5.1 Coastal adaptive capacity in this study

This study was the first attempt to assess the adaptive capacity by using thirteen sub-variables and nine variables combined into the three sub-components. Table 6.10 gives a summary of the rankings of coastal adaptive capacity for each district.

Table 6.10 Overall aggregated rankings from three sub-components: socioeconomic, technological, and infrastructure in representing adaptive capacity component for each district.

Rank	Socioeconomic	Technological	Infrastructure	*Adaptive capacity*
1	Rach Gia	An Minh	Rach Gia	*Rach Gia*
2	Kien Luong	Chau Thanh	Ha Tien	*Kien Luong*
3	An Bien	Kien Luong	Kien Luong	*Ha Tien*
4	Ha Tien	Rach Gia	Chau Thanh	*Chau Thanh*
5	Chau Thanh	An Bien	Hon Dat	*An Bien*
6	Hon Dat	Hon Dat	An Bien	*An Minh*
7	**An Minh**	**Ha Tien**	**An Minh**	***Hon Dat***

Note: As described in Table 6.2.

As seen in Table 6.10, Hon Dat, An Minh, and An Bien seem to be the districts least able to cope with potential impacts, whereas Rach Gia, Ha Tien, and Kien Luong appear to have the strongest adaptabilities. It also indicates the fact that urban areas are expected to be more adaptable to the impacts, except Kien Luong. Kien Luong appeared to have second least proportion representing low to very low adaptable (only 31.2%, ranked at 2) due to high capabilities of socioeconomic (ranked at 2), technological and infrastructure (both ranked at 3). One discrepancy was the ranking for Hon Dat. Hon Dat appeared to have the least adaptive capacity (ranked at 7) due to low capabilities of socioeconomic, technological, and infrastructure (ranked at 6, 6, and 5, respectively). It is noted that unavailable data on adaptive capacity for quarter of the area of Ha Tien, and the limitations of these input data at an entire district level in representing socioeconomic and infrastructure, may influence these rankings.

The weight value of the study adaptive capacity component is summarised in equations as follows. The consistency ratios (CR) obtained were acceptable according to the procedures of Saaty (1980; 1994).

$\mathbf{Layer_A} = \mathbf{0.4641} * layer_{SO} + \mathbf{0.2714} * layer_{TE} + \mathbf{0.2645} * layer_{IN}$ **[Equation 6.4[25]]**

$\Leftrightarrow \mathbf{Layer_A} = \mathbf{0.4641} * [0.2972 * layer_{in} + 0.2891 * layer_{ed} + 0.2564 * layer_{he} + 0.1573 * layer_{po}] + \mathbf{0.2714} * [0.5625 * layer_{id} + 0.4375 * layer_{ey}] + \mathbf{0.2645} * [0.4263 * layer_{ho} + 0.3408 * layer_{rd} + 0.2329 * layer_{te}]$ **[Equation 6.4.1[26]]**

$\Leftrightarrow \mathbf{Layer_A} = [0.1379 * layer_{in} + 0.1342 * layer_{ed} + 0.1190 * layer_{he} + 0.0730 * layer_{po}] + [0.1527 * layer_{id} + 0.1187 * layer_{ey}] + [0.1128 * layer_{ho} + 0.0901 * layer_{rd} + 0.0616 * layer_{te}]$

[Equation 6.4.2]

Note: Abbreviation of sub-variables, variables, and sub-components constituent to the adaptive capacity, and relative weights of those sub-variables, variables, and sub-components, obtained by AHP as presented in Figures 6.1, 6.4, 6.7, and 6.8. See a summary of those relative weights in Appendix 21.

The results in Equations 6.4.1 and 6.4.2 show relative weights of mapping the adaptive capacity component being the sum of relative weights of the four variables: [in], [ed], [he], and [po] in mapping the socioeconomic sub-component, two variables: [id], and [ey] in mapping the technological sub-component, and three variables: [ho], [rd], and [te] in mapping the infrastructure sub-component (see Figures 6.1, 6.4, and 6.7). A summary of relative weights of the three sub-components: [SO], [TE], and [IN] was used in order to represent the adaptive capacity component, presented in Equations 6.4 (see Figure 6.8). The [SO] is considered as the most priority (its relative value obtained as 0.4641). This was followed by [TE] (its relative value obtained as 0.2714). The least is [IN] (its relative value obtained as 0.2645).

6.3.5.2 Evaluation of the adaptive capacity outcome

Scale-based approaches using input data within district level, comprising only three variables, irrigation and drainage, electricity, and road capabilities, were evaluated to assess their influence on the aggregated adaptive capacity outcome. Relative weights of these variables, were obtained simultaneously (see Appendix 22). The objectives of this sub-section are two-fold. The first objective is to evaluate how sensitive the adaptive capacity outcome is to the weighting of input data. The second objective is to use the aggregated sub-components in the broader study of adaptive capacity (see sub-section 6.4.3.2).

[25] See Figure 6.8.
[26] See Figures 6.1b, 6.4, 6.7, and 6.8.

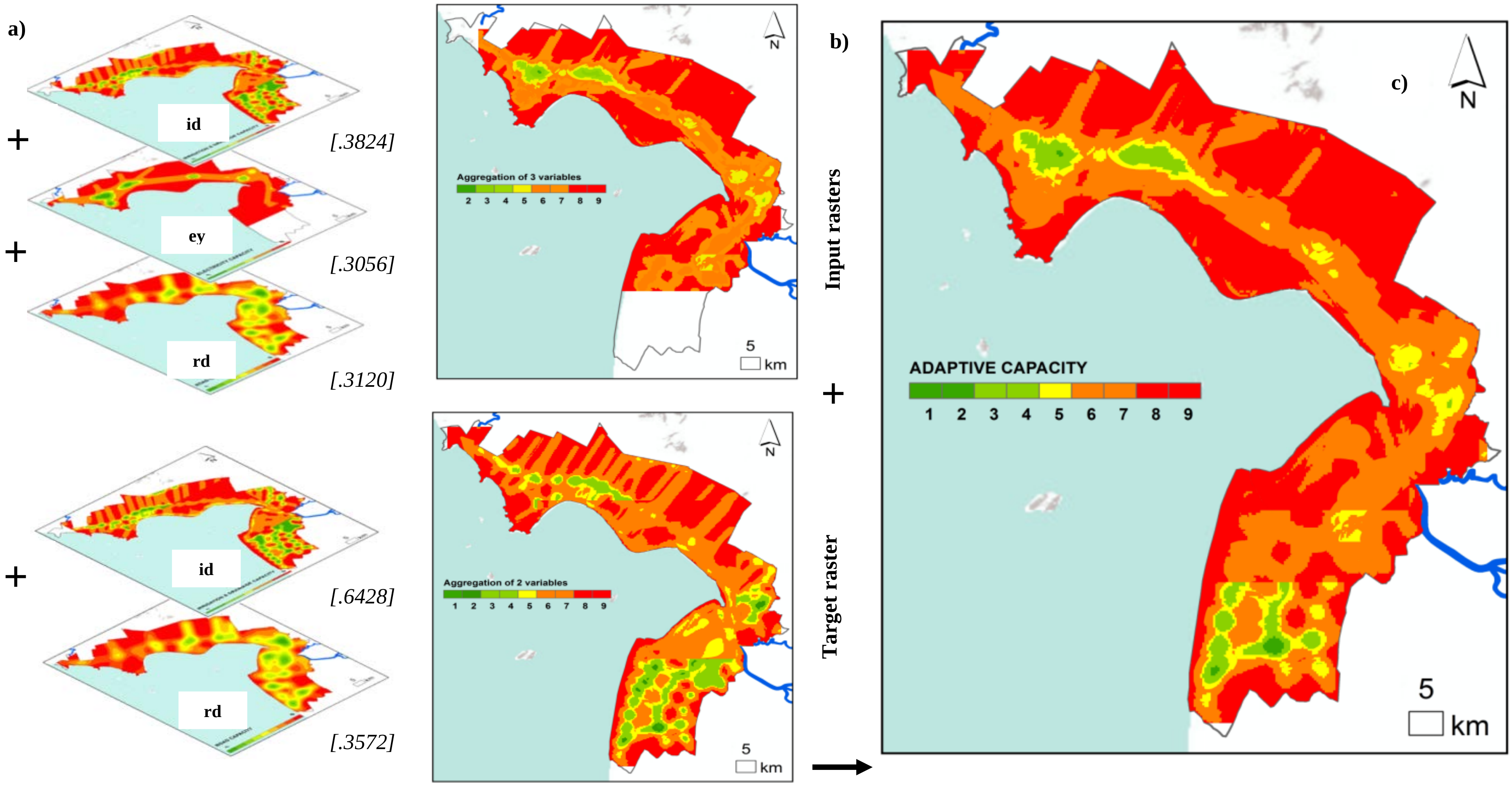


Figure 6.9 GIS-AHP mapping of adaptive capacity component within district level: a) aggregate of variables: irrigation and drainage capability [id], electricity capability [ey], and road capability [rd]; b) mosaic raster dataset[27]; and c) reclassified adaptive capacity component [A].

Note: As described in Figure 6.1; Numbers in square brackets are presented together with variables indicating relative weights of those variables, simultaneously obtained by AHP; See details in Appendix 22.

[27] As similar to Figure 5.7[5]; [id], [ey], and [rd] were aggregated by AHP to generate the input raster, whereas [id] and [rd] were aggregated by AHP to generate the target raster. And then, mosaics multiple input rasters into the target raster to get the final outcome.

Figure 6.9 presents GIS-AHP mapping of the adaptive capacity component within district level. In Figure 6.9, the left hand side a) presents the three variables irrigation and drainage (see sub-section 6.3.2.1), electricity (see sub-section 6.3.2.2), and road capabilities (see sub-section 6.3.3.1) used in the analysis, the middle b) displays maps of raster dataset were used to produce the mosaic adaptive capacity map, whereas the right hand side c) presents the map of reclassified adaptive capacity within district level.

The analyses from a comparison between the adaptive capacity at an entire district level (see Figure 6.8b and Table 6.9), and the adaptive capacity within district level (see Figure 6.9c) indicate that there was an extent of low to very low adaptability (89.74%, especially a large proportion of which was 47.87% representing very low) in the adaptive capacity within district level. This was 80.9% representing low to very low adaptability, and a major proportion (53.1%) representing very low for adaptive capacity at an entire district level. These results indicate that scale-based approaches of input data may be influence the outcomes, finer resolution input data can give better output projection. Interestingly, the analysis shows that the adaptive capacity in the study is likely to be relatively low in both the assessments.

The maps of adaptive capacity levels shown in Figures 6.8b and 6.9c can offer policy makers a generalised overview of areas within the study area that area likely to be least adaptable to potential impacts, indicated by shaded red, and therefore remaining vulnerable. But policy making needs to keep in mind the limitations of empirical research, and these maps have not enabled identification of all adaptation strategies, and supporting adaptation in the long term. Adaptive capacity to climate change can be improved by including socioeconomic factors at finer spatial scales, which are considered to be the main driving forces of social vulnerability to the impacts of climate change.

6.4 Coastal vulnerability assessment

This study uses the initial vulnerability definition of the IPCC (2007) as the starting point based on the three key components: exposure, sensitivity, and adaptive capacity, and the subsequently extended definition developed by Schauser et al. (2010) to allow a better assignment of different variable to those three components of vulnerability. As mentioned in the literature review chapter (chapter 2), according to Soares et al. (2012), vulnerability assessments that are considered as “second generation” further address relevant non-climatic

drivers (i.e., economic, demographic), and the adaptive capacity of the system under analysis (Fussel and Klein, 2006). At a macro-scale level (i.e., national to global scale) vulnerability assessment highlights the overall significance of climate changes for coastal societies and could provide useful information for central Government policies, while meso- to micro-scale studies, (i.e., sub-national/regional to local scale) allow identification of more specific vulnerable areas (i.e., regional and sectors), and could support policy makers in the design of appropriate adaptation strategies (Torresan et al., 2008).

6.4.1 Overview

The study area comprises seven coastal districts along the Kien Giang coast that is home for ~921 000 people in 2011, based on the statistical data obtained from the Kien Giang Statistical Office (2012). It comprises much very low-lying land, with elevations on average of 0.3 - 0.8 m above MSL.

The analyses in the previous chapter showed that much of the study area was likely to be highly exposed (~69% of total area high to very high) (see sub-section 5.3.5.1), and moderately sensitive (~40%) (see sub-section 5.4.4.1), resulting in relatively high potential impacts (~58%). Furthermore, the analyses of the adaptive capacity study, from sub-sections 6.3.4 and 6.3.5, showed that the adaptive capacity is likely to be relatively low, with ~81% of the total area low to very low in terms of adaptability, making it difficult to handle negative impacts. It is important to keep in mind that although results from this analysis look realisable and realistic, these are relative values, and they may be influenced by thresholds, weightings, and Jenks.

The exposure component was judged to have an extremely high influence on coastal vulnerability, and was considered the most important of the three key components: exposure, sensitivity, and adaptive capacity. It was assigned a priority of [9], based on the fundamental rule scale by Saaty (1980). While the sensitivity was judged to have a strong influence, it was considered the second most important component, and therefore, it was assigned a priority of [7]. Correspondingly, the adaptive capacity component was judged to have a relatively lesser influence on coastal vulnerability, considered the least important component, and was assigned a priority of [4.5]. That is because of several reasons:

- As mentioned in the previous chapter (section 5.5), exposure is considered a higher priority than sensitivity because it includes physical aspects of vulnerability.

- Sensitivity refers to the degree to which a system is affected by such changes, whereas adaptive capacity describes the system's ability to adjust to these changes. Future sensitivity depends on current adaptive capacities and measures. The adaptive capacity is considered a lesser priority than exposure, because adaptive capacity, like sensitivity, it comprises social factors that could be changed, whereas exposure comprises physical factors that can not really be changed.

- The adaptive capacity is inversely related to vulnerability, compared to exposure and sensitivity. In other words, the greater the exposure or sensitivity, and the less the adaptive capacity, the greater is the vulnerability. The adaptive capacity of the study area seems to be limited, which makes it difficult to reduce adverse impacts; therefore, it is considered to least influence vulnerability in this analysis. Although the adaptive capacity does not necessarily contribute to effective adaptation, it can never eliminate all vulnerabilities. Moreover, responsibility for management of some risks may be beyond the household or local authorities' level.

6.4.2 Vulnerability assessment

Figure 6.10 presents GIS-AHP mapping of the final vulnerability for the study area. The vulnerability map was reclassified into 9 categories by using Jenks, and mapped into 5 levels from very low to very high, shaded as for the final vulnerability outcome, with proportions of the study area reported in Table 6.11. Relative weights of components, were obtained simultaneously (see details in Appendix 20).

Table 6.11 Proportions of the study area classed as very high to very low in representing the final vulnerability.

Coastal district	Vulnerability using AHP, % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6 - 7	Very high 8 - 9
An Bien	0.00	0.00	0.03	3.13	96.83
An Minh	0.00	0.11	3.15	54.05	42.70
Chau Thanh	0.25	2.48	11.24	45.50	40.52
Hon Dat	8.84	27.80	30.66	29.67	3.04
Ha Tien*	0.36	7.33	9.16	32.65	50.51
Kien Luong	6.42	22.80	22.01	47.93	0.85
Rach Gia	6.77	25.86	10.48	45.82	11.08
Average	*4.46*	*14.87*	*16.74*	*36.03*	*27.91*

Note: As described in Table 6.3; (*): Data on vulnerability outcome was unavailable for quarter of the area of Ha Tien.

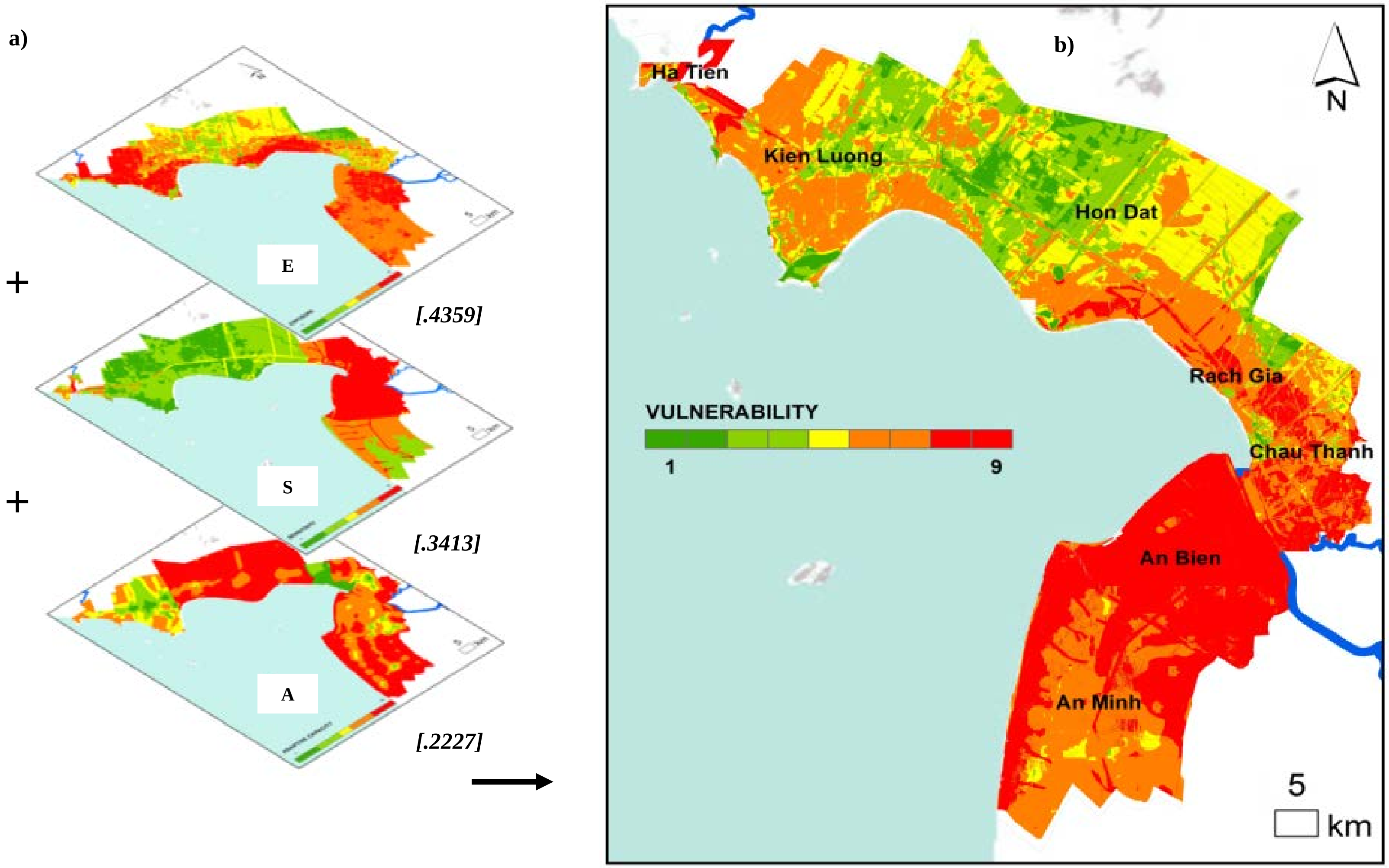


Figure 6.10 GIS-AHP mapping of the final vulnerability study: a) aggregate of sub-components: exposure [E], sensitivity [S], and adaptive capacity [A]; and b) reclassified final vulnerability [V].

Note: As described in Figure 6.1; Numbers in square brackets are presented together with components indicating relative weights of those components, simultaneously obtained by AHP. [E], [S], and [A] as presented in Figures 5.7b, 5.11b and 6.8b, respectively.

6.4.3 Discussion

6.4.3.1 Coastal vulnerability study

This study was the first attempt to rigorously examine coastal vulnerability assessment using associated GIS and AHP. It explored applying this to seven districts along the Kien Giang coast as a case study. The hierarchical structure comprised three key components: [E], [S], and [A], at level 1. At the next level, 8 sub-components were mapped: [SI], [FR], and [SC]; [SF], and [LU]; and [SO], [IN], and [TE]. A further 22 variables (level 3) and 24 sub-variables (level 4) were incorporated into the analysis. Outcomes indicate that the study area is expected to be relatively high in vulnerability (~64% of area representing very high to high vulnerability) as a result of ~69% high exposure, ~40% moderate sensitivity, with ~81% relatively low adaptability to the impacts. Mapping indicates the areas that are most vulnerable, although the percentages obtained may be influenced by the nature of the classification algorithm underlying Jenks.

Table 6.11 records the major proportions of the study area represented as either moderate (16.7%, ~50 100 ha) or high (36%, ~108 000 ha), and very high vulnerability (27.9%, ~89 100 ha). This finding seems to accord with earlier outcomes, which showed that the study was highly exposed, moderately sensitive, with relatively low adaptability. Moreover, Figure 6.10 shows that An Bien, and An Minh appear the most vulnerable (shaded red and orange). An Bien was the most vulnerable district with ~100% of area (~38 720 ha) high, and very high vulnerability. This was followed by An Minh with ~97% (~ 56 120 ha). On the other hand, Hon Dat was the least vulnerable district with only 32.71% (~33 910 ha) in this class. Again, these values are not absolute values, and the ranking is based on the largest percentage of the area of each district representing very high to high vulnerability. Identified and visualised patterns or areas representing very high to high vulnerability in Figure 6.10b are more useful to policy makers and planners in order to provide an overview of potential impacts of climate change than relative proportions of area or rankings. However, the proportions provide a guide for making decisions.

Figure 6.11 gives a summary of proportions of area representing very high to high potential impacts on the left hand side a), low to very low capacities in the middle b), and very high to high vulnerability on the right hand side c). In addition to this, Table 6.12 gives a summary of the rankings of the three key components: exposure, sensitivity, and adaptive capacity to show combined potential impacts as discussed in chapter 5, sub-section 5.5.3.1.

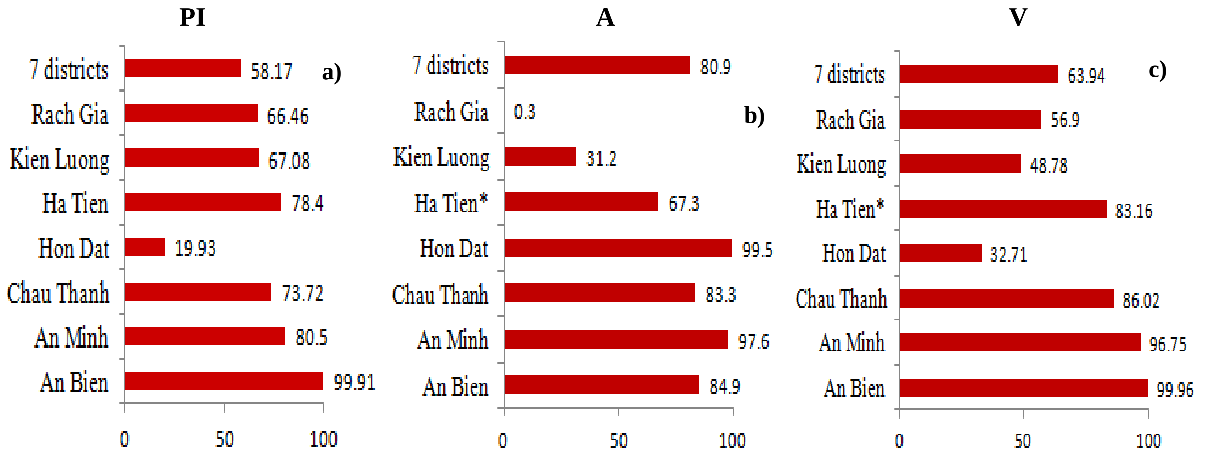


Figure 6.11 Proportions of the study area within seven districts indicating: a) very high to high in terms of potential impacts; b) low to very low adaptive capacity; and c) very high to high final vulnerability.

Note: [PI], [A], and [V] as presented in Tables 5.19 (chapter 5), 6.9, and 6.11, respectively.

A comparison between potential impacts, and vulnerability, which involves adaptive capacity as summarised in Figure 6.11, aims to examine adaptability to manage impacts so as to further assist the local authorities and communities in better coastal management and conservation. An Minh, An Bien, and Chau Thanh appear to have the least adaptive capacities to reduce potential impacts (with 97.6%, 84.9%, and 83.3% of area representing low to very low adaptability, respectively), whereas Rach Gia, and Kien Luong appear to have higher adaptive capacities (with 0.3%, and 31.2%, respectively). An Bien, An Minh, and Chau Thanh appear to be the districts most vulnerable (with 99.96%, 96.97%, and 86.02% of area representing very high to high vulnerability, respectively), while Kien Luong, and Rach Gia appear the districts least vulnerable (with 48.78%, and 56.9%, respectively). These results may be explained by the fact that if areas have low adaptability, they find it difficult to manage potential impacts, and therefore can reduce the vulnerability only a little, while if areas have high adaptability, they may be able to manage potential impacts, and reduce the vulnerability. Another interesting finding was the results for Hon Dat which appears to have little adaptive capacity to reduce potential impacts (99.5%), associated with district least potential impacts (19.93%), therefore appears to be the most vulnerable district (32.72%). This supports the idea that the adaptive capacity influences vulnerability less in some cases. The result in the vulnerability for Ha Tien, however, needs to be treated with caution due to unavailable data on adaptive capacity for quarter of the area.

Table 6.12 Overall aggregated rankings from three components: exposure, sensitivity, and adaptive capacity in representing the final vulnerability for each district.

Rank	Exposure	Sensitivity	Potential impacts	Adaptive capacity	Vulnerability
7	**An Minh**	**Chau Thanh**	***An Bien***	**Hon Dat**	**An Bien (~)**
6	An Bien	An Bien	***An Minh***	An Minh	**An Minh (+)**
5	Kien Luong	Rach Gia	***Ha Tien***	An Bien	**Chau Thanh (+)**
4	Ha Tien	An Minh	***Chau Thanh***	Chau Thanh	**Ha Tien (+)**
3	Rach Gia	Ha Tien	***Kien Luong***	Ha Tien	**Rach Gia (-)**
2	Chau Thanh	Kien Luong	***Rach Gia***	Kien Luong	**Kien Luong (-)**
1	Hon Dat	Hon Dat	***Hon Dat***	Rach Gia	**Hon Dat (+)**

Note: A value of 7 assigns the highest rank within seven coastal districts in representing exposure, sensitivity, potential impacts, and vulnerability, while assigning the lowest rank in representing adaptive capacity; the minus (-) indicates a decrease, (~) a stability, (+) an increase in the final vulnerability outcomes involved in adaptive capacity, compared to potential impacts outcomes.

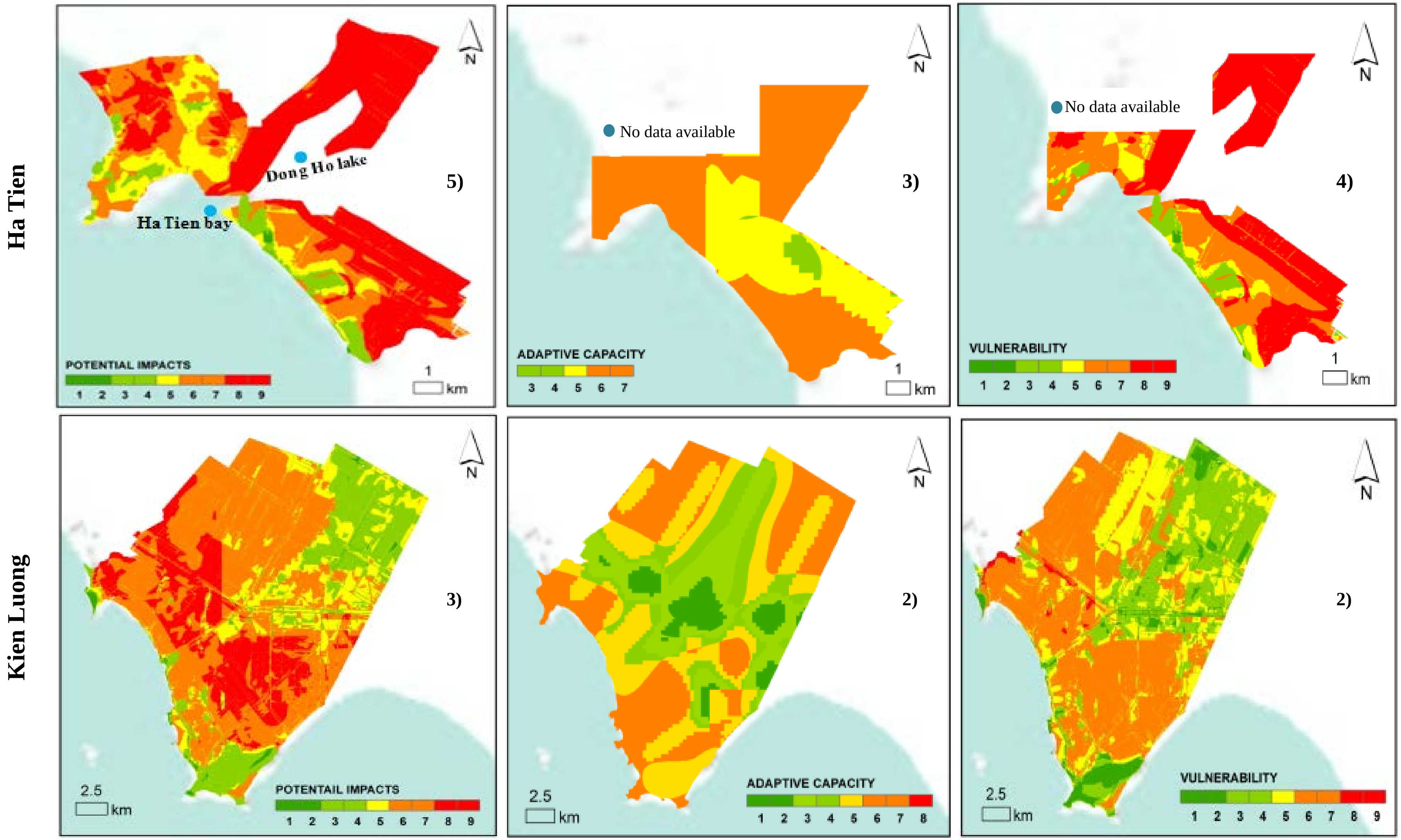
A quick inspection of Table 6.12 reveals the overall aggregated rankings of exposure, sensitivity, potential impacts, adaptive capacity, and vulnerability among the seven coastal districts. The rank order of districts for potential impacts and that for vulnerability, including the adaptive capacity, is fairly similar. An Minh, An Bien, and Kien Luong appear districts most exposed, whereas Chau Thanh, An Bien, and Rach Gia appear districts most sensitive. An Bien, An Minh, and Ha Tien appear districts with highest potential impacts. The adaptive capacities of Rach Gia and Kien Luong mean they are the least vulnerable, which reflects how adaptive capacity helps these districts. The rankings of Chau Thanh and Rach Gia, however, were discrepant. The vulnerability for Chau Thanh ranked at 5 (relatively high) as a result of aggregate of moderate potential impacts and adaptive capacity (ranked at 4), while the vulnerability for Rach Gia ranked at 3 (relatively low) as a result of aggregate of low potential impacts (ranked at 2) and the least adaptive capacity (ranked at 1, very low). Therefore, the rankings for other districts should be interpreted with caution.

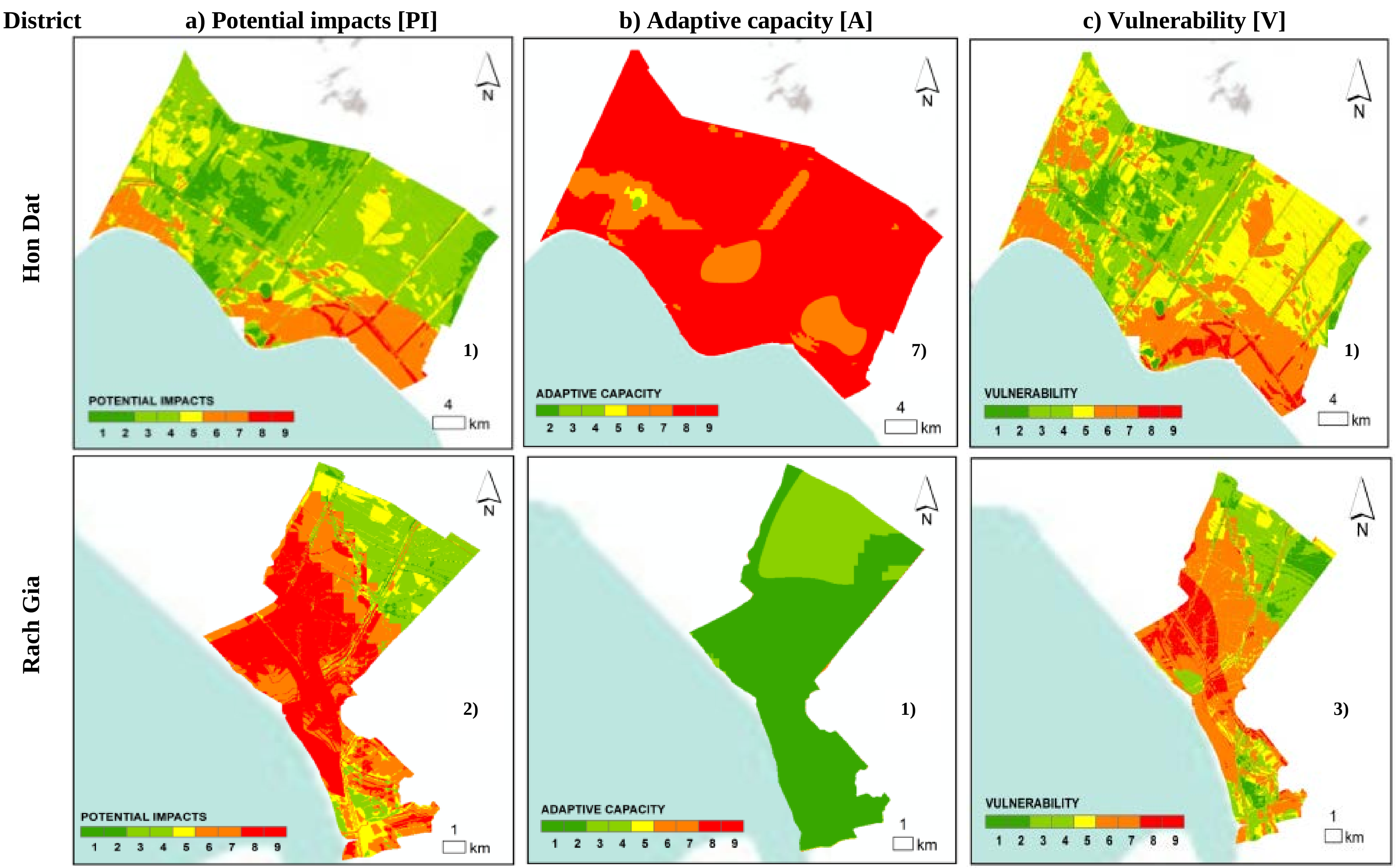
Kien Giang, especially the seven coastal district areas, is a highly vulnerability part of the MRD. First, it experiences relatively high exposure to salinity, flood, and moderate loss of mangroves which characterise the coastal fringe of each district. Second, those areas found to be most sensitive tended to have moderate population density, generally with a large rural population and high numbers of ethnic households with limited availability of agricultural land. Third, many aspects of adaptive capacity could only be represented at district scale, with the least adaptable areas consisting of high numbers of poor households, low income, and moderate densities of transport, irrigation and drainage systems. Hon Dat, Kien Luong, Rach Gia, and Ha Tien appear to be the districts with the least vulnerability, while An Bien, An Minh, and Chau Thanh appear districts with most vulnerability. Rach Gia and Ha Tien are

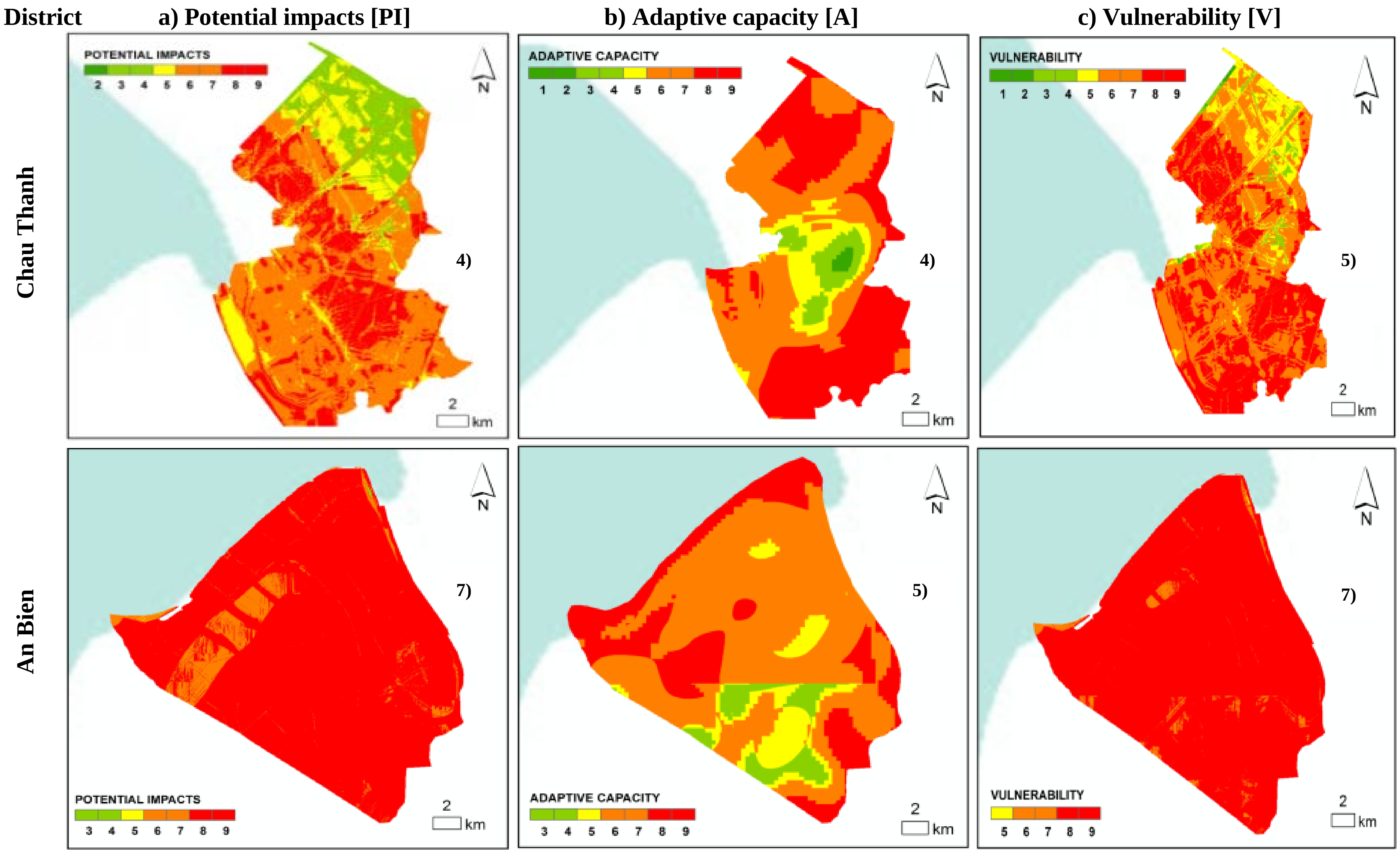
urban areas, in fact they have many options to adapt (e.g., good income, education, and health care). On the other hand, An Bien is particularly low-lying, and after a reduction of a thin line of mangroves, much is already at risk of inundation at high tide.

Subsidence of deltas has been shown to be a threat that can accentuate relative sea-level rise at rates well in excess of the global mean rate of sea-level rise (Syvitski, 2008; Syvitski et al., 2009). Subsidence has been omitted in this study as there is no data on the rate of subsidence for this part of the MRD. Recent assessment of subsidence rates based on drawdown of groundwater compared with interferometric synthetic aperature radar (InSAR), indicates that subsidence rates are likely to be of the order of 1 cm/yr, exceeding rates of eustatic sea-level rise in the Kien Giang region (Erban et al., 2014). This will exacerbate the threat to low-lying areas like An Bien and An Minh.

District **a) Potential impacts [PI]** **b) Adaptive capacity [A]** **c) Vulnerability [V]**




District
a) Potential impacts [PI]
b) Adaptive capacity [A]
c) Vulnerability [V]
Hon Dat
Rach Gia
POTENTIAL IMPACTS
1 2 3 4 5 6 7 8 9
ADAPTIVE CAPACITY
2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
VULNERABILITY
1 2 3 4 5 6 7 8 9
N
4 km
1 km
1)
7)
1)
2)
1)
3)


District
a) Potential impacts [PI]
b) Adaptive capacity [A]
c) Vulnerability [V]
Chau Thanh
An Bien
POTENTIAL IMPACTS
2 3 4 5 6 7 8 9
4)
2 km
ADAPTIVE CAPACITY
1 2 3 4 5 6 7 8 9
4)
2 km
VULNERABILITY
1 2 3 4 5 6 7 8 9
5)
2 km
N
7)
POTENTIAL IMPACTS
3 4 5 6 7 8 9
2 km
5)
ADAPTIVE CAPACITY
3 4 5 6 7 8 9
2 km
7)
VULNERABILITY
5 6 7 8 9
2 km

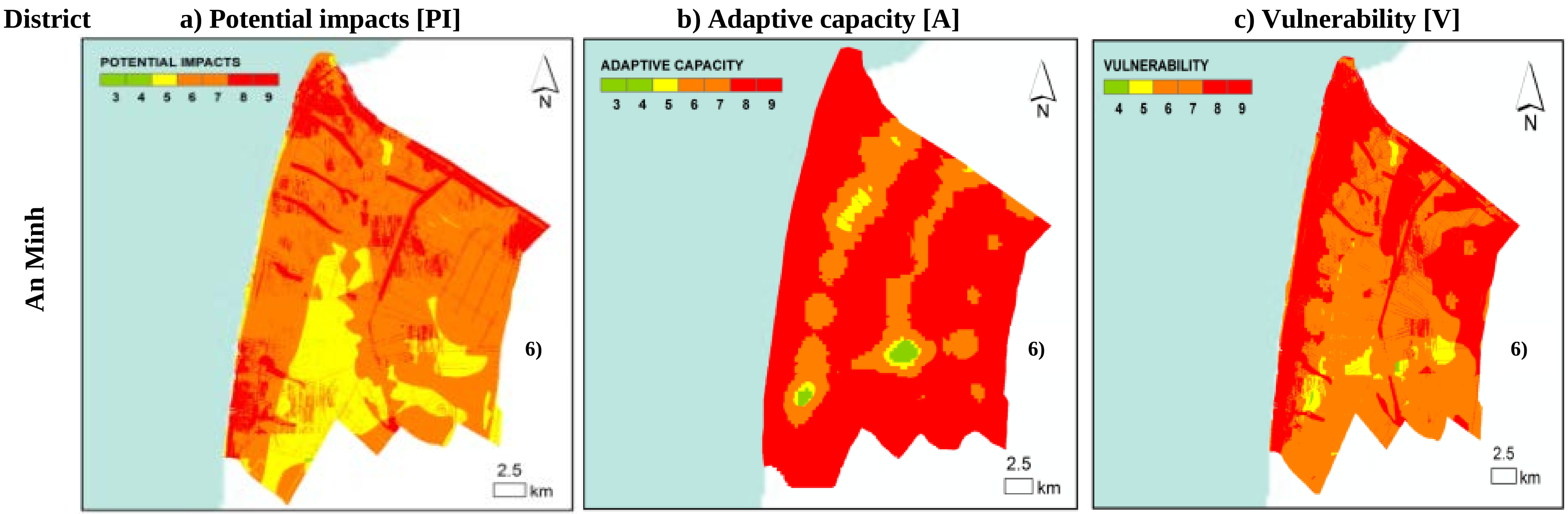


Figure 6.12 GIS-AHP mapping of the final vulnerability study: a) potential impacts [PI][14]; b) adaptive capacity [A][28]; and c) vulnerability [V][29] for each district, comprising Ha Tien, Kien Luong, Hon Dat, Rach Gia, Chau Thanh, An Bien, and An Minh.

Note: Numbers are in each map that indicating overall aggregated rankings of each coastal district in representing potential impacts, adaptive capacity, and vulnerability, respectively (see Table 6.12).

[28] Extracted from the adaptive map in Figure 6.8b.
[29] Extracted from the vulnerability map in Figure 6.10b.

Figure 6.12 gives a summary of extracted maps for each district, comprising potential impacts on the left hand side a), adaptive capacity in the middle b), and aggregated vulnerability on the right hand side c). Maps of the vulnerability reflect the maps for potential impacts. There are larger areas indicating high to very high vulnerability in the maps for An Minh, Hon Dat, and Chau Thanh, whereas there are less areas indicating high to very high potential impacts for Kien Luong and Rach Gia. The map of vulnerability for An Bien looks the same as the map of potential impacts. Maps show the relative variability in a district. Areas shaded green indicate strong adaptabilities, (i.e., high capabilities of road, canals, electricity to reduce potential impacts), whereas areas shaded red indicate weak adaptive capacity. However, if socioeconomic and infrastructure input data were available at finer resolution, this might influence the outcome. The maps of adaptive capacity for Hon Dat and An Minh look almost entirely red, whereas that for Rach Gia looks green. These maps give policy makers or planners, especially local authorities (at provincial or district level), and communities, a generalised overview of potential impacts, indicate adaptability, and enable users to identify and visualise which areas are likely to be most vulnerable, related to seawater incursion, flood risk, shoreline erosion and human effects.

Relative weights of variables for the coastal vulnerability assessment for the study area were obtained from AHP and are summarised in Appendices 20 and 21.

$$\mathbf{Layer_V} = \mathbf{0.6428} * \text{layer}_{PI} + \mathbf{0.3572} * \text{layer}_A$$ **[Equation 6.5[30]]**

$$\Leftrightarrow \mathbf{Layer_V} = \mathbf{0.4359} * \text{layer}_E + \mathbf{0.3413} * \text{layer}_S + \mathbf{0.2227} * \text{layer}_A$$ **[Equation 6.6[31]]**

Results in Equation 6.5 summarise the relative weights of potential impacts, and adaptive capacity, whereas those in Equation 6.6 summarise the relative weights of the three key components: exposure, sensitivity, and adaptive capacity, both in order to represent the final vulnerability. The relative weight of potential impacts was 0.6428, while the relative weight of adaptive capacity was 0.3572. On the other hand, the relative weights were 0.4359 for exposure, 0.3413 for sensitivity, and 0.2227 for adaptive capacity, with its acceptable CR which was 0.0005 (see a summary in Appendix 21). It is important to bear in mind that changing the priorities of variables (changing the subjective judgements) based on pair-wise

[30] See Appendix 20.
[31] See Figure 6.10.

comparisons can influence the outcomes (see an evaluation of representing the exposure in the previous chapter, sub-section 5.3.5.2).

6.4.3.2 Evaluation of the vulnerability outcome

Scale-based approaches of input data, representing three components obtained within district level: exposure (see chapter 5, sub-section 5.3.5.1), sensitivity (see sub-section 5.4.4.2), and adaptive capacity (see sub-section 6.3.5.2), were aggregated in order to examine the final vulnerability outcome. Figure 6.13 presents GIS-AHP mapping of the vulnerability within district level. This vulnerability map was reclassified into 9 categories by using Jenks, and mapped using 5 levels from very low to very high, with proportions of the study area reported in Table 6.13. Relative weights of components, were obtained simultaneously (see Appendix 23).

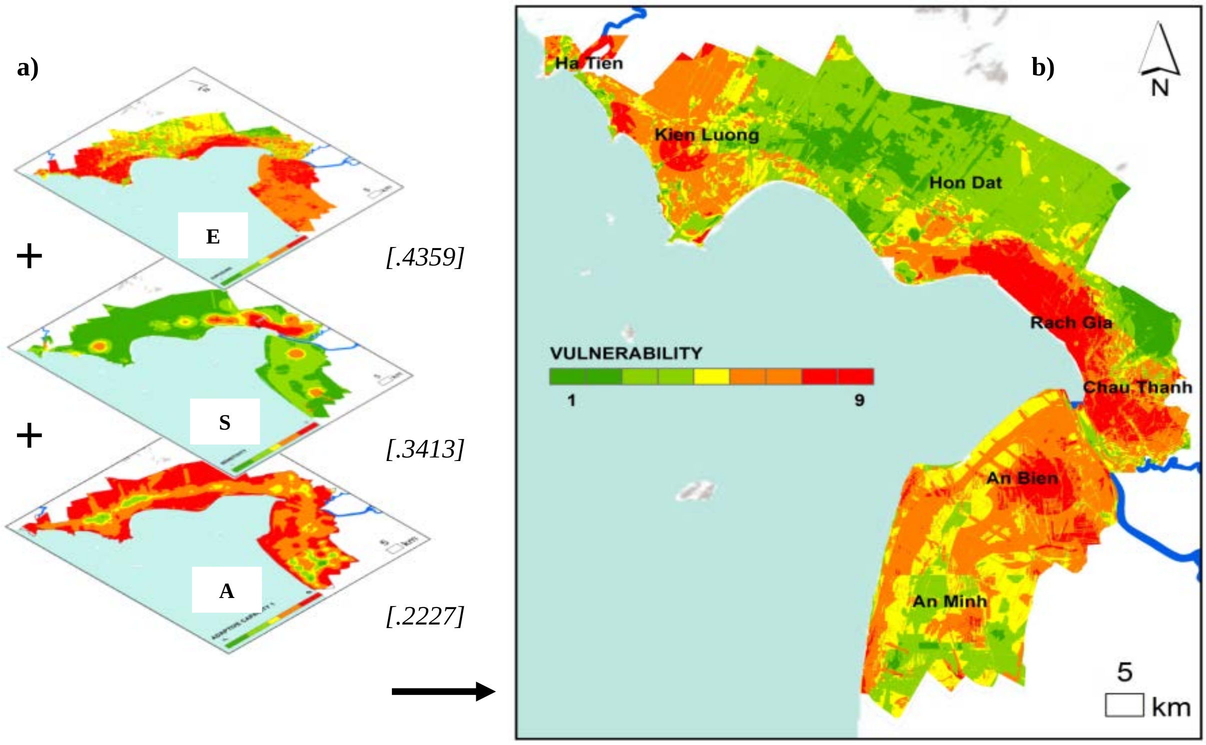


Figure 6.13 GIS-AHP mapping of the vulnerability within district level: a) aggregate of components: exposure [E], sensitivity [S], and adaptive capacity [A]; and b) reclassified vulnerability [V].

Note: [E] as presented in Figure 5.7c, [S] in Figure 5.12c, and [A] in Figure 6.9c.

The analyses from a comparison between the final vulnerability at an entire district (see Figure 6.10b and Table 6.11), and the vulnerability within district level (see Figure 6.13b and Table 6.13) indicate that there was an extent of very high to high vulnerability (shaded red and orange) in the final vulnerability at an entire district (63.94%, ~191 800 ha), compared to

only 43.43% (~130 300 ha) for those within district level. Particularly, proportions representing very high vulnerability (shaded red) was 27.91% (~78 879 ha) for the vulnerability at an entire district, whereas only 11.52% of total area (~32 736 ha) for the vulnerability within district level. This finding again supports the idea that finer data would help produce better maps. Moreover, as seen in Figure 6.13b, shaded red indicates areas most likely to be densely populated. These areas will be discussed in the following sub-section.

6.4.3.3 Sensitive analysis using ModelBuilder with weighted overlay

The overall aim of this sub-section is to test how sensitive the vulnerability map is to concerning weightings using ModelBuilder (MB). MB is an application in ArcGIS allowing you to create, edit, modify and share your models as tools. It can also be thought of as a visual programming language for building workflows, therefore, can minimise time running analyses with different parameters. It is possible to repeat procedures, modifying values used in AHP priorities. The objectives of this sub-section are two-fold. The first objective is to evaluate the vulnerability outcome in terms of considering weightings using MB with the weighted overlay tool[32], compared to those using AHP. The second objective is to further support the idea of using MB with the weighted overlay tool, and supplement AHP, both can be applied in order to represent the vulnerability at local scale.

Percentages of influence of parameters, (e.g., sub-variables, variables, sub-components, and components) representing the vulnerability by using the weighted overlay in MB, were adopted from the relative values of those using AHP. For instance, relative weights of three components, exposure, sensitivity, and adaptive capacity representing the aggregated vulnerability by AHP were 0.4359, 0.3413, and 0.2227 out of 1, respectively (see Equation 6.6). Percentages of influence of exposure, sensitivity, adaptive capacity by using the weighted overlay in MB, therefore, were 44%, 34%, and 22% out of 100%, respectively. MB was used in order to represent the aggregated vulnerability map. Figure 6.14 shows four attempts to test influence of two different methods of processing data.

[32] It is one of the Spatial Analyst Tools, aims to overlay several rasters using a common measurement scale, and weights each according to its importance.

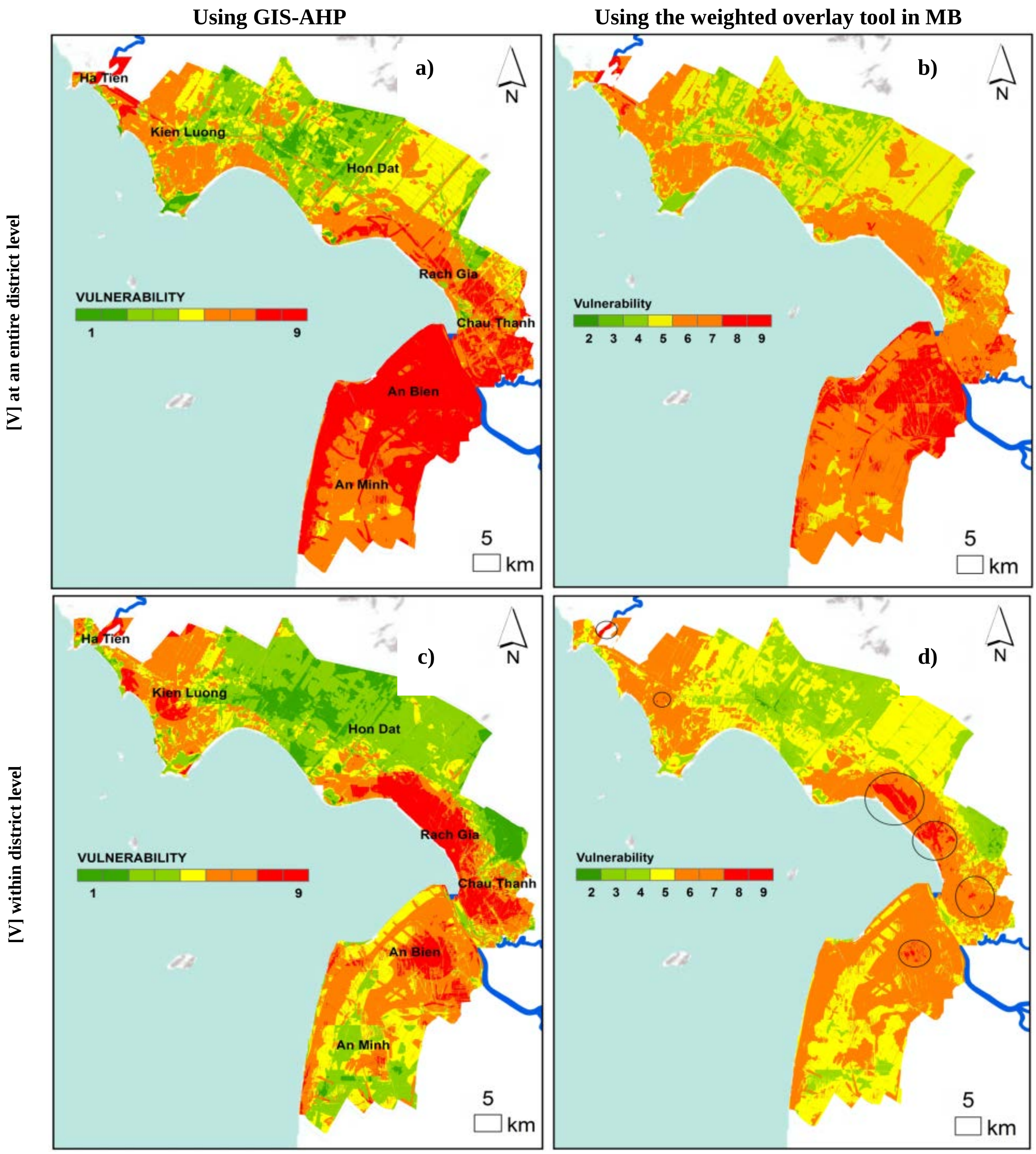


Figure 6.14 Mapping of the vulnerability outcomes: the final vulnerability at an entire district a) obtained from AHP[33] and b) obtained from the weighted overlay[34]; the vulnerability within district level c) obtained from AHP[35] and d) obtained from the weighted overlay[34].

Note: a) presented in Figure 6.10, and c) in Figure 6.13; b) and d) in Appendix 24.

In Figure 6.14, the left hand side a) and c) presents the vulnerability outcomes by using AHP, whereas the right hand side b) and d) displays the vulnerability outcomes by using the

[33] See Figure 6.10.
[34] See Appendix 24.
[35] See Figure 6.13.

weighted overlay in MB. These vulnerability maps were reclassified into 9 categories by using Jenks, and mapped using 5 levels from very low to very high, shaded as for these maps, with proportions of the study area reported in Table 6.13.

Table 6.13 A comparison of proportions of the study area classed as very high to very low in representing the vulnerability outcomes, respectively.

Coastal district	Vulnerability using AHP or the weighted overlay in MB, % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6 - 7	Very high 8 – 9
[V] for an entire district in a)	4.46	14.87	16.74	36.03	27.91
[V] within district level in *b)*	0.02	10.85	27.61	50.15	11.37
[V] for an entire district in c)	9.54	31.96	15.08	31.91	11.52
[V] within district level in *d)*	0.23	18.89	35.77	43.30	1.81

Note: a) as presented in Table 6.11 and c) results using AHP, whereas b) and d) results using MB with weighted overlay.

Table 6.13 shows comparisons of these four attempts. It indicates that the study area varies from moderate vulnerability with 43.43% of area (~127 874 ha) high to very high vulnerability obtained from the analysis of the vulnerability within district level by using the weighted overlay in MB (see Figure 6.14d), to high vulnerability (64%, ~184 700 ha) obtained from the analysis of the vulnerability at an entire district level by using AHP (see Figure 6.14a). Each analysis indicates that the study area appears to be highly vulnerable to potential impacts. There was a marked reduction of the proportion of the study area mapped as very high vulnerability (shaded red areas) in d) with only 1.81% (~5 128 ha), compared to 27.91% (~78 879 ha) in a). Different scale-based approaches and different relative weights of variables can influence the outcomes somewhat. Finer resolution data would help produce better maps. Vulnerability mapping is shown in Figure 6.14d that identifies and visualises a number of hotspots (shaded red) within the study area which are considered most at risk to the effects of sea-level rise. These hotspots will be extracted and further discussed in the following sub-section 6.4.3.4. On the other hand, it is noted that percentages of area (i.e., % of map) are a relative indicator. It is more important to look at the patterns in the maps. For instance, almost all (~100% of area) of An Bien and An Minh are mapped as highly vulnerable, but there are local areas of higher ground within each district which are not vulnerable.

Changing percentages of influence of sub-variables, variables, sub-components, and components using the weighted overlay in MB that are similar to that of changing relative

weights using AHP, therefore, can be generated different outcomes. Moreover, running analyses with different parameters by taking advantages of MB with the weighted overlay tool, can be independent or adopted from AHP that suggests for further studies.

6.4.3.4 Coastal vulnerability assessment at a settlement scale

The overall aim of this sub-section is to test areas, patterns, or hotspots representing very high vulnerability obtained from the vulnerability map. Figure 6.15 examines some hotspots (shaded red) obtained, extracted from the map showing the vulnerability levels within district level obtained (a finer scale) by using the weighted overlay in MB as preliminary outcome (see Figure 6.14d), as accounted to 1.81% of area (~5 128 ha) (see Table 6.13).

Finer data help produce better maps, but they are not always useful ones. In Figure 6.15, the left hand side a) shows hotspots, comprising Dong Ho, Binh San, and Phao Dai wards[36] along the left bank of the Giang Thanh River in Ha Tien; Kien Luong town in Kien Luong; Soc Son town in Hon Dat; Vinh Thanh, Vinh Thanh Van, Vinh Bao, and Vinh Lac wards in Rach Gia; Minh Luong town in Chau Thanh; and Thu Ba town in An Bien (see their population densities in Figure 6.16), as overlaid on Google Earth. On the right hand side c) showing some photos, some houses may be off ground so not flooded, but others will be flooded. Maps can not capture this level of detail. On-ground assessment of settlements shows several aspects that are not captured in general maps. This finding suggests that settlements may require further on-ground assessment. The visit to hotspot locations as identified in the analysis is a valuable contribution of the study that paid more attention to show the strengths and limitations of the vulnerability assessment methodology employed.

[36] A ward in Vietnam is subordinates to the second-level units, including district-level town or the provincial city or the urban district of centrally-controlled municipality. Currently, for management the urban areas and associating families, each ward is divided into neighbourhoods, the neighbourhoods is the organisation of population.

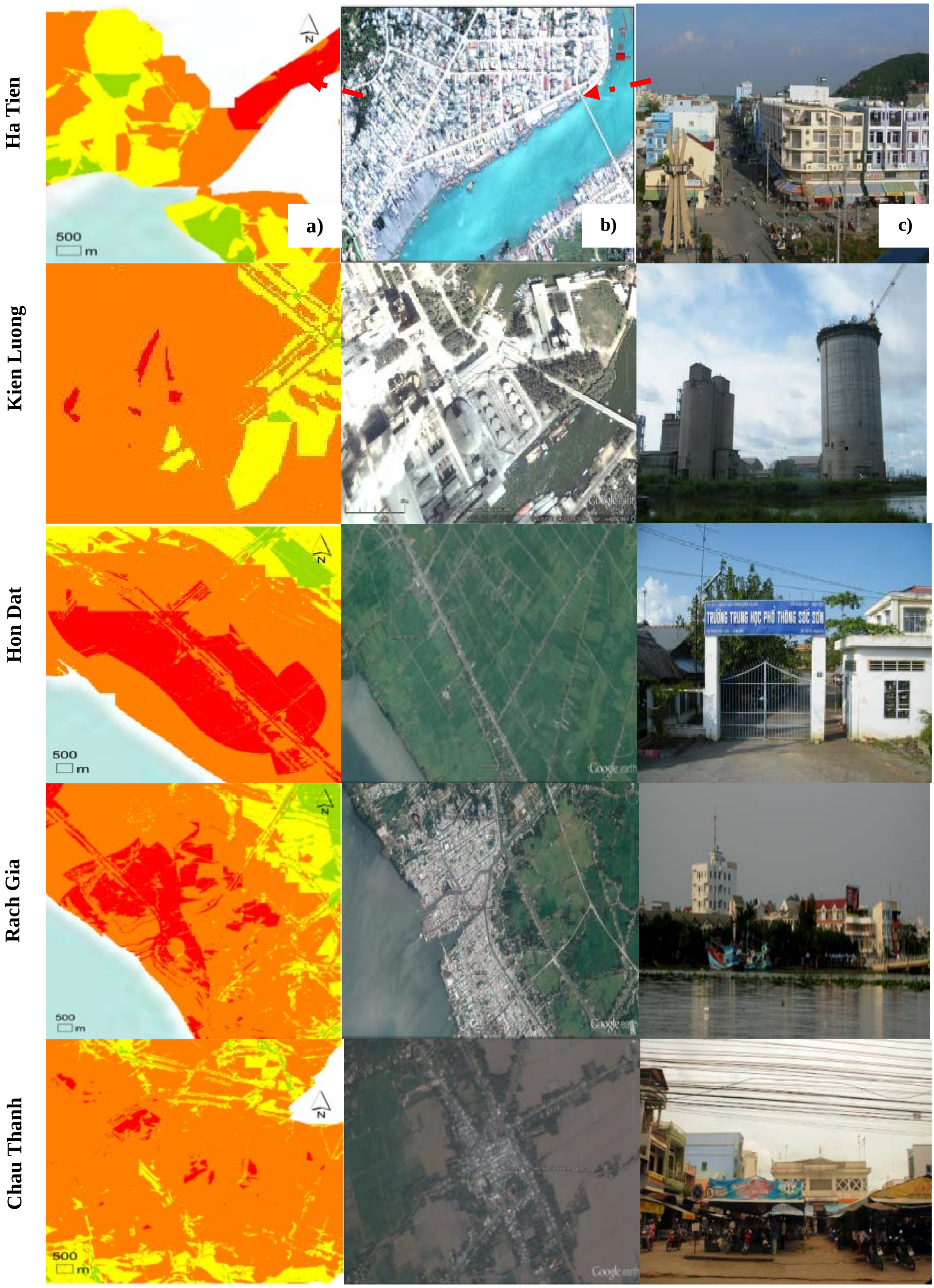

Ha Tien
a)
b)
c)
500
m
Kien Luong
Hon Dat
500
m
Rach Gia
500
m
Chau Thanh
500
m

Figure 6.15 Hotspots (shaded red) obtained from the evaluating vulnerability outcomes in Ha Tien, Hon Dat, Rach Gia, Chau Thanh, An Bien: a) obtained from the weighted overlay in MB; b) and c) relative images, and photos taken from the fieldtrip during the dry season in 2015, and obtained from Google Earth.

Note: a) presented in Figure 6.14d.

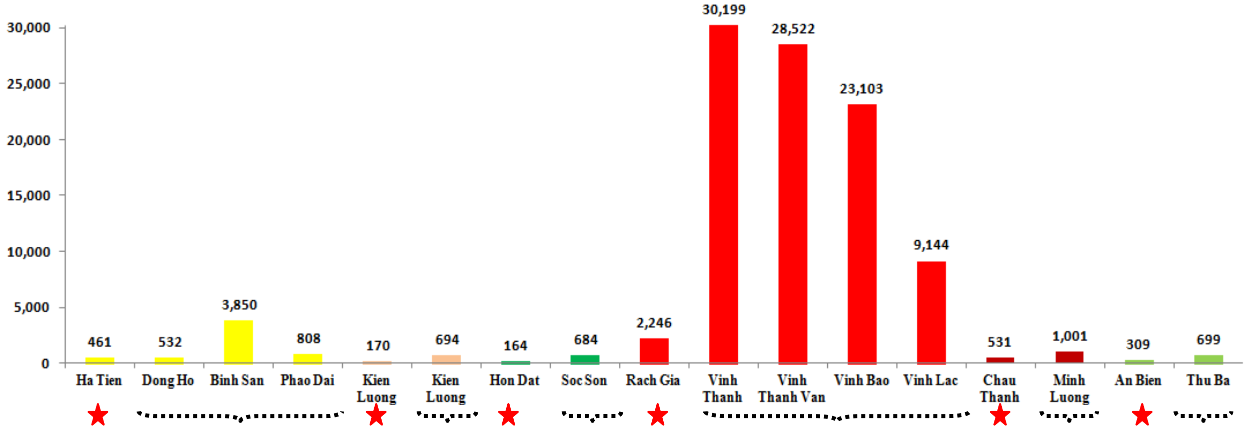


Figure 6.16 Population densities (inhabitants/km²) derived from the Kien Giang Statistical Office of hotspots obtained from evaluating vulnerability outcomes in towns, compared to their population densitites, on the average, in Ha Tien, Hon Dat, Rach Gia, Chau Thanh, and An Bien, respectively.

Note: (★): a district ~ a city level or a satellite town level; ⋯ a ward[36] or a town.

Figure 6.16 shows that the population densities in towns, particularly in wards in Rach Gia, were much higher than those on the average at district level. For some instances, on the one hand, the largest population density was 30 199 inhabitants/ km^2 for Vinh Thanh, followed by 28 522 inhabitants/ km^2 for Vinh Thanh Van, 23 103 inhabitants/ km^2 for Vinh Bao, and 9 144 inhabitants/ km^2 for Vinh Lac. The least proportion was 2 246 inhabitants/ km^2 on average for Rach Gia. On the other hand, Hon Dat was the least proportion on the average (164 inhabitants/ km^2), while Soc Son was much higher with its proportion at 684 inhabitants/ km^2. Generally, settlements in wards in Rach Gia and a town in Ha Tien appear hotspots most likely to be vulnerable due to an existing population at high density combined with large in-migration, a range of different industries and services contributing to households high income streams, a low number of poor households, the large area of the urban area and the

concentration of transport, and better access to health and education facilities. In addition to this, other towns in Hon Dat, Chau Thanh, and An Bien appear hotspots most likely to be vulnerable due to high population densities with a high number of rural households, a range of different agricultural activities contributing to households poorer access to other sources of income streams, limited access to health and education facilities compared to those in Rach Gia and Ha Tien.

The maps of vulnerability could be used as a starting point for subsequent discussions of the vulnerability and adaptive capacity among local government authorities (at district level), and settlements (hotspots) within the seven coastal districts in Kien Giang, and further discussed with provincial or state governmental levels. Therefore, while the assessment provides an indication of potential areas that should be considered further, ultimately more focused work is required to develop a comprehensive understanding of risk that may guide future management decisions.

Results of vulnerability from this study support the evaluations of Mackey and Russell (2011), as mentioned in the literature review chapter (chapter 2), who indicate that seven coastal districts along the Kien Giang coast are likely to be more vulnerable than other inland districts to potential impacts, such as flood, seawater incursion, and storm surge. Mackey and Russell (2011) have undertaken a study to identify the comparative vulnerability and adaptive capacity of natural and human systems, across four sectors: socioeconomic, agriculture and livelihoods, urban settlements and transport, energy and industry, among particularly vulnerable geographic hotspots (a district boundary). They adopted a standard comparative vulnerability and risk assessment methodology and framework, that comprised 15 districts in the inland of Kien Giang province. Their findings on overall rankings of vulnerability for each district, however, are different. They indicated that rankings of vulnerability for each district were currently low, becoming low to moderate (particularly Rach Gia appears to be the most vulnerable district) in 2030, and moderate to high (particularly Rach Gia, Hon Dat, and Chau Thanh appear to be most vulnerable districts) in 2050. Reasons can be:

- First, the vulnerability assessments in both studies were based to some extent on subjective judgements. In the study by Mackey and Russell (2011), the process started with team meetings designed to develop questionnaires that were used to survey officials. In addition to this, the questionnaire was designed to provide data for measures and indices,

considered to be useful by the experts in each sector. It is important to keep in mind the possible bias or over-estimate in these results obtained, when undertaking simultaneous comparisons of many variables selected at a time (more than 7 ± 2 variables) as previously mentioned in chapter 3, section 3.4. In this study, AHP was used to permit explicit exhibition of appraisement variables, and handle complicated situations where different weights are assigned, with the accepted inconsistency for judgements. However, these are also subjective in some cases.

- Second, biophysical vulnerability assessments in Mackey and Russell (2011) were based on a range of time horizons for impacts seawater incursion (a period of 1998 - 2050), and river-flood depth (2000 - 2050), while in this study, the current biophysical factors were based on impacts of seawater incursion (a year 2010), flood risk (a year 2000, combined with elevations) and shoreline erosion of 40 years (1973 - 2013).
- Finally, social vulnerability assessments in Mackey and Russell (2011) were based on statistical data provincially across four sectors from 2010, and conducted at an entire district level, while in this study, the social factors were based on data from 2011, and conducted using different scale-based approaches. The outcomes in social factors, therefore, may have changed over time and space, respectively.

Vulnerability maps should be interpreted with caution in the context of the framework used to generate the vulnerability and the limitations imposed by the methods (Preston et al., 2011). One must also be cautious in how one interprets "very high" or "very low" estimates of vulnerability. Vulnerability estimates should not be viewed here in such absolute values, but rather in a more relative context, based on the subjective judgements. Questions of "*vulnerability of what*" and "*vulnerability to what*" are also related to how vulnerability mapping exercises represent proxy data. Hotspots or areas indicated by shaded red identified as being most vulnerable are presumed to have a greater likelihood of experiencing an adverse effect than those that are least vulnerable, even if the nature, absolute probability, or severity of the impacts remains unknown. Therefore, vulnerability cannot necessarily provide information on where development activities should be restricted, or where management planning should be taken into account, but it can support identification of areas which require further examination and investigation (Preston et al., 2008). The maps of vulnerability in the seven coastal districts along the Kien Giang coast could be used as a starting point for subsequent discussions of the vulnerability and adaptive capacity among local government

authorities (at district level), and settlements or hotspots (within district level), and further discussed with provincial or state governmental levels. Therefore, while the assessment provides an indication of potential areas that should be considered further, ultimately more focused work is required to develop a comprehensive understanding of risk that may guide future management decisions.

6.5 Summary of this chapter

This chapter describes the first attempt to assess the adaptive capacity using the Spatial Analyst tools and the AHP tool. Thirteen sub-variables and nine variables were used, aggregated into the three sub-components, comprising socioeconomic, technological, and infrastructure capabilities (see Table 6.1). The analysis showed that generally the adaptive capacity of the study area was considered relatively low; with 81% of area low to very low adaptability to manage the impacts, therefore, scarcely reducing the vulnerability.

This chapter also aimed to examine the vulnerability levels, when the adaptive capacity was combined with potential impacts. This enabled identification and prioritisation of hotspots or patterns, and areas most likely to be vulnerable to impacts of climate change, particularly sea-level rise. A hierarchical structure of 24 sub-variables and 22 variables, combined into 8 sub-components of the three key components: exposure, sensitivity, and adaptive capacity, was used in representing the vulnerability levels.

Table 6.12 gives a summary of overall aggregated rankings of the seven coastal districts final vulnerability, comprising the three components: exposure, sensitivity, and adaptive capacity. The analysis indicated that An Bien, An Minh, and Chau Thanh appeared to be the most vulnerable districts, while Hon Dat, Kien Luong, and Rach Gia appeared to be the least vulnerable districts.

Scale-based approaches using AHP have been conducted to examine the adaptive capacity and the vulnerability outcomes. Particularly, variations of input data within district level were used to evaluate these mapping outcomes. Furthermore, the weighted overlay was used in MB to compare the effect of different weightings, in order to evaluate the vulnerability outcomes. Figure 6.14 is therefore meant to assist policy makers, or planners, in identifying areas or hotspots most likely to be vulnerable, indicated by shaded red. But policy making needs to

keep in mind the specificities and limitations of empirical research, and the different scale-based approaches, and social contexts. Coastal settlements within the study area were preliminary tested, and are shown in Figures 6.15 and 6.16. Conclusions, together with future research directions will be discussed in the last chapter.

Chapter Seven

Conclusions and future directions

7.1 Introduction

Coastal areas are highly vulnerable to sea-level rise. Capacity to cope with the impacts of sea-level rise in coastal areas is especially significant because many megacities are located along the coast and the existing problems due to high exploitation of resources in coastal areas may be exacerbated by climate change risks. Developing and implementing effective adaptation options are crucial for future development. The Mekong River Delta plays a staple role for the region in terms of food security and socioeconomic development in Vietnam; however, it is widely considered as one of the most low-lying and densely populated areas in the world. It is vulnerable to seawater incursion, flood risk, and shoreline change, exacerbated as a consequence of climate change, particularly sea-level rise. Therefore, management of these impacts is a priority at all levels in Vietnam, particularly the local level. This study examined the seven coastal districts of the Kien Giang coast in the western part of the delta, the economy of which is important in terms of agriculture and aquaculture.

A comprehensive coastal vulnerability assessment needs to assess both physical and social factors, combining exposure and sensitivity in relation to potential impacts, as well as adaptive capacity (Soares et al., 2012). The overall aim of this thesis was to enable identification and prioritisation of hotspots, or areas most likely to be vulnerable, specifically for Kien Giang. It attempted to look at the local level, comprising the seven coastal districts, by using GIS and MCDM. The site-specific assessments were intended to further assist the local authorities and communities in better coastal management and conservation. This chapter presents the key contributions of the research, its implications and recommendations for future studies for coastal vulnerability assessments of the MRD.

As a result, several regional patterns emerged. First, relatively high exposure to salinity, flood risk, and moderate loss of mangroves characterised the coastal fringe of each district. Second, those areas found to be most sensitive tended to have moderate population density, generally

with a large rural population and high numbers of ethnic households with limited availability of agricultural land, although societal factor sensitivity could only be represented at district scale. Third, the least adaptable areas consisted of high numbers of poor households, low income, literate but educational standard not high, poor healthcare services, and moderate densities of transport, irrigation and drainage systems, although several aspects of adaptive capacity could only be represented at district scale. Finally, most coastal districts were determined to be of relatively moderate to high vulnerability, with scattered hotspots along the Kien Giang coast, particularly in the settlement areas.

7.2 Research contribution

This study attempts to fill research gaps to provide a comprehensive analysis of coastal vulnerability in terms of climate change induced sea-level rise, by aggregating local physical and social effects in relation to three key components: exposure, sensitivity, and adaptive capacity. It makes significant contributions in three areas, including: 1) the concept of vulnerability, 2) methodology, and 3) application to coastal vulnerability assessment:

1) Regarding the concept of vulnerability: first, the literature review chapter indicates that there are various concepts of vulnerability in the context of climate change and its impacts. The present study is considered to be the first empirical study at a local scale for a key section of the MRD to map all three components, exposure, sensitivity, and adaptive capacity, consistent with the IPCC's concept of vulnerability to the impacts of climate change, and sea-level rise. Second, the literature review chapter also indicates that a majority of vulnerability assessments have considered biophysical factors and relatively few examine social factors. This study is one of only a few empirical studies to rigorously apply both biophysical and social aspects in representing vulnerability. Third, many studies have contributed to expanding scientific knowledge about the risks posed by climatic variability to agricultural production and water resources in the MRD. However, such studies have mainly concentrated on analysis at regional and national scale, with fewer at local scale. This thesis is innovative because it applies analysis at different spatial scales, focused mainly on the local scale.

2) Regarding the methodology: the present study is one of only a few empirical studies to examine multi-criteria-based approaches in vulnerability assessments (i.e., indicator and mapping-based approaches to vulnerability assessment). Doing so, first, the present study is one of only a few empirical studies to examine multi-criteria-based approaches in

vulnerability assessments. The framework adopted from the European Environment Agency undertaken by Schauser et al. (2010) was proposed for this assessment, and is presented in chapter 3 (Figures 3.1 and 3.3). Second, six variables were used in representing the three sub-components of the exposure component for the study area (see chapter 5, section 5.3). Third, eleven sub-variables and seven variables were used in representing the two sub-components of sensitivity (see section 5.4). Fourth, thirteen sub-variables and nine variables were used in representing the three sub-components of the adaptive capacity (see chapter 6, section 6.3). Finally, the three main components exposure, sensitivity, and adaptive capacity, were used in the aggregated vulnerability for the study area (see section 6.4).

This research, on the other hand, examined weighting of factors by using the AHP multi-criteria-based approach, an extension tool run in ArcGIS, for the vulnerability assessments. This is an objective way to handle many variables or rank them based on pair-wise comparisons. Moreover, this combination of GIS and AHP enhances the analysis by reducing the time spent in considering other complicated weighting methods. The results obtained enable visualisation, and prioritisation of the hotspots, or areas that appear most likely to be vulnerable.

3) Regarding the application: vulnerability maps are just one of a number of tools that were utilised in the study to elicit information about adaptive capacity. In addition, local authorities, and policy makers may be able to respond to the vulnerability maps to identify potential strengths or weaknesses, creating the opportunity for revision of the vulnerability maps in light of new insight, information, and data.

This assessment of climate change vulnerability represents a starting point for further exploration of vulnerability and adaptive capacity within the entire Kien Giang province, which could be extended to the other six coastal provinces, and their districts. Moreover, this research represents only a preliminary examination of vulnerability at the settlement scale. The research findings provide a basis for further study at a finer scale. Future more site-specific assessments might further assist the local authorities and communities in better coastal management and conservation of hotspots.

7.3. Directions for future research

The current research is exploratory work and there is much more that could be done. Findings from this study are significant in explaining how spatial and temporal factors, particularly social factors, can affect the mapping of vulnerability outcomes. In addition to this, the

application of GIS-AHP is a useful technique in order to visualise, and prioritise hotspots or areas most likely to be vulnerable to the potential impacts. The following ideas are recommended for future study of the coastal vulnerability assessments:

1) This study indicates that GIS-based multi-criteria analysis, involving weightings using AHP, can be used for coastal vulnerability assessments at the local scale. The integrated GIS-AHP framework can be easily re-run in ArcGIS ModelBuilder with adjusted weightings reducing the limitations of other less-tested methods, with potential to improve decision making and the quality and consistency of decisions.

2) As weighting of the variables might be considered subjective judgements, it is suggested that future contributions might adopt rankings proposed by groups of local experts, scientists, policy makers, and particularly local communities, in terms of prioritisation of variables, in order to generate increasingly objective outcomes.

3) Further mapping of this kind could be easily and effectively applied in relevant coastal areas along the coast of the Mekong River Delta in Vietnam (e.g., coastal districts along the western side of Ca Mau) adopting the framework proposed for this vulnerability assessment.

4) This study provides support for the suggestions from the coastal vulnerability assessment using AHP that the inclusion of social factors (e.g., public awareness, policy foundation, and governance) for coastal vulnerability index assessment should be encouraged.

5) As data becomes available, the approach can be applied further at finer scales, such as the settlement scale, identifying, as shown in the previous chapter, coastal settlements, or individual households within them, that are considered hotspots. It will be more significant to consider local issues such as appropriate sustainable adaptation strategies, at these finer scales.

7.4. Conclusion

This study demonstrates comprehensive approaches to provide quantitative and qualitative information to guide the process of adaptation, and provide visualisations that will enhance local authority’s decision making to adapt to climate change, particularly sea-level rise. Based on the concept of vulnerability discussed, and methods integrated into the GIS-AHP framework, biophysical and social effects have been mapped over different space and time scales to visualise and prioritise hotspots and areas most likely to be vulnerable to the

potential impacts. The study, applied in Kien Giang, has been able to draw the following conclusions:

1) The study has yielded new insights, in terms of the concept of vulnerability, comprising three components: exposure, sensitivity, and adaptive capacity; and multi-criteria and holistic vulnerability mapping using AHP with scale-based approaches which have been conducted to examine these three components and the vulnerability outcomes for case studies (e.g., seven coastal districts along the Kien Giang province, a commune scale, hotspots).

2) Mappable factors, including biophysical and social data were combined based on pair-wise comparisons to develop a final composite vulnerability index, visualisation and prioritisation and targeting of adaptation strategies. In particular, estimates of adaptive capacity enable policy makers and other stakeholders to adopt suitable strategies in order to enhance the adaptive capacity or resilience of the system to respond to the impacts of climate change.

3) The results highlight, and suggest the wider implications, beyond the case study area for other localities and situations confronting similar challenges.

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Appendices

Appendix 1 A review of vulnerability indices used to assess vulnerability to impacts of climate change.

No.	Name of indicator	Purpose	Scale (spatial/ temporal)	Methods/ Tools (Aggregation)	Exposure	Sensitivity	Adaptive Capacity	Reference
	Overall vulnerability							
1	An overall vulnerability indicator	Estimate & compare overall vulnerability of very different cities	Cities observed trend & projections for 2050s	City experts	1. Temperature 2. Precipitation 3. Sea-level 4. Tropical cyclone 5. Drought 6. Heat waves	1. Population 2. Density 3. Percent slum population 4. Percent of urban area susceptible to flooding 5. City % of national GDP	*Institutions and Governance* 1. Urban governance (corruption index ranking for city) 2. City leadership is willing to address climate change *Information and Resources* 3. Comprehensive analysis of climate risks for the city 4. Administrative unit assigned to address climate change 5. Balance between adaptation & mitigation	Mehrotra et al. (2009)
	Climatic threat/ issue: Heat wave: Higher temperatures, heat wave and health problems							
2	Heat vulnerability indicator	Neighbourhood level heat vulnerability assessment for the city of Toronto to assess cartographic design decisions in creating heat vulnerability maps	City, Toronto, Canada	Aggregation by specific multi criteria & cluster analysis methods	1. Surface temperature	19 components (related to dwellings, income, specific population groups, age classes)	Partly included in S	Rinner et al. (2010)
3	Heat waves vulnerability index	Components influencing the vulnerability of European populations to heat waves	European Regions	Not aggregated	1. Warm spell duration index 2. Tropical nights	1. Age classes 2. Age > 65 yrs	1. GDP 2. Education level	Harvey et al. (2009)
4	Cumulative heat vulnerability index	Cumulative heat vulnerability index for the USA to create maps for comparison & to give guidance at regional (county) & national scales for further analysis & intervention	At regional (county) & national, USA	Aggregated by principal component analysis	None	1. Race 2. Age ≥ 65 3. Living alone & age ≥ 65, 4. Diabetes 5. Area without vegetation	1. Poor 2. Education level 3. Living alone 4. Without central 5. Any air conditioning	Reid et al. (2009)

5	Vulnerability Indicators for Extreme Heat and Human Health	Vulnerability Indicators for Extreme Heat & Human Health for the region to initiate a dialogue among researchers & stakeholders & a bottom-up assessment of local governments	Regional, Sydney Coastal Councils Groups in 2030	Aggregation by summation of components values for each element, scoring, weighting based on expert values & summation of the elements values for vulnerability indicator	1. Present average January maximum temperature 2. Present average January minimum Temperature 3. Present # Days > 30°C 4. Projected change in average DJF maximum temperature in 2030 5. Land cover 6. Population density 7. Road density	1. % population≥65 years of age 2. % population≥65 years of age & living alone 3. % population≤4 years of age 4. % of housing as multiunit dwellings 5. Projected population growth to 2019	1. % population completing year 12 2. % population that speaks language other than English 3. Median home loan repayment 4. % home ownership 5. Median household income 6. % households requiring financial assistance 7. % population with internet access 8. Current ratios 9. Per capita business rates 10. Per capita residential rates 11. Per capita community service expenses 12. Per capita environment & health expenses	Preston et al. (2008)
6	Indicator for heat related risk	Heat related risk assessment & a generic framework for risk management	Local, Greater Manchester & Lewes	Normalised in classes, ggregated by unweighted addition	1. Daily max. & min. temperatures	1. Urban Morphology Types 2. Age > 75 3. Age < 4, 4. Population health 5. Residence dependency	None	Lindley et al. (2006)
	Climatic threat/ issue: Decreased precipitation, water scarcity and drought							
7	Indicators of vulnerability to climate change	Indicators of vulnerability to climate change to inform the pertinent political debate on international adaptation funding within the framework of the UNFCCC	Global	No aggregation suggested	3 variables (median & standard deviation of projected change in precipitation, median of the projected change in runoff)	3 variables (current population weighted precipitation, renewable water resources per person, water use ratio)	2 variables (households with improved water supply or with improved sanitation)	Füssel (2010)
8	The social vulnerability index for water availability	The social vulnerability index for countries in Africa is an aggregate index of human vulnerability to	Africa (country level) / water availability	Weights are applied to the indicators in forming the sub-indices, & then when aggregating the sub-		Natural resources sensitive to water stress & water availability	1. Economic well-being & stability 2. Demographic structure 3. Institutional stability 4. Strength of public	Adger and Vincent (2005)

		climate change-induced changes in water availability		indices to form the aggregate index, in keeping with the theory-driven nature of the index, & based on expert judgment			infrastructure 5. Global interconnectivity & dependence	
9	Drought vulnerability index	To assess vulnerability index to agricultural drought in Nebraska	In Nebraska	Each factor a relative weight was given between 1 & 5, & 5 is the most significant. 4 classes of vulnerability: low, low-to-moderate, moderate & high	1. biophysical: soil & climate	1. social: landuse & irrigation		Wilhelmi and Wilhite (2002)
10	Indicators for water resources	Indicators for water resources to investigate the integrated impacts of potential global warming	National, USA	Only graphical aggregation as percentage of thresholds	2 variables (Climate & economic scenarios, runoff ratio)	3 variables (Storage vulnerability, hydropower, water quality, coefficient of variation, dependence ratio)	5 variables (consumptive use, relative poverty, import demand ratio, withdrawal ratio)	Lane et al. (1999)
	Climatic threat/ issue: Wild fires							
11	Vulnerability Indicators for Bush Fires	Vulnerability Indicators for Bush Fires for the region to initiate a dialogue among researchers & stakeholders & a bottom up assessment of local governments	Regional, Sydney Coastal Councils Groups in 2030	Aggregation by summation of components values for each element, scoring, weighting based on expert values & summation of the elements values for vulnerability indicator	1. Present average maximum January temperature 2. Present # Days > 30°C 3. Projected change in average maximum DJF temperature in 2030 4. Present average annual rainfall 5. Present average annual 10th percentile rainfall 6. Projected average annual rainfall change in 2030	1. Annual primary production 2. Land cover 3. Slope 4. Aspect 5. Population density 6. Road density	1. % population completing year 12 2. % population that speaks language other than English 3. Median home loan repayment 4. % home ownership 5. Median household income 6. % households requiring financial assistance 7. % population with internet access & Current ratios 8. Per capita business rates 9. Per capita residential rates 10. Per capita community service expenses	Preston et al. (2008)

	Climatic threat/ issue: Fluvial floods, flood claims and health effects of flooding							
12	Flood Vulnerability Index (FVI) for river basins	To use 11 indicators (out of 40 indicators) divided in 4 components, 2 sub-indices, as a tool for assessing flood risk due to climate change in relation to underlying socioeconomic conditions & management policies	River basins	Acknowledged by a group of over 50 participants to the Asian Development Bank Water Week of 2004 in Manila	1. Frequency of heavy rainfall (I1) belonging to climate component (C) 2. Average slope (I2), urbanised area rationa (I3) belonging to hydro-geological component (H)	The human index, which corresponds to the social effects of floods & the material which covers the economic effects of floods: 1. TV penetration rate (I4), literacy rate (I5), population rate under poverty (I6), years sustaining healthy life (I7), population in flooded area (I8), infant mortality rate (I9) belonging to socioeconomic component (S) 2. Investment amount for structural measures (I10), investment amount for non-structural measures (I11) belonging to countermeasures component (M)		Connor and Hiroki (2005); Quinn et al. (2010)
13	Flood Vulnerability Index (FVI)	To develop a Flood Vulnerability Index methodology, based on 3 factors of vulnerability: exposure, susceptibility & resilience; these factors are interlinked with the three components, using 19 indicators	Coastal cities		1. Hydro-geological (sea level rise, storm surge, number of cyclones, river discharge, foreshore slope, soil subsidence, coastal line)		1. Socioeconomic (cultural heritage, population close to coastal line, growing coastal population, shelters, awareness/ preparedness, disable people, km of drainage, recovery time) 2. Politico-administrative (uncontrolled planning zones, flood hazard maps, institutional organizations & flood protection)	Balica and Wright (2009, 2010); Balica et al. (2009)
14	Indicator for river flooding vulnerability	Components influencing vulnerability of European urban areas to river flooding to raise awareness of river flooding risk & to identify hotspots for more detailed analysis	European urban areas	No aggregation suggested	1. River flows 2. River floods	1. Population density	1. GDP 2. Education level 3. Money spend on flood protection	Harvey et al. (2009)
15	Social vulnerability index in context to river-floods	Social vulnerability index in context to river-floods in Germany to generate information about people potentially flooded	Elbe & Rhine river valleys, Germany	Aggregation by component analysis & regression analysis to derive 3 most sensitive parameters (fragility, region, socio-economic conditions), which	None	1. Age >65 yrs 2. Population density 3. Housing type	1. Living space per person 2. Unemployment ratio 3. Education level	Fekete (2009)

				were combined to an index				
16	Indicator for flood vulnerability	Integrated urban flood risk assessment	Leipzig	Aggregation by multi criteria assessment to derive different risks (social, economic, land value, ecologic)	1. Depth of inundation	11 variables (landuse, classification of buildings, land values, affected population & special population groups per building, social hot spots, contaminated sites, soil erodibility, oligotrophic biotopes, protected biotopes, vulnerable trees)	None	Kubal et al. (2009); Meyer et al. (2009)
17	Spatial vulnerability based on flood modeling	Spatial vulnerability units for socio-economic flood modeling	Regional, urban areas	Aggregation based on multiple criterion analysis & on expert opinion (weights)	None	6 variables (with more sub-variables) (households & building uses, infrastructure length, assets, sensitive land covers age distribution, employments)	7 variables (with more sub-variables) (workforce in different economy sectors, size of companies/ workplaces, ecosystem integrity of sensitive areas, distance to health facilities & roads, early warning system available, origin of population, education level)	Kienberger et al. (2009)
18	Social Flood Vulnerability Index	Social Flood Vulnerability Index for communities	Communities, i.e., Manchester & Maidenhead	Aggregation by simple weighting & summation the components in an index. The index was classified in 5 bands	None	3 variables (long-term sick, single parents elderly > 75 yrs)	4 variables (unemployment, overcrowding, non-car ownership, non-home ownership)	Tapsell et al. (2002)
	Climatic threat/ issue: Intensive precipitation and urban drainage floods							
19	Vulnerability Indicators for Extreme Rainfall and Storm water Management	Vulnerability Indicators for Extreme Rainfall & Storm water management for the region to initiate a dialogue among researchers & stakeholders & a bottom up assessment of local governments	Sydney Coastal Councils Groups in 2030	Aggregation by summation of components values for each element, scoring, weighting based on expert values & summation of the elements values for vulnerability indicator	1. Present average annual rainfall 2. Present average 90th percentile annual rainfall 3. Projected change in extreme rainfall events in 2030	1. Land cover 2. Elevation 3. Slope 4. Drainage 5. Average soil water holding capacity 6. Population density 7. Road density 8. Projected population growth to 2019	1. % population completing year 12 2. % population that speaks language other than English 3. Median home loan repayment 4. % home ownership 5. Median household income 6. % households requiring financial assistance 7. % population with	Preston et al. (2008)

							internet access 8. Current ratios 9. Per capita business rates 10. Per capita residential rates 11. Per capita community service expenses	
	Climatic threat/ issue: Sea level rise and storm surge-driven flooding							
20	The coastal vulnerability index	The coastal vulnerability index to identify areas at risk of erosion &/or extreme climatic events	Coastal areas	Aggregation based on classification & ranking into one indicator	1. Average swell 2. Relative sea-level change tax 3. Average tidal range	1. Geology resistance 2. Erosion tax 3. Coastal slope	None	Gornitz (1991)
21	A multi-scale coastal vulnerability index: a tool for coastal managers	A multi-scale coastal vulnerability index based on coastal characteristics, coastal forcing, socioeconomic factors	A multi-scale			1. Coastal characteristics (solid geology, drift geology, shoreline type, elevation, river mouths, orientation, inland buffer) 2. Coastal forcing (significant wave height, tidal range, difference in storm & modal wave height, storm frequently)	1. Socioeconomic: (population, cultural heritage, roads, railways, landuse & conservation status)	McLaughlin and Cooper (2010)
22	Coastal sensitivity index	Coastal sensitivity index (CSI) to assess & characterise susceptibility	Coastal areas	Aggregation based on classification & ranking into one indicator		1. Relative sea-level rise 2. Mean wave height 3. Mean tidal range 4. Rock type 5. Coastal slope 6. Geomorphology 7. Barrier type 8. Shoreline exposure 9. Shoreline change	None	Abuodha and Woodroffe (2010)
23	Indicator for storm surge-driven flooding vulnerability	Components influencing the vulnerability of European urban coastal areas to storm surge-driven flooding to raise awareness of the potential increase in flooding events	European urban coastal area	No aggregation suggested	1. Sea-level rise projection 2. Change in height of storm surges)	1. Flooded people 2. Population density 3. Elevation & slope 4. Sea defences	1. GDP 2. Education level	Harvey et al. (2009)

24	Vulnerability Indicators for Sea-Level Rise and Coastal Management	Vulnerability Indicators for Sea-Level Rise & Coastal Management for the region to initiate a dialogue among Researchers & stakeholders & a bottom-up assessment of local governments	Sydney Coastal Councils Groups Up to 2019	Aggregation by summation of components values for each element, scoring, weighting based on expert values & summation of the elements values for vulnerability indicator	1. Distance to coastline 2. Present relative storm surge along Sydney Coastal Councils Groups coast 3. SEPP 71-defined sensitive coastal locations 4. Coastal elevation 5. Slope	1. Land cover 2. Population density 3. Road density 4. Projected population growth to 2019 5. Acid sulphate soils	1. % population completing year 12 2. % population that speaks language other than English 3. Median home loan repayment 4. % home ownership 5. Median household income 6. % households requiring financial assistance 7. % population with internet access 8. Current ratios 9. Per capita business rates 10. Per capita residential rates 11. Per capita community service expenses	Preston et al. (2008)
25	Indicators for coastal vulnerability assessment	Indicators for coastal vulnerability assessment at the regional scale to understand & manage the complexities of a specific study area	Regional, coastal areas	Aggregation by classification & GIS overlay to derive homogeneous units	None	1. Administrative units 2. Location of rivers 3. Geo-morphological characteristics 4. Wetland migratory potential 5. Coastal population density	None	Torresan et al. (2008)
26	Physical & social Vulnerability to sea level rise & storm-surge flooding	Physical & social vulnerability to sea-level rise & storm-surge flooding for local planners at a region to understand how sea-level rise will increase the vulnerability of people & infrastructure to hurricane storm surge flooding over the next century	Hampton Roads, metropolitan, Counties, cities, southeastern Virginia Next century	Aggregation by combination of statistical methods & combination of physical & social vulnerability	maximum surge heights, elevation	S, AC: different approaches: 1. 3 variables based on principal component analysis (current poverty, income, old age/ disabilities) 2. current spatial distribution of critical features 3. projected spatial distribution of population density Combination of current & future physical (based on storm-surge model) & social vulnerability (based on different approaches)		Kleinosky et al. (2007)
	Climatic threat/ issue: Erosion							

27	Spatial & numerical methodologies on Coastal Erosion and Flooding Risk Assessment	Spatial analysis based on GIS & numerical Modeling: DINAS-COAST & DIVA; CVAT, The Geomorphic Stability Mapping – GSM; CVI, Digital Shoreline Analysis System-DSAS & the Wind Fetch Model (ArcGIS extension tools)	The 3 case studies of beaches with historical sensibility to erosion & storm surge flooding presented a very good correlation with reality in southern Brazil					Bonetti et al. (2013)
28	To produce a social vulnerability index in terms of erosion hazard vulnerability	To use socioeconomic data from US- Census database in order to produce a social vulnerability index in terms of erosion hazard vulnerability	213 US coastal counties: socioeconomic variables (SoVI) placed in a principal components analysis (PCA) & physical variables (CVI)	An analysis of variance (ANOVA) for regional differences in the overall place (PVI), SoVI, & CVI (at the 95% confidence level)		6 physical variables (CVI)	39 availability data out of 42 socioeconomic variables (SoVI)	Boruff et al. (2005); Cutter et al. (2003); Thieler and Hammer-Klose (1999, 2000a, b)
	Social/ ecological vulnerability							
29	Social Vulnerability Index (SoVI) to environmental hazards	To define a robust set of variables that capture the characteristics of social vulnerability of counties, which then allows us to monitor changes in social vulnerability geographically & over time.	US counties Spatial: all 3,141 U.S. counties Temporal: 1990 data	After all the computations & normalization of data (to percentages, per capita, or density functions), 42 independent variables used, reduce to 11 independent components (76% of the variance). These components were placed in an additive model which equal weights to compute a summary score - the SoVI	None	1. Personal wealth (per capita income, % of households earning > $75,000/ year, median house values, & median rents) 2. Age (median age) 3. Density of the built environment (No. commercial establishments/mi^2) 4. Single-sector economic dependence (employed in extractive industries) 5. Housing stock & tenancy (housing units that are mobile homes) 6. Race-African American	None	Cutter et al. (2003)

						(African American) 7. Ethnicity-Hispanic (Hispanic) 8. Ethnicity-Native American (Native American) 9. Race-Asian (Asian) 10. Occupation (employed in service occupations) 11. Infrastructure dependence (employed in transportation, communication, & public utilities)		
30	To examine the vulnerability to climate change	Citizen participation in emergency response following the Loma Prieta Earthquake			Earthquake	1. The structure & health of the population: Age is an important consideration as to be inherently more susceptible to environmental risk & hazard exposure		O’Brien and Mileti (1992)
31	To study the coping mechanisms to environmental shock/ or hazard by biophysical vulnerability	Societal Vulnerability to Climate Change and Variability				1. Human population	1. Institutional stability 2. Strength of public infrastructure	Handmer et al. (1999)
32	To construct vulnerability resilience variables to climate change	To identify 10 proxies for 5 sectors of climate sensitivities & 7 proxies for 3 sectors of coping/or adaptive capacity	US	Proxies aggregated into sectoral variables, sensitivity variables & coping/ or adaptive capacity variables to finally construct vulnerability resilience variables to climate change		1. Settlement sensitivity 2. Food security 3. Human health sensitivity 4. Ecosystem sensitivity 5. Water availability	1. Economic capacity 2. Human resources 3. Environmental /or natural resources capacity	Moss et al. (2001)
33	Socioeconomic indicators of Community vulnerability to natural hazards	To use socioeconomic indicators of Community vulnerability to natural hazards/ disasters in Northern Australia & address limitations: ageing of the data, the	In Northern Australia		1. Tropical cyclones 2. Floods	1. Land data 2. Demographic indicators	1. Socioeconomic indicators	King (2001)

		arbitrary nature of boundaries, problems of weighting indicators, & categorisation of vulnerability						
34	The environmental vulnerability index (EnVI)	50 smart indicators used to capture a large number of elements in a complex interactive system while simultaneously showing how the value obtained relates to some ideal condition	Country level	Country experts, international experts, interest groups & other agencies judgments	The indicators are classified into 5 classes: 1. M = Meteorological 2. G = Geological 3. B = Biological 4. C = Country Characteristics 5. A = Anthropogenic classified into a range of sub-indices including: hazards, resistance, damage, climate change, biodiversity, water, agriculture & fisheries, human health aspects, desertification, & exposure to natural disasters; grouped into three sub-indices namely: REI = Exposure to human & natural risks per hazards; EDI = Environmental Degradation Index; measures the present position of the "health" of the environment. IRI = Intrinsic Resilience Index; values are rated on a scale of 1 to 7, with 7 representing high vulnerability, an overall average of all is calculated to generate a country's EnVI			Peduzzi et al. (2003); Peduzzi et al. (2001)
35	The Climate Vulnerability Index (CVI) for assessing Water Poverty Index		Country-level	Every component is made up of subcomponents; the components are joint using a composite index structure. The index ranges between 0 to 100	6 major categories/components: Resource (R), Access (A), Capacity (C), Use (U), Environment (E) & Geospatial (G). There are different vulnerabilities to climate change, some of the studied are vulnerability to climate related mortality, social vulnerability to climate change, even some countries have defined their vulnerability to climate change using different indicators; for example: Canada, Peru, USA etc. Mortality from climate-related disasters can be quantified via emergency actions database data set, statistical relations between mortality & select likely proxies for vulnerability are used to spot key vulnerability indicators. Other CVI use 11 indicators: literacy rate; literacy rate, > 15 yrs; population with access to sanitation; maternal mortality; life expectancy at birth; 15-25 yrs; calorific intake; civil liberties & political rights; voice & accountability; government effectiveness literacy ratio (female or male). The indicators can be separated in three categories: Governance; Health status & Education. Almost 100 possible indicators were examined for climate change report in Canada; 2 groups (Nature: sea-level rise, sea ice, river & lake ice, glaciers, polar bears, plant development & People: traditional way of life, drought, great lakes, frost & frost free season, heating & cooling, extreme weather)			Sullivan (2002); Sullivan et al. (2003)
36	The Composite Vulnerability Index	The Composite Vulnerability Index for Small Island States	Country Level focusing On developing Small island states/ hazard	Point out the intrinsic vulnerability of small island states in comparison to large countries which possess several advantages				Briguglio (2003, 2004)

				associated with their large scale Application of weighted least square (determination of weights through regression) routines to integrate the basic indicators				
37	Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM)	To assess potential impacts of global change on ecosystem sensitivity to climate change in Europe, & to translate these impacts into maps of our vulnerability; the sectors: agriculture, forestry, carbon storage, water, nature conservation & mountain tourism in the 21st century were mapped	European data sets at regional scale 10' x 10' grid resolution over EU15 plus Norway & Switzerland, baseline 1990, future time slices 2020, 2050, 2080	Fuzzy inference rules were applied to aggregate the individual indicator values into one generic measure of adaptive capacity per spatial unit. The resulting generic index captures one of many dimensions of adaptive capacity	A consistent set of multiple, spatially explicit global change scenarios for A1F, A2, B1 & B2. 1. Past & future climate change scenarios for monthly values of five different climatic variables (monthly temperature, diurnal temperature range, precipitation, vapour pressure & cloud cover)	A range of state of the art ecosystem models that represent the sensitivity of the human- environment system were used. *Agriculture sensitivity indicators:* 1. Agricultural land area (Farmer livelihood) 2. Soil organic carbon content 3. Nitrate leaching 4. Suitability of crops 5. Biomass energy yield *Forestry sensitivity indicators:* 6. Forest area 7. Tree productivity: growing stock, increment, age class distribution 8. Tree species suitability *Carbon storage sensitivity indicators:* 9. Net biome exchange 10. Carbon off-set by fossil fuel substitution *Water sensitivity indicators:* 11. Runoff quantity 12. Runoff seasonality 13. Water resources per capita 14. "Drought runoff" (the annual runoff that is exceeded in 9 years out of 10) 15. "Flood runoff" (the	Spatially explicit & quantitative generic index of adaptive capacity (macro-scale: provincial level). This index is based on 6 determinants identified by the IPCC TAR (power, lexibility, freedom, motivation, knowledge & urgency) categorized into 12 indicators, such as: 1. GDP 2. Female activity rate 3. Age structure 4. Literacy index 5. Urbanisation, etc	Schröter, D., et al, (2004); Schröter, D., (2004)

						mean maximum monthly runoff) *Biodiversity & nature conservation sensitivity indicators:* 16. Species richness & turnover (plants, mammals, birds, reptiles, amphibian) 17. Shifts in suitable habitats *Mountains sensitivity indicators:* 18. Elevation of reliable snow cover 19. Number of heat days		
38	Vulnerability Index to climate change	Vulnerability Index to climate change in Africa	Africa (country level) / water availability	Expert weighted index of five indicators; however the indicators are not directly related to "water availability" Draws from the global climate change research community who align social vulnerability with adaptation capacity		1. Economic well-being & stability (Standard of living/poverty, Change in % urban population) 2. Demographic structure (Dependent population, Proportion of the working population with HIV/AIDS) 3. Institutional stability & strength of public infrastructure (Health expenditure as a proportion of GDP, Telephones, Corruption) 4. Global interconnectivity (Trade balance) 5. Natural resource dependence (Rural population)		Vincent (2004)
39	Mapping vulnerability to multiple stressors: climate change & globalization	Mapping vulnerability to multiple stressors: climate change & globalization in India	India	To measure adaptive capacity, significant biophysical, socioeconomic, & technological components that influence agricultural production were identified. To measure sensitivity under exposure to climate change in	1. Biophysical (soil conditions (quality & depth), ground water availability)	None	1. Socio-economic (levels of human & social capital, presence or lack of alternative economic activities) 2. Technological (availability of irrigation & quality of infrastructure)	O'Brien et al. (2004)

				regard to dryness & monsoon dependence, they constructed a climate sensitivity index				
40	Predictive Indicators of Vulnerability	Predictive Indicators of Vulnerability	Global	Set of 11 indicators based on correlations with decadal hazard mortality; unweighted combination within an index (no ranking, classification of different vulnerabilities)	Selection of social vulnerability indicators guided by historic hazard mortality	1. Population with access to sanitation 2. Literacy rate, 15-24 year olds 3. Maternal mortality 4. Literacy rate, > 15 yrs 5. Calorie intake 6. Voice & accountability 7. Civil liberties 8. Political rights 9. Government effectiveness 10. Literacy ratio (female to male) 11. Life expectancy at birth	None	Adger et al. (2004)
41	Indicators for vulnerability	National level indicators of vulnerability & capacity to adapt to climate hazards to support policy	Spatial: national data Temporal: averaged, decadal data for past damages & system characteristics	Adaptive capacity variables were selected by correlation analysis with the exposure component. Standarisation based on ranges (quintiles) & scores between 1 & 5. Different weightings of the indicators based on expert interviews	None	1. Numbers of people killed by climate related disasters per decade as percentage of national population	1. Population with access to sanitation 2. Literacy rate (15-24 yrs) 3. Maternal mortality 4. Literacy rate > 15 yrs 5. Calorific intake 6. Voice & accountability 7. Civil liberties 8. Political rights 9. Government effectiveness 10. Literacy ratio (female to male) 11. Life expectancy at birth	Brooks et al. (2005)
42	The climate vulnerability index (CVI)	Assessment of human vulnerability to develop adaptation strategies	Variable	Composite index as weighted average of all components. The weighs should be assigned by participatory consultation & expert opinion. Here they were all given the value 1	1. Different scenarios	1. Resource factor, i.e., evaluation of water storage capacity 2. Access factor 3. Environment factor 4. Geospatial factor	1. Capacity factor 2. Use factor	Sullivan and Meigh (2005)

43	Indicators for country- level adaptive capacity	To suggest 8 determinants of country- level adaptive capacity; To develop a set of indices of (aggregated outcome) vulnerability to climate change; The indices endure from fundamental methodological & conceptual limitations. The project website displays 144 global vulnerability maps	country- level		None	Climate sensitivity	1. The availability of technological options for adaptation 2. The availability of resources and their distribution 3. The structure of critical institutions 4. The stocks of human and social capital 5. Access to risk spreading mechanisms 6. The ability of decision-makers to manage risks and information 7. The public's perceived attribution of the source of the stress 8. The significance of exposure to its local manifestations	Yohe et al. (2006); Yohe and Tol (2002)
44	A case study of coastal assessment of climate change vulnerabilities	A case study of assessment of climate change vulnerabilities in the Canada's most sensitive coast, Graham Island.	Coastal vulnerability assessment at a case study in Graham Island (Canada)	Based on a qualitative statement: Local & traditional knowledge is the key to research design & implementation & allows for locally relevant outcomes that could aid in more effective decision making, planning & management in remote coastal regions	1. Biophysical impacts: extreme climate variability	1. Sensitive landscape 2. Restricted natural resources	1. Socioeconomic capacity: access to and distribution of wealth, technology, and information, risk perception & awareness, social capital & critical institutional frameworks	Dolan and Walker (2006)
45	Vulnerability concepts in hazard & risk assessment	Vulnerability concepts in hazard & risk assessment	Regional	The indicators were weighted in a way that the overall regional vulnerability is 100%. Integrated vulnerability index: regional GDP/capita	None	1. Damage potential: GDP/capita; population density; tourism; culturally significant sites; significant natural areas; fragmented natural areas	1. Coping capacity: education rate; dependency ratio; risk perception; level of mitigation; medical infrastructure	Kumpulainen (2006)

				30%, population density 30%, fragmented natural areas 10% (only 10% because this component only depicts one aspect of ecological vulnerability), national GDP/capita 30%.				
46	To evaluate impacts of natural disasters across income Groups (social vulnerability)	Distribution of impacts of natural disasters across income groups: A case study of New Orleans	A case study of New Orleans (USA) impacted differently by Hurricane Katrina		1. Elevation 2. Flood levels	1. Population characteristics: gender, race & ethnicity, age, residential property, renters, education, health status, social dependence, special-needs populations (infirm, institutionalized, transient, & homeless)	1. Socioeconomic status (income, savings, employment, access to communication channels and information, insurance influences, political power, prestige) 2. Transport	Cutter et al. (2001); Masozera et al. (2007)
47	To select indicators and methods to measure revealed and emergent vulnerability of coastal communities at the local scale	To focus on the social dimension of vulnerability to select indicators & methods to measure revealed & emergent vulnerability of coastal communities at the local scale: susceptibility & degree of exposure, coping capacities, & intervention tools	Coastal communities at local scale in the examples of Batticaloa & Galle tsunami-affected in Sri Lanka	A meta-framework to structure the questionnaire survey & the analysis of the tsunami census data Not mention about the aggregation		1. Impact of tsunami on household members & their assets 2. Structure of household (age, gender, education & income, etc) 3. Housing conditions & impact of tsunami 4. Direct loss of possessions 5. Activity & occupation of household members	1. Social networks 2. Knowledge of coastal hazards & tsunami 3. Financial support from formal & informal organisations 4. Access to information (radio) 5. Intervention tools (Relocation of housing & infrastructure to inland; Early warning system; 100-metre 'buffer zone' (implemented by government)	Birkmann and Fernando (2008)
48	The new Climate Change Vulnerability Index (CCVI)	A new global ranking, calculating the vulnerability of 170 countries to the impacts of climate change over the next 30 years	National-scale, 42 indicators categorized into 3 areas: social, economic, & environmental factors		Exposure to climate-related natural disasters & sea-level rise	Human sensitivity, in terms of population patterns, development, natural resources, agricultural dependency & conflicts	The future vulnerability index assessed by considering the adaptive capacity of a country's government & infrastructure to combat climate change	Maplecroft (2010)
49	Human vulnerability to		Central America,			1. Population density is one of indices of human		Samson et al. (2011)

	climate change		central South America, the Arabian Peninsula, Southeast Asia, & much of Africa			vulnerability to climate change 2. Agriculture sector		
50	Assess the impacts of climate change	Assess the impacts of climate change based on 5 climate hazard crossed 4 sectoral effects for western part of the Mekong river delta in Vietnam (Kien Giang, Ca Mau)	District level for 2 provinces in the western part of the Mekong river delta in Vietnam	No aggregation	1. Sea-level rise 2. Flood 3. Typhoon 4. Storm surge 5. Heat wave		1. Energy & industry 2. Urban planning & transportation 3. Livelihood & agriculture 4. Socioeconomic pattern	Mackey and Russell (2011)
	Intergrated vulnerability assessment							
51	A conventional methodology to assess vulnerability to climate change	A general methodology to assess vulnerability to climate change followed the conceptual framework provided by IPCC	Coastal cities in South Korea	Synthesizing by standardized using a dimension index method (Min-Max), expert suggestions for weighting	1. Sea-level rise 2. Heavy rain-storm 3. Heat wave	1. Population density (with more sub-variables: age at 65yrs & >65yrs or < 5 yrs) 2. Land cover (with more sub-variables: flooded area, ratio between flooded area & total area in each county): agricultural land, forest/ wetland/ grassland, commercial area, residential area, industrial area, & recreational & other urbanized parts.	1. Economic capability: financial independence) 2. Infra-structure (green area, state support for health, water resource accessibility) 3. Institutional capability (awareness, governance, policy foundation)	Yoo et al. (2011)
52	An index of the climate change vulnerability	Construct an index of the climate change vulnerability	Sub-national areas, regions, provinces, districts for South East Asia	Synthesizing by standardized using a dimension index method (Min-Max), expert suggestions for weighting	1. Tropical cyclones 2. Floods 3. Landslides 4. Droughts 5. Sea-level rise	1. Population density *(Human sensitivity)* 2. Percentage of protected areas *(Ecological sensitivity)*	1. Soci-economic factors (HDI: Standard of living, longevity, education; poverty incidence, income inequality) 2. Technology (electricity coverage, extent of irrigation) 3. Infra-structure (road density, communication) 4. Policy & institutions	Yusuf and Francisco (2009)
53	Vulnerability Indicators for Ecosystems & Natural Resources	Vulnerability Indicators for Ecosystems & Natural Resources for the	Regional, Sydney Coastal Councils	Aggregation by summation of components values for each	1. Projected change in annual average temperature in 2030 2. Projected change in	1. Elevation 2. Land cover 3. % Native vegetation 4. Water condition	1. % population completing year 12 2. % population that speaks language	Preston et al. (2008)

		region to initiate a dialogue among researchers & stakeholders & a bottom-up assessment of local governments	Groups in 2030	element, scoring, weighting based on expert values & summation of the elements values for vulnerability indicator	average DJF maximum temperature in 2030 3. Projected change in annual average JJA minimum temperature in 2030 4. Projected change in average annual rainfall in 2030	5. Land condition 6. Population density 7. Road density 8. Projected population growth to 2019 9. SEPP 14 wetland areas	other than English 3. Median home loan repayment 4. % home ownership 5. Median household income 6. % households requiring financial assistance 7. % population with internet access 8. Current ratios 9. Per capita business rates 10. Per capita residential rates 11. Per capita community service expenses 12. Per capita environment & health expenses 13. Per capita annual recycling	

Appendix 2 Description of the landform units in the MRD, adapted from Nguyen (1993).

No.	Landform	Subunits 1	Subunits 2	Location
1	Old alluvial terrace			Occupy small areas, about 150 000 ha in the northeast of the delta, along the Cambodia-Vietnam border. The soil is very compact, containing many gravel, Fe-oxide and brown mottles.
2	Floodplain	High floodplain		The northwest of the delta; the greatest inundation depth: 2 - 3 m in the flood season
			Natural levee	Parallel to the banks of the Mekong and Bassac Rivers; occupying the highest position in the floodplain: 3 - 4 m a.MSL and showing a gradual decrease in elevation away from the river banks; width from 0.5 to several km
			Sand bar	Lie between branches of rivers; They look like natural levees: small areas (5 - 10 ha) but others are very large, having the same area as a village several hundred ha
			Back swamp	Lie behind the natural levees. The maximum inundation can reach as deep as 2 - 3 m at the end of September. Several kinds of ASS are found here.
			Closed floodplain	A plain of reeds enclosed by sand ridges between CanTho and Saigon, the natural levee of the Mekong River in the southwest, and the old alluvial terrace in the north; Resembles a big shallow lake, the water level can rise up to 3 m and very difficult and slow drainage. Today, more than 60% of the area is under cultivation and the remainder is covered by Melaleuca and Eleocharis, which can tolerate the strongly ASS.
			Opened floodplain	It slopesgently from the Bassac river to the Gulf of Thailand (the west sea), forming a fan-like terrain from which floodwater easily drains. Strong ASS are also found here.
		Tide affected floodplain		Occupies the center of the delta; It is strongly influenced by the daily tides of the rivers Mekong and Bassac. ASS are also present here but their effects are less serious because toxicity is readily washed away by the tidal rivers. Therefore, the soil quality is constantly improving, and the tide affected floodplain has the highest potential for agricultural production in the delta
			Natural levee	Along the Mekong and Bassac Rivers and their branches; These levees are narrow and low compared to those of the high floodplain.
			Back swamp	These are the same as the back swamps in the high floodplain, but the water regime is quite different, being strongly influenced by the diurnal tides of the Mekong and Bassac Rivers.
			Broad depression	This area is situated between the tide affected floodplain and the broad depression and is low-lying and poorly drained. Several kinds of ASS

		floodplain	can be found here.
3	Coastal complex		Along the coasts of the east sea and west sea
		Sand ridge	Run parallel with the coastline
		Coastal flat	These have moderate relief of about 1 - 1.5 m above MSL. Seawater cannot intrude directly but it can enter by capillary movement from the subsoil to the topsoil layer during the dry season.
		Inter ridge	The tides of the east sea determine the water regime of these areas. ASS are also common in these areas but they pose no serious effect, because toxicity is washed away by tidal action and fresh sediments are deposited on the soil surface every year. On the other hand, they are always submerged under alternately brackish or freshwater in the dry and rainy seasons, respectively.
		Mangrove swamp	These are dominant along the coast, the mouth of the Mekong River and Ca Mau cape. ASS are found in these swamps, and a sulfidic horizon lies very close to the topsoil. Many species of mangrove thrive in these swamps, of which the dominants are Avicennia and Rhizophora. Every year the mangrove continues to extend seaward, especially in the Ca Mau cape and the mouth of Mekong River.
4	Broad depression		Occupies a large area in the south of the delta; It is very flat and low, 0.5 - 1 m a.MSL, and it encompasses Ca Mau and parts of Hau Giang and Kien Giang province.
		Broad depression	Nearly isolated from the delta system; water of the Bassac river cannot reach this area. Although there are some artificial canals, these are only used for drainage and transportation, because the broad depression is so far from the river. As a result, the soil is influenced by saltwater and acidity in the dry season
		Peat depression	Located at U Minh Thuong (Kien Giang) and U Minh Ha (Ca Mau), they have a lot of peat soil on which Phragmites and Melaleuca are dominant. They resemble two large natural big lakes, and they provide supplementary irrigation water for the surrounding areas during the dry season
5	Hill and mountain		Consist of large and small separate ranges in the west of the delta. The highest mountain is the Cam Mountain, 710 m. All of these hills and mountains are composed of granitic rock, except for some small mountains in Kien Luong, Ha Tien district (Kien Giang), where the dominant component is limestone

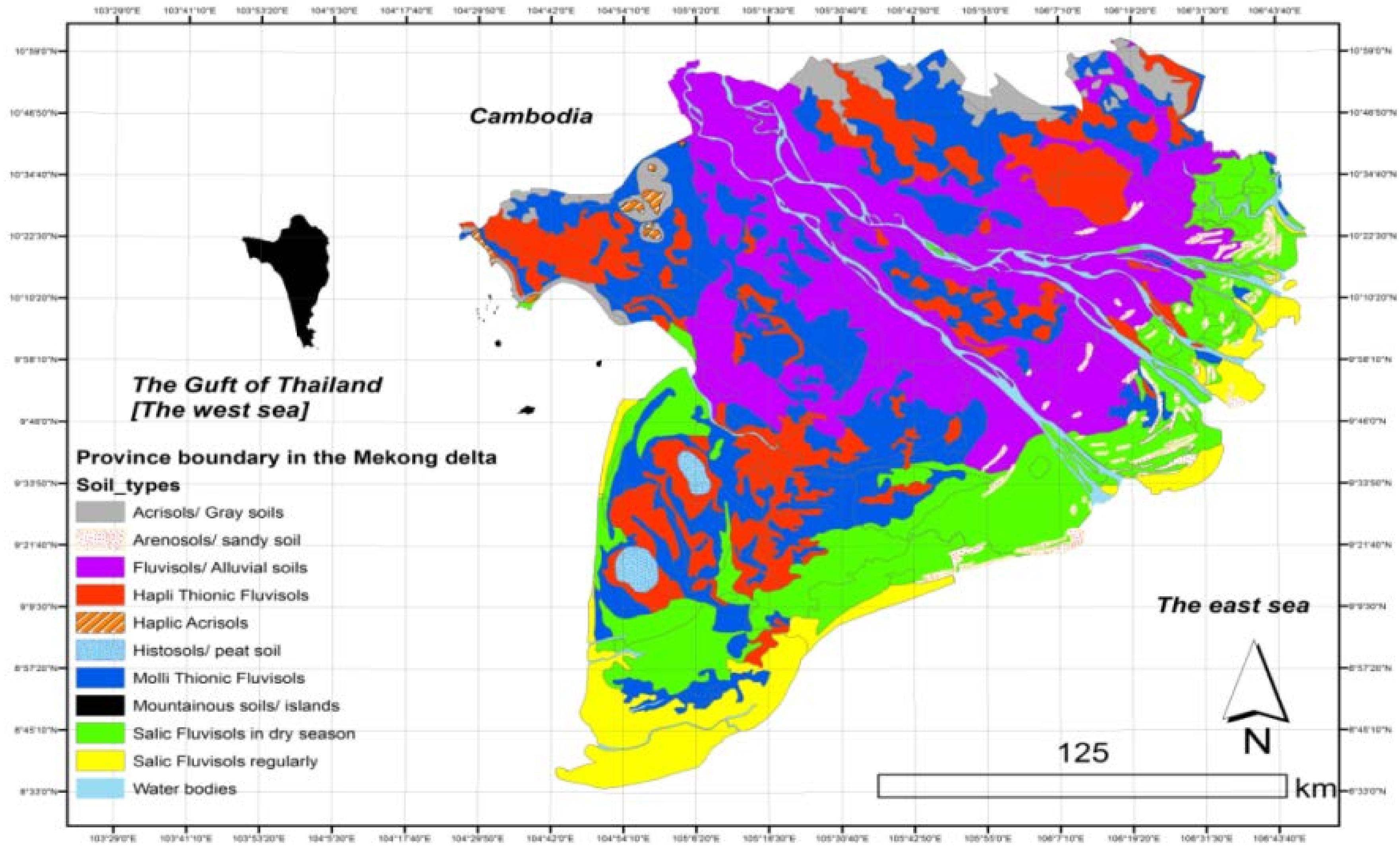
Appendix 3 Soils in the MRD and the seven coastal districts in Kien Giang.

Appendix 3a Classification of soil names and groups to Vietnam and the MRD by FAO/UNESCO.

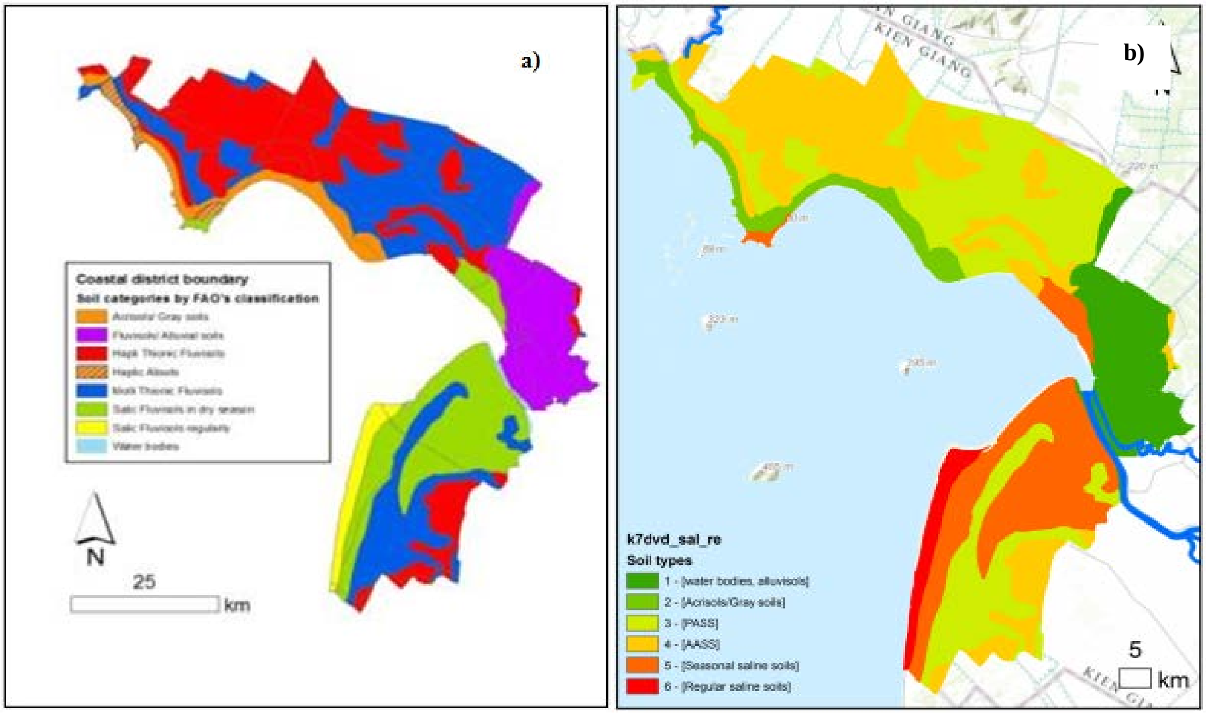
Việt Nam	FAO	(%)
I. ĐẤT CÁT	Arenosols	1,10
1. Đất cát giồng	Haplic Arenosols	1,10
II. ĐẤT MẶN	Salic Fluvisols	18,93
2. Đất mặn dưới rừng ngập mặn	Gleyi- Salic Fluvisols	1,42
3. Đất mặn nhiều	*Hapli- Salic Fluvisols*	2,60
4. Đất mặn trung bình	*Molli*- Salic Fluvisols	3,79
5. Đất mặn ít	Molli- Salic Fluvisols	11,12
III. ĐẤT PHÈN	Thionic Fluvisols	40,69
Đất phèn tiềm tàng (PTT)	Protothionic Fluvisols	10,73
6. Đất PTT nông nghiệp rừng ngập mặn	Sali-Epiproto- Thionic Fluvisols	3,43
7. Đất PTT sâu dưới rừng ngập mặn	Sali- Endoproto- Thionic Fluvisols	0,78
8. Đất PTT nông, mặn	Sali-Epiproto- Thionic Fluvisols	1,28
9. Đất PTT sâu, mặn	Sali- Endoproto- Thionic Fluvisols	0,88
10. Đất PTT nông	Epiproto- Thionic Fluvisols	1,40
11. Đất PTT sâu	Endoproto- Thionic Fluvisols	2,96
Đất phèn hoạt động (PHĐ)	Orthi- Thionic Fluvisols	29,96
12. Đất PHĐ nông, mặn	Sali- Epiorthi- Thionic Fluvisols	3,01
13. Đất PHĐ sâu, mặn	Sali- Endoorthi- Thionic Fluvisols	8,26
14. Đất PHĐ nông	Epiorthi- Thionic Fluvisols	4,88
15. Đất PHĐ sâu	Endoorthi –Thionic Fluvisols	13,81
IV. ĐẤT PHÙ SA	Fluvisols	30,13
16. Đất phù sa được bồi	Eutric Fluvisols	2,13
17. Đất phù sa không được bồi (KĐB)	Eutric Fluvisols	2,46
18. Đất phù sa KĐB gely	Gleyic Fluvisols	9,04
19. Đất phù sa KĐB có tầng loang lổ	Cambic Fluvisols	16,49
V. ĐẤT LẦY VÀ THAN BÙN	Histosols	0,61
20. Đất than bùn- Phèn	Thionic Histosols	0,61
VI. ĐẤT XÁM	Acrisols	3,42
21. Đất xám trên phù sa cổ	Haplic Acrisols	2,16
22. Đất xám đọng mùn trên phù sa cổ	Gleyic Acrisols	0,79
23. Đất xám trên Granit	*Haplic Acrisols*	0,48
VII. ĐẤT ĐỎ VÀNG	Acrisols	0,06
24. Đất đỏ vàng trên đá Granit	Haplic Acrisols	0,06
VIII. ĐẤT XÓI MÒN TRƠ SỎI ĐÁ	Leptosols	0,22
25. Đất xói mòn trơ sỏi đá	Dystric Leptosols	0,22
SÔNG RẠCH	Water bodies	4,84
TỔNG CỘNG TOÀN ĐBSCL	Total of the whole delta	100

Source: NIAPP Vietnam

Appendix 3b Distribution of several main soil types in the MRD classification by FAO, adopted by MONRE (undated), and then modified in 2013 by the author.



Appendix 3c Distribution of soil types in the seven coastal districts in Kien Giang, derived from the soil map for the MRD by MONRE, and then modified in 2013 by the author.



Very low **1**	Low **2**	Moderate **3**	High **4**	Very high **5 + 6**
Water bodies, Alluvial soils	Acrisols & Gray soils	PASS	AASS	Seasonal & regular saline soils

Note: The left figure was extracted from the soil map for the whole MRD (see Appendix 3b), whereas the right figure is the reclassified the soil map, comprising 6 classes that were used for the analysis.

Appendix 4 A classification of landuse patterns in Vietnam by MONRE.

Group	Land type	Code	Definition
I	**Agricultural land**	NNP	
	Agricultural production land	SXN	The land used in agricultural production, including annual and perennial crop land
	Annual crop land	HNK	
	Paddy land	LUA	
	Land for growing water-rice	LUC	
	Annual crops in the plain-field	BHK	
	Perennial crop land	CLN	
	Perennial industry-tree land	LNC	
	Perennial fruit crop land	LNQ	
	Forestry land	LNP	Land used in forestall production or experiment which includes productive, protective, and specially used forest
	Productive forest	RSX	
	Protective forest	RPH	
	Specially used forest	RDD	
	Water surface land for fishing	NTS	
	Salt ponds	LMU	
	Others	NKH	
II	**Non- agricultural land**	PNN	
	Homestead land	OTC	Land used for houses and buildings other buildings
	Rural	ONT	
	Urban	ODT	
	Specially used land	CDG	Land being used for other purposes, not for agriculture, forestry and living which includes land used by offices and non-profit agencies, security and defence land, land for non-agricultural production and business and public land
	Water bodies	SMN	
	Others	ODT	
III	**Unused land**	CSD	It includes unused flat and mountainous land, and non-tree rocky mountain

Appendix 5 Selected variables for coastal vulnerability assessment in the seven coastal districts along the Kien Giang coast.

Appendix 5a. Variables used for study area.

No	Component	Variables	Definition	Format input data	Source	Note
I	**Exposure**					
1	***Flood risk***	Flood depth, m (benefits from the flood and inundation)	0 -0.2; 0.2-0.5; 0.5-1.0; 1-2; >2 DEM (<0.3; 0.3-0.5; 0.5-0.8; 0.8-1; 1-1.2; 1.2-2; >2)	Scenario maps/ Raster (in 2000, 2030, & 2050)	Tran et al. 2013 and others	Rising/ high/ falling stage ≠ river-flood depth warning in the rivers MK, Bassac by MRC Limit of data: duration
2	***Seawater incursion***	Salinity, ppt (rice crops, shrimp)	< 4ppt (rice & veg); 4 - 8 (rice & shrimp); >8 (special shrimp) Soil type (water bodies, alluvisols; acrisols, gray soils; PASS; AASS; seasonal and regular saline soil)	Scenario maps/ Raster (in 2010, 2030, & 2050)	Le and Le (2013), Mackey and Russell (2011); MONRE undated	Reduce the acidity from acid sulphat soil ASS/ thionic fluvisols Limit of data: duration, ASS; classification by FAO
3	***Shoreline change***	Shoreline displacement based on EPR (1km), area	EPR: -37- -15; -15- -5; -5-5; 5-15; >15 Adjacent coastal landuse	Landsat images from 1973 - 2013	MARD 2010; US Geological Survey; the Global land cover Facility	DSAS, EPR, NSM, etc Limit of data: Landsat images 1973 - 2013 (coarse resolutions: 30 m or 60 m)
II	**Sensitivity**					All strategies/ master plans for development on socioeconomic; education, health care etc in Kien Giang have been approved only up to 2020
1	***Societal factors sensitivity***					
1.1	*Population density*	PD, inhabitants/ km^2		Statistical data	KGI SO, 2012	The trend of population growth in Kien Giang/ district scale
1.2	*Rural people*	% rural persons living out of district population		Statistical data	KGI SO, 2012	District scale
1.3	*Females*	% females out of district population		Statistical data	KGI SO, 2012	District scale
1.4	*Ethnic group*	%		Statistical data	KGI district survey 2011	District scale
2	***Landuse factors sensitivity***		The bare land: 1; agri land: 2-4; non.agri land: 5-7	Map/ polygon	MONRE, 2008	Landuse classified by MONRE
2.1	*Agriculture landuse*	NNP, area (ha) (Area NPP (ha)/district inhabitants)				
2.1.1	Paddy fields	LUA, area				
2.1.1.1	Water rice fields	LUC, area				
2.1.2	Annual crop land	HNK, area				
2.1.2.1	Annual crops in the plain-field	BHK, area				
2.1.3	Perennial crops	CLN, area				
2.1.3.1	Perennial industrial plants	LNC, area				
2.1.3.2	Perennial fruits and orchards	LNQ, area				
2.1.4	Forests	LNP, area			Sub-FIPI 2008	References
2.1.4.1	Productive forests	RSX, area				Planting forests
2.1.4.2	Protective forests	RPH, area				Maybe mangroves
2.1.4.3	Specially used forests	RDD, area				Conservation
2.1.5	Fishing farming	NTS, area				Rice-shrimp farming
2.1.6	Salt pond	LMU, area				
2.1.7	Water bodies	SMN, area				

2.2	*Non agri.land*	PNN, area (Area PNN (ha)/ district inhabitants)				
2.2.1	Homestead land	OTC, area				
2.2.1.1	Urban land	ODT, area				
2.2.1.2	Rural land	ONT, area				
2.2.2	Specially used land	CDG, area				
2.3	*Unused land*	CSD, area (Area CSD (ha)/ district inhabitants)				Plain and hill unused land and bare mountains
III	**Adaptive capacity**					
1	***Socioeconomic***					
1.1	*Income*	$USD/capita		Statistical data	KGI district survey 2011	District scale
1.2	*Poverty ratio*	%		Statistical data	KGI SO, 2012	District scale
1.3	*Health*			Statistical data	KGI SO, 2012	District scale
1.3.1	Capacity of health establishments	Inhabitants/health establishment				
1.3.2	Capacity of medical and pharmacy staffs	Inhabitants/medical and pharmacy staff				
1.4	*Education*			Statistical data	KGI SO, 2012	District scale
1.4.1	Kindergartens/ school	Kids/school				
1.4.2	Kindergartens/ teacher	Kids/teacher				
1.4.3	Primary & secondary/ school	Pupils/school				
1.4.4	Primary & secondary/ teacher	Pupils/teacher				
2	***Infrastructure***					
2.1	*Road capability*	Road density	A Kernel function radius 5km	Map/ raster	Tran et al. 2013	
2.2	*Solid house capability*	% household having solid houses		Statistical data	KGI SO, 2012	District scale
2.3	*Communication access*	Inhabitants per fixed-telephone subscriber		Statistical data	KGI SO, 2012	District scale
3	***Technological***					
3.1	*Electricity capability*	Electricity density	A Kernel function radius 5km	Map/ polylines & multi-points	Tran et al. 2013	A modern and extensive power distribution system; Technically reliable, 100% covered at district level
3.1.1	Substation: transformers					
3.1.2	Substation: voltage power lines					
3.2	*Irrigation and drainage capability*	Irrigation and drainage density	A Kernel function radius 5km	Map/ raster	SIWRP, 2010	An extensive network of river, canals, sluices, etc. connected to the open sea
3.2.1	River density		River density			
3.2.2	Canal capability		Canal density			
3.2.3	Sluice capability		Sluice density			
3.2.4	River embankment capability		River embankment density			
3.2.5	Sea dyke capability		Sea dyke density			

Appendix 5b. Outcomes during the fieldwork for coastal vulnerability assessment.

The most widely adopted analytical approaches to vulnerability assessment are described, including spatial scales, the need for hybrid approaches comprising both biophysical and social dimensions of vulnerability, and the gradual incorporation of resilience aspects in such methodologies. In particular, the development and application of vulnerability indices is examined, based on a review of fifty-three studies that applied such indices across a range of hazards.

The coastal vulnerability assessment contributes a variety of datasets, combining assessment findings from physical as well as social factors. With regard to the specific physical factors, maps of inundation, seawater incursion, and shoreline erosion with others will be used and aggregated to generate the exposure map. With regard to the specific challenges, statistical data on census, socioeconomic transformation processes, such as economic growth, landuse, household income, poverty, health services, education, irrigation and drainage system, electricity network, road, etc. Moreover, based on meetings during the fieldwork with the relevant planning agencies, expert workshops, joint science seminars with partners from academic institutions, and other stakeholders such as farmers, policy makers, all of which remain an important basis of this work, vulnerability profiles are developed which are represented in schematic figures highlighting archetype vulnerability pathways as well as in maps showing the spatial distribution of the main vulnerability parameters, hence allowing for the identification of vulnerability hotspots and priority areas for action. Particularly for estimation weightings of pair-wise comparisons, a group of five (05) experts from different disciplines was asked for their general judgements:

- 02 experts from remote sensing and GIS application;
- 01 expert from meteorological and hydrological modelling;
- 01 economist and landuse expert;
- 01 policy maker and environmental and climate change.

1.	**The first fieldwork:** *Duration:* from 30 of November 2011 to 10 February of 2012
	Location/ Organisation: - In Ha Noi **(03)**: ✓ Vietnam Institute of Meteorology, Hydrology and Environment (IMHEN)- MONRE; ✓ Vietnam administration of seas and islands- MONRE; ✓ Hanoi University of Science
	- Ho Chi Minh **(03)**: ✓ Ho Chi Minh City University of Technology ✓ Ho Chi Minh City University of Agriculture and Forestry ✓ Institute of Agricultural Science for Southern Vietnam
	- Can Tho **(02)**: ✓ Can Tho University ✓ Research Institute for Climate Change
	- An Giang **(01)**: ✓ Phu My Tan town, Phu Tan district (along to the Mekong River)
	- Kien Giang **(05)**: ✓ Department of Industry and Trade of Kien Giang (DOIT) ✓ Department of Science and Technology of Kien Giang (DOST) ✓ GIZ Kien Giang ✓ Kien Giang biosphere reserve ✓ Department of Natural resources and Environment (DONRE)
	***Activities and Outcomes*:** ✓ Meeting with policy makers, scientists, engineers, etc in different disciplines ✓ Informal talks with other stakeholders such as local farmers, communities ✓ Review approaches and methodologies or parameters to VAs. ✓ Collect primary datasets
2.	**The second fieldwork:** *Duration*: from 12 October of 2012 to 3 March of 2013
	Location/ Organisation: - In Ha Noi **(04)**: ✓ Center for Hydrology and Water Resources, IMHEN ✓ National Center for Water Resources Planning and Investigation, MONRE ✓ Marine natural resources- environment survey Centre, Vietnam administration of seas and islands ✓ Hanoi University of Science
	- Ho Chi Minh **(05)**: ✓ Institute of coastal and offshore engineering (ICOE), MARD ✓ Southern Institute for water resources planning, MARD ✓ Ho Chi Minh City University of Agriculture and Forestry ✓ Ho Chi Minh City Institute of resources geography, VAST ✓ Institute for environment and resources, Ho Chi Minh City University of Technology
	- Kien Giang **(04)**: ✓ The Kien Giang Statistical Office ✓ Department of Science and Technology of Kien Giang (DOST) ✓ GIZ Kien Giang ✓ Department of Natural resources and Environment (DONRE)
	- Long An **(01)**: ✓ Vinh Hung town, Vinh Hung district
	Activities and Outcomes: ✓ *Supplementary data collected*
3.	**The third fieldwork:** *Duration:* from 18 to 26 of January 2015
	Location: Ha Noi, Nam Dinh, Ho Chi Minh, Kien Giang, and Ca Mau - Kien Giang ✓ Department of Science and Technology of Kien Giang (DOST) ✓ GIZ Kien Giang ✓ Kien Giang biosphere reserve ✓ Coastal districts, such as Rach Gia, Hon Dat, and An Bien and some communes
	Activities and Outcomes: ✓ Validation of hotspots, which determine areas most vulnerable in the coastal districts along the Kien Giang coast. ✓ The visit to hotspot locations as identified in the analysis is a valuable contribution of the study that warranted more attention to show the strengths and limitations of the vulnerability assessment methodology employed.

Appendix 6 Information of mangroves in the seven coastal districts in Kien Giang, adapted from GIZ Kien Giang (2008 - 2011).

TT	Names			Distribution						
	Vietnamese names	**English names**	**Scientific names**	**Ha Tien**	**Kien Luong**	**Hon Dat**	**Rach Gia**	**Chau Thanh**	**An Bien**	**An Minh**
1	Ô rô trắng	Bractless holly mangroves	*Acanthus ebracteatus*			X				
2	Ô rô tím	Spiny holly mangroves	*Acanthus ilicifolius*	X	X				X	X
3	Ráng đại	Golden leather fern	*Acrostichum aureum*	X	X	X		X	X	X
4	Ráng biển thường	Mangrove fern	*Acrostichum speciosum*	X		X	X	X	X	X
5	Sú	River mangroves	*Aegiceras corniculatum*	X	X	X				
6	Mấm trắng	White mangrove	*Avicennia alba*	X	X	X	X	X	X	X
7	Mấm biển	Grey & white mangroves	*Avicennia marina*	X	X	X	X		X	X
8	Mấm đen	Black mangrove	*Avicennia officinalis*	X						X
9	Vẹt trụ	Reflexed orange mangrove	*Bruguiera cylindrica*	X		X	X		X	X
10	Vẹt dù	Large-leafed orange mangrove	*Bruguiera gymnorhiza*		X	X	X			
11	Vẹt khang (Vẹt đen)	Upriver orange mangrove	*Bruguiera sexangula*	X	X	X				X
12	Dà quánh	Clumped yellow mangrove	*Ceriops decandra (C. zippeliana)*	X	X				X	X
13	Dà vôi	Rib-fruited yellow mangrove	*Ceriops tagal*		X				X	X
14	Quao nước	Trumpet mangrove	*Dolichandrone spathacea*	X					X	X
15	Giá	Milky mangroves	*Excoecaria agallocha*	X	X	X	X	X	X	X
16	Cui biển	Keeled-pod mangrove	*Heritiera littoralis*	X	X	X		X	X	
17	Tra nhớt	Beach hibiscus	*Hibiscus tiliaceous*	X	X	X				X
18	Cóc đỏ	Red-flowered black mangrove	*Lumnitzera littorea*	X		X				
19	Cóc vàng	White-flowered black mangrove	*Lumnitzera racemosa*	X	X	X			X	X
20	Cóc hồng (cây lai)	Pink-flowered black mangrove	*Lumnitzera X rosea*	X						
21	Dừa nước	Mangrove palm	*Nypa fruticans*	X	X	X	X	X	X	X
22	Đước đôi	Corky stilt mangrove	*Rhizophora apiculata*	X	X	X	X	X	X	X
23	Đước bộp (Đưng)	Upriver stilt mangrove	*Rhizophora mucronata*						X	X
24	Côi	Yamstick mangrove	*Scyphiphora hydrophylacea*	X	X					
25	Bần trắng	White-flowered apple mangrove	*Sonneratia alba*	X	X	X			X	X
26	Bần chua	Red-flowered apple mangrove	*Sonneratia caseolaris*	X		X	X	X	X	X
27	Bần ổi	Apple mangrove	*Sonneratia ovata*	X	X	X	X		X	X
28	Tra bồ đề	Portia Tree, Umberlla Tree, Indian Tulip Tree, False Rosewood	*Thespesia populnea*	X	X	X				X
29	Xu ổi	Cannonball mangrove	*Xylocarpus granatum*		X				X	X
30	Xu Mekong	Cedar mangrove	*Xylocarpus moluccensis (X. mekongensis)*	X						X

Appendix 7 The scenarios of climate change and sea-level rise by the year 2100, relative to 1980 - 1999, based on the IPCC SRES for 12 provinces, and Can Tho City in the MRD, especially Kien Giang.

Appendix 7a The scenarios of an increase in temperature (°C) by 2100, relative to 1980 - 1999, based on the IPCC SRES medium (B2) in 13 provinces in the MRD derived from The-Second-Scenarios-VN (2011).

No	City/ Province	Years								
		2020	2030	2040	2050	2060	2070	2080	2090	2100
1	Long An	0.4	0.6	0.9	1.1 (1.0- 1.4)	1.4	1.6	1.8	2.0	2.2 (1.9 - 2.8)
2	Dong Thap	0.4	0.7	1.0	1.3 (1.0 - 1.4)	1.6	1.9	2.1	2.3	2.5 (2.2 - 2.8)
3	Tien Giang	0.5	0.6	0.8	1.0 (0.9 - 1.2)	1.3	1.5	1.7	1.8	2.0 (1.9 - 2.5)
4	Ben Tre	0.4	0.7	0.9	1.2 (1.0 - 1.4)	1.5	1.7	1.9	2.1	2.3 (1.9 - 2.5)
5	Vinh Long	0.4	0.6	0.8	1.0 (1.0 - 1.2)	1.3	1.5	1.7	1.8	2.0 (1.8 - 2.5)
6	Tra Vinh	0.4	0.6	0.9	1.2 (1.0 - 1.4)	1.4	1.6	1.8	2.0	2.2 (1.9 - 2.4)
7	An Giang	0.4	0.6	0.8	1.0 (0.5 - 1.2)	1.3	1.5	1.7	1.8	2.0 (1.8 - 2.3)
8	Can Tho	0.5	0.7	1.0	1.2 (1.0 - 1.4)	1.5	1.7	2.0	2.2	2.3 (1.9 - 2.5)
9	Hau Giang	0.4	0.6	0.9	1.1 (1.0 - 1.4)	1.4	1.6	1.8	2.0	2.2 (1.9 - 2.5)
10	Soc Trang	0.4	0.6	0.8	1.1 (1.0 - 1.4)	1.3	1.5	1.7	1.9	2.0 (1.9 - 2.5)
11	Bac Lieu	0.5	0.7	1.0	1.3 (1.0 - 1.4)	1.5	1.8	2.0	2.2	2.4 (2.2 - 2.8)
12	Kien Giang	0.4	0.6	0.9	1.1 (0.9 - 1.2)	1.3	1.6	1.8	1.9	2.1 (1.5 - 2.2)
13	Ca Mau	0.5	0.7	1.0	1.4 (1.2 - 1.6)	1.6	1.9	2.2	2.4	2.6 (1.9 - 2.8)

Appendix 7b The scenarios of average temperature increase (°C) in 2030 and 2050, relative to 1980 - 1999, based on the IPCC SRES medium (B2), and high (A2) for Kien Giang province, derived from reports prepared by IMHEN (2010a, b).

Average temperature increase, °C	Kien Giang province			
	B2		A2	
	2030	2050	2030	2050
January	0.5	0.8	0.5	0.8
February	0.3	0.5	0.3	0.5
March	0.3	0.6	0.3	0.6
April	0.4	0.6	0.4	0.6
May	0.5	0.9	0.5	0.9
June	0.7	1.2	0.7	1.1
July	0.6	1.1	0.6	1.1
August	0.3	0.5	0.3	0.5
September	0.5	0.8	0.5	0.8
October	0.5	1	0.5	0.9
November	0.7	1.2	0.7	1.2
December	0.6	1.1	0.6	1

Appendix 7c The scenarios of an increase in rainfall (%) by the 2100, relative to 1980 - 1999, based on the IPCC SRES medium (B2) in 13 provinces in the MRD derived from The-Second-Scenarios-VN (2011).

No	City/ Province	Years								
		2020	2030	2040	2050	2060	2070	2080	2090	2100
1	Long An	1.6	2.3	3.2	4.2 (1.0 - 5.0)	5.1	5.9	6.7	7.4	8.0 (4.0 - 8.0)
2	Dong Thap	1.3	1.9	2.6	3.4 (3.0 - 5.0)	4.1	4.8	5.4	6.0	6.5 (6.0 - 8.0)
3	Tien Giang	0.8	1.2	1.7	2.1 (2.0 - 4.0)	2.6	3.0	3.4	3.8	4.1 (4.0 - 7.0)
4	Ben Tre	1.3	1.8	2.6	3.3 (2.0 - 4.0)	4.0	4.7	5.3	5.8	6.3 (4.0 - 7.0)
5	Vinh Long	1.0	1.5	2.1	2.7 (2.0 - 4.0)	3.2	3.8	4.3	4.7	5.1 (4.0 - 6.0)
6	Tra Vinh	0.9	1.3	1.8	2.3 (2.0 - 4.0)	2.8	3.2	3.7	4.0	4.4 (4.0 - 6.0)
7	An Giang	1.1	1.7	2.4	3.0 (2.0 - 4.0)	3.7	4.3	4.9	5.4	5.8 (5.0 - 7.0)
8	Can Tho	1.2	1.8	2.5	3.2 (3.0 - 4.0)	3.9	4.5	5.1	5.6	6.1 (5.0 - 7.0)
9	Hau Giang	1.2	1.8	2.5	3.2 (2.0 - 4.0)	3.9	4.5	5.1	5.6	6.1 (5.0 - 7.0)
10	Soc Trang	1.1	1.7	2.4	3.0 (2.0 - 4.0)	3.7	4.3	4.9	5.4	5.8 (5.0 - 6.0)
11	Bac Lieu	1.0	1.5	2.1	2.7 (2.0 - 3.0)	3.3	3.9	4.4	4.8	5.2 (4.0 - 6.0)
12	Kien Giang	1.0	1.5	2.1	2.8 (2.0 - 3.0)	3.4	3.9	4.4	4.9	5.3 (4.0 - 6.0)
13	Ca Mau	0.9	1.3	1.9	2.4 (2.0 - 3.0)	2.9	3.4	3.8	4.2	4.6 (4.0 - 5.0)

Appendix 7d The scenarios of change in rainfall (%) in 2030 and 2050, relative to 1980 - 1999, based on the IPCC SRES medium (B2), and high (A2) for Kien Giang province, derived from reports prepared by IMHEN (2010a, b).

Change in rainfall, %	Kien Giang province			
	B2		A2	
	2030	2050	2030	2050
January	-5.8	-10.5	-5.9	-10.1
February	-2.1	-3.8	-2.1	-3.6
March	-10.8	-19.5	-10.9	-18.7
April	-4	-7.2	-4	-6.9
May	-0.3	-0.6	-0.4	-0.6
June	1.5	2.7	1.5	2.6
July	1.8	3.3	1.8	3.1
August	0.7	1.2	0.7	1.2
September	0.9	1.6	0.9	1.5
October	7.4	13.5	7.6	12.9
November	1.9	3.4	1.9	3.2
December	-3.6	-6.5	-3.6	-6.3

Appendix 7e The scenarios of sea-level rise (cm) by 2100, relative to 1980 - 1999, based on the IPCC SRES low (B1), medium (B2), and high (A1FI) along the Vietnam coast, extracted from The-Second-Scenarios-VN (2011).

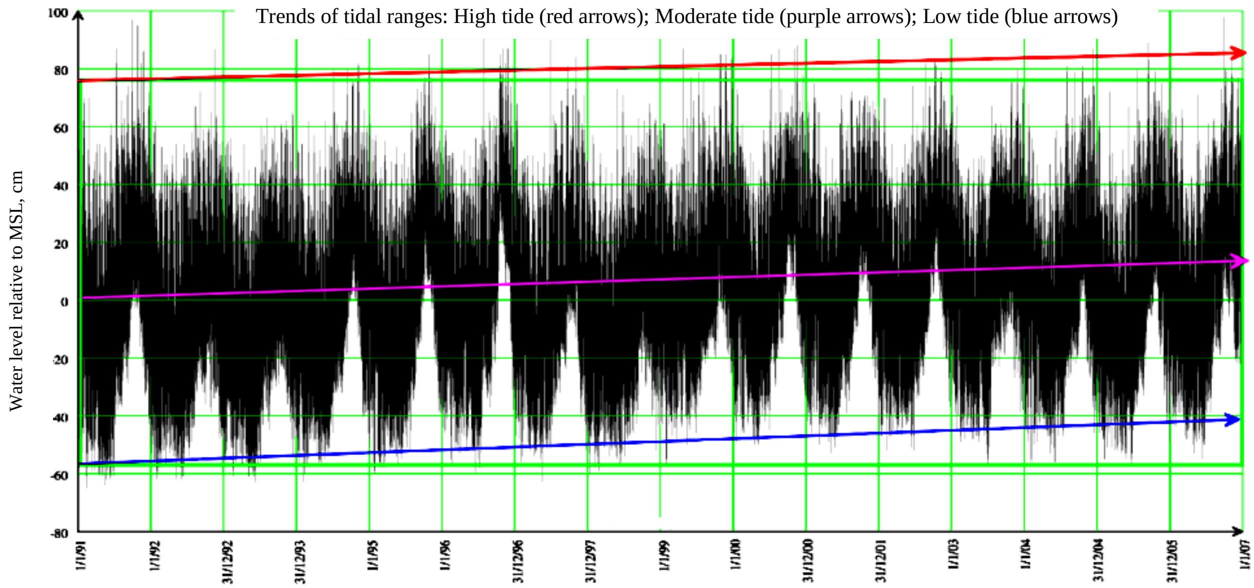
No.	Region	Years								
		2020	2030	2040	2050	2060	2070	2080	2090	2100
I	Mong Cai-Hon Dau									
1	Low emissions scenario B1	7-8	10-12	14-17	19-22	23-29	28-36	33-43	38-50	42-57
2	Medium emissions scenario B2	7-8	11-12	15-17	20-24	25-31	31-38	36-47	42-55	49-64
3	High emissions scenario A1FI	7-8	11-13	16-18	22-26	29-35	38-46	47-58	56-71	66-85
II	Hon Dau- Deo Ngang									
1	Low emissions scenario B1	8-9	11-13	15-17	19-23	24-30	29-37	34-44	38-51	42-58
2	Medium emissions scenario B2	7-8	11-13	15-18	20-24	25-32	31-39	37-48	43-56	49-65
3	High emissions scenario A1FI	8-9	12-14	16-19	22-27	30-36	38-47	47-59	56-72	66-86
III	Deo Ngang- Deo Hai Van									
1	Low emissions scenario B1	7-8	11-12	16-18	22-24	28-31	34-39	41-47	46-55	52-63
2	Medium emissions scenario B2	8-9	12-13	17-19	23-25	30-33	37-42	45-51	52-61	60-71
3	High emissions scenario A1FI	8-9	13-14	19-20	26-28	36-39	46-51	58-64	70-79	82-94
IV	Deo Hai Van- Dai Lanh Cape									
1	Low emissions scenario B1	7-8	12-13	17-18	22-25	29-33	35-41	41-49	47-57	52-65
2	Medium emissions scenario B2	8-9	12-13	18-19	24-26	31-35	38-44	45-53	53-63	61-74
3	High emissions scenario A1FI	8-9	13-14	19-21	27-29	36-40	47-53	58-67	70-82	83-97
V	Dai Lanh Cape- Ke Ga Cape									
1	Low emissions scenario B1	7-8	11-13	16-19	22-26	29-34	35-42	42-51	47-59	53-68
2	Medium emissions scenario B2	8-9	12-13	17-20	24-27	31-36	38-45	46-55	54-66	62-77
3	High emissions scenario A1FI	8-9	13-14	19-21	27-30	37-42	48-55	59-70	72-85	84-102
VI	Ke Ga cape - Ca Mau cape (The east coast)									
1	Low emissions scenario B1	8-9	11-13	17-19	22-26	28-34	34-42	40-50	46-59	51-66
2	Medium emissions scenario B2	8-9	12-14	17-20	23-27	30-35	37-44	44-54	51-64	59-75
3	High emissions scenario A1FI	8-9	13-14	19-21	26-30	35-41	45-53	56-68	68-83	79-99
VII	*Ca Mau cape – Ha Tien (The west coast)*									
1	Low emissions scenario B1	9-10	13-15	18-21	24-28	30-37	36-45	43-54	48-63	54-72
2	Medium emissions scenario B2	9-10	13-15	19-22	25-30	32-39	39-49	47-59	55-70	62-82
3	High emissions scenario A1FI	9-10	14-15	20-23	28-32	38-44	48-57	60-72	72-88	85-105

Appendix 7f The scenarios of sea-level rise (cm) by the 2100, relative to 1980 - 1999, based on the IPCC SRES low (B1), medium (B2), and high (A1FI) for Kien Giang coast, derived from reports prepared by IMHEN (2010a, b).

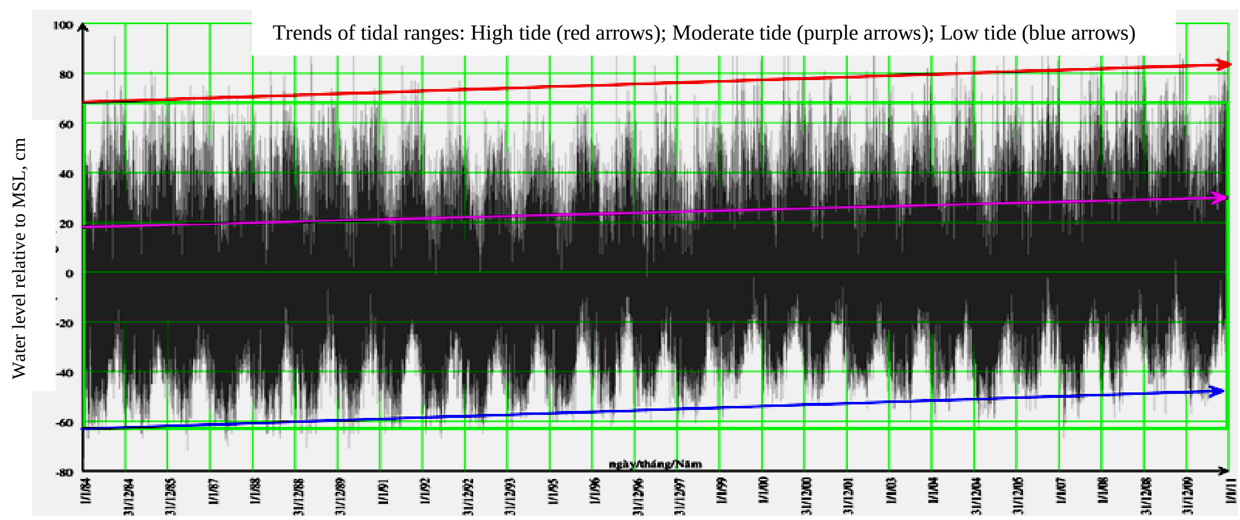
Emission scenario	Years				
	2030	2050	2070	2090	2100
Low (B1)	15	28	45	63	72
Medium (B2)	15	30	49	70	82
High (A1F1)	16	32	57	88	105

Appendix 8 Physical factors in provinces in the MRD, and Kien Giang.

Appendix 8a.1 The tidal station Rach Gia, measured tidal ranges from 1991 to 2007.



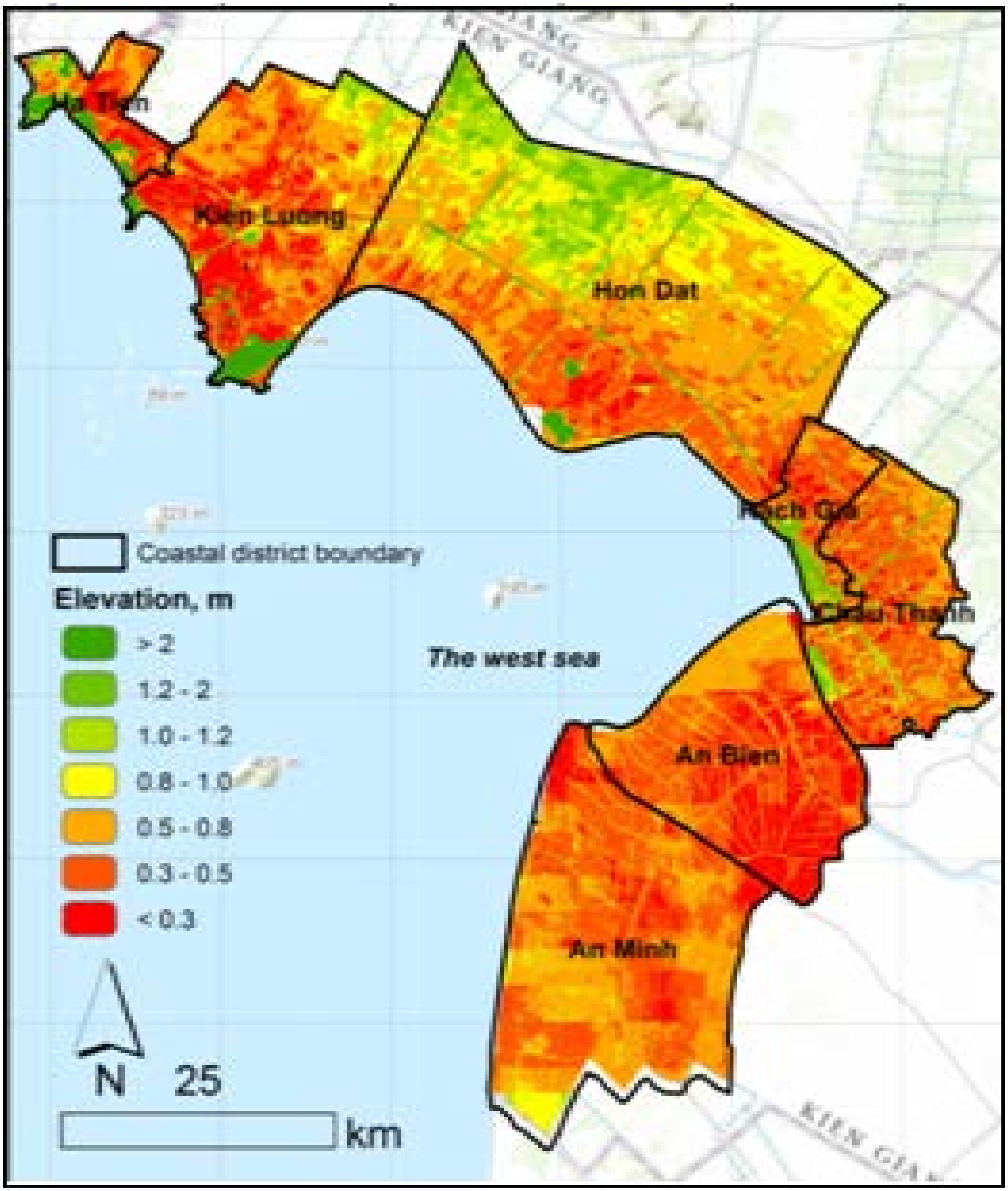
Appendix 8a.2 The tidal station Xeo Ro, measured tidal ranges from 1984 to 2010.



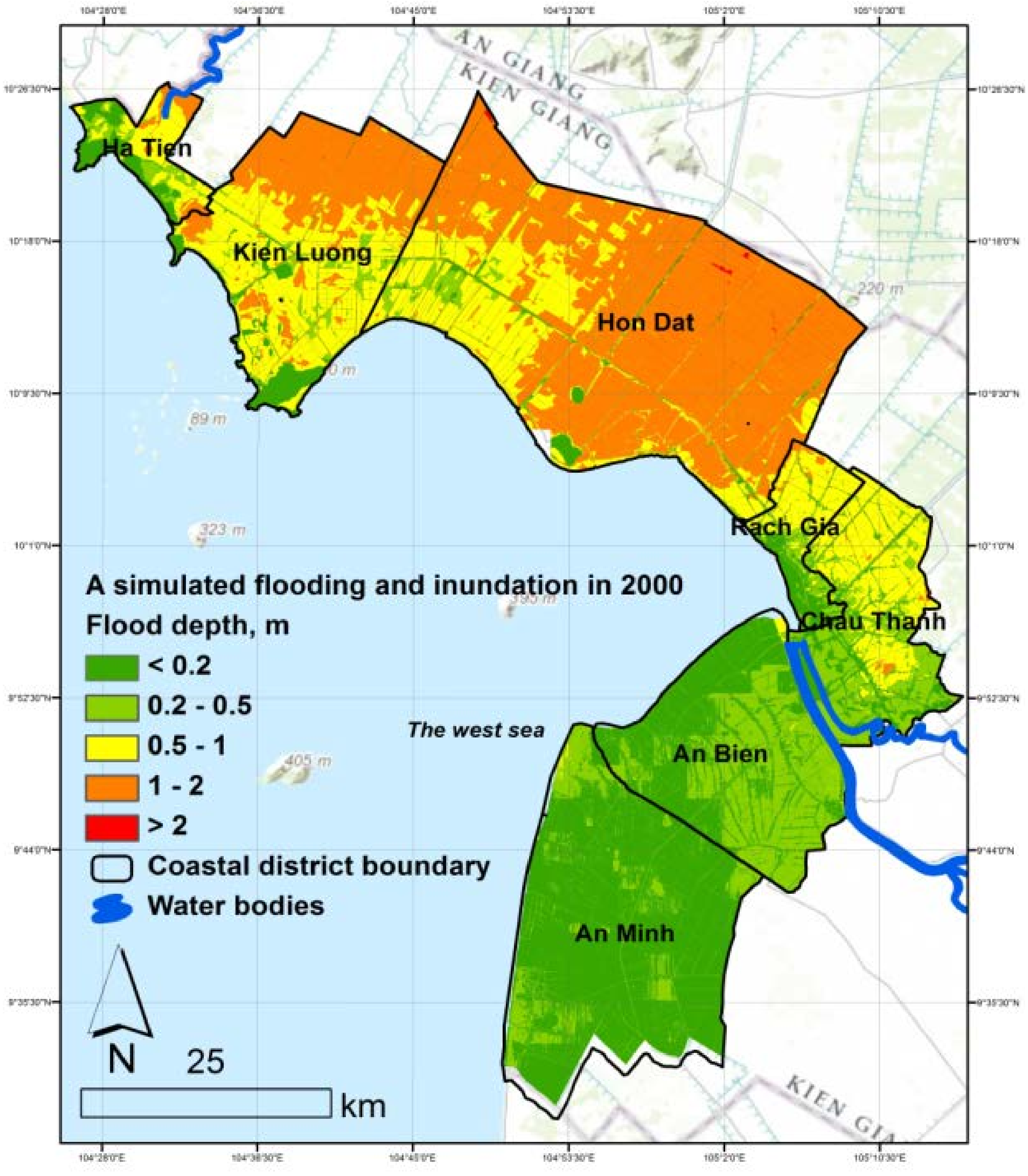
Appendix 8a.3 The dominated wind direction at the west and the east seas of Southern Vietnam.

Direction	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
West Sea	←	↖	↖	↖	↖	→	→	→	↗	↙	←	↙
	E	SE	SE	SE	SE	W	W	W	SW	NE	E	ENE
East Sea	↙	↙	←	↖	↖	↗	↗	↗	↗	↘	↙	↙
	NE	NE	E	SE	SE	SW	SW	SW	SW	NW	ENE	NE

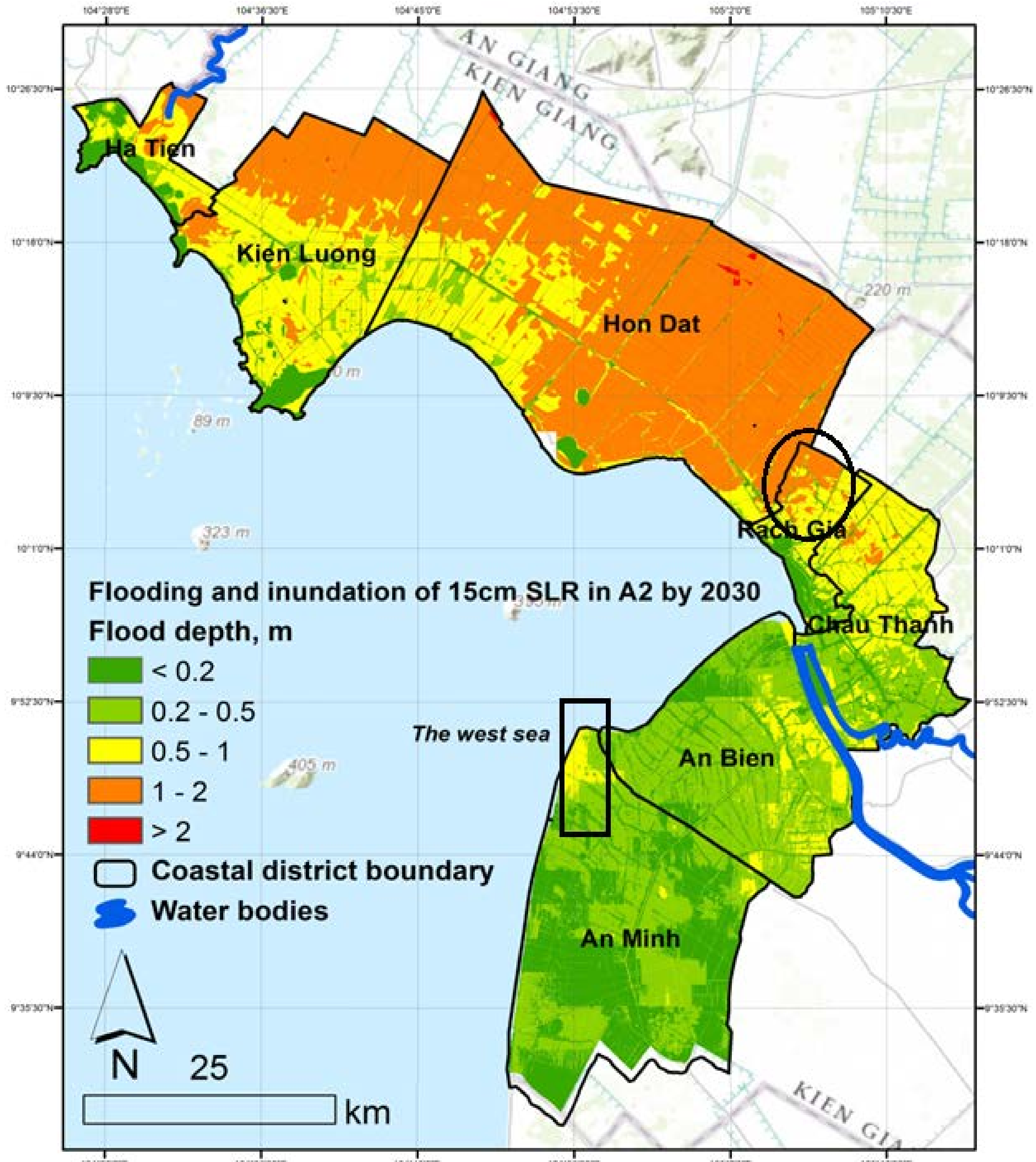
Appendix 8b The Digital Elevation Model classification in the seven coastal districts along the Kien Giang coast, derived from the project conducted by Tran et al. (2013) with permission.



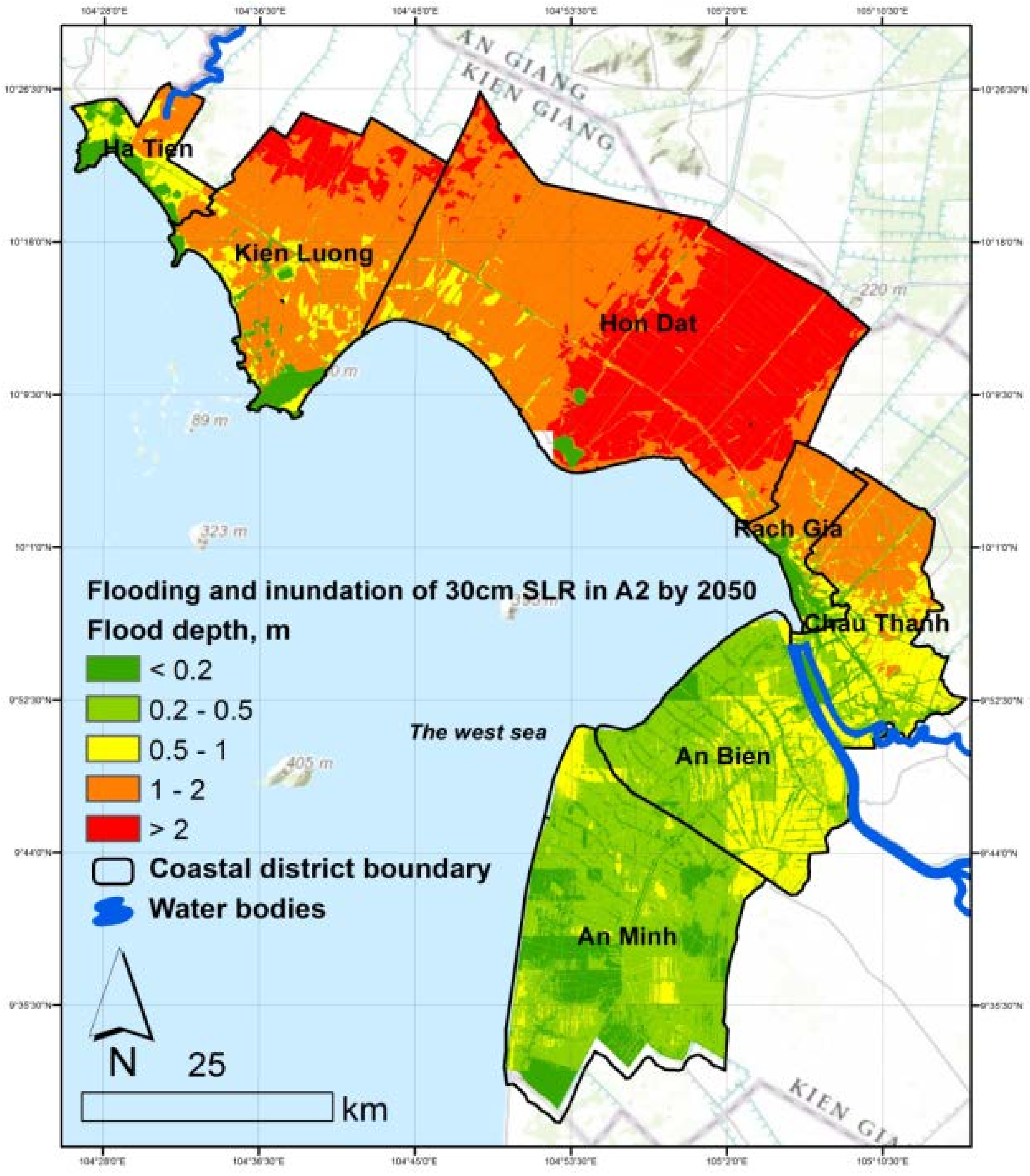
Appendix 8c.1 Simulated extreme historical flood depth (m) that occurred in 2000 (A baseline scenario) classification in the seven coastal districts, derived from Tran et al. (2013).



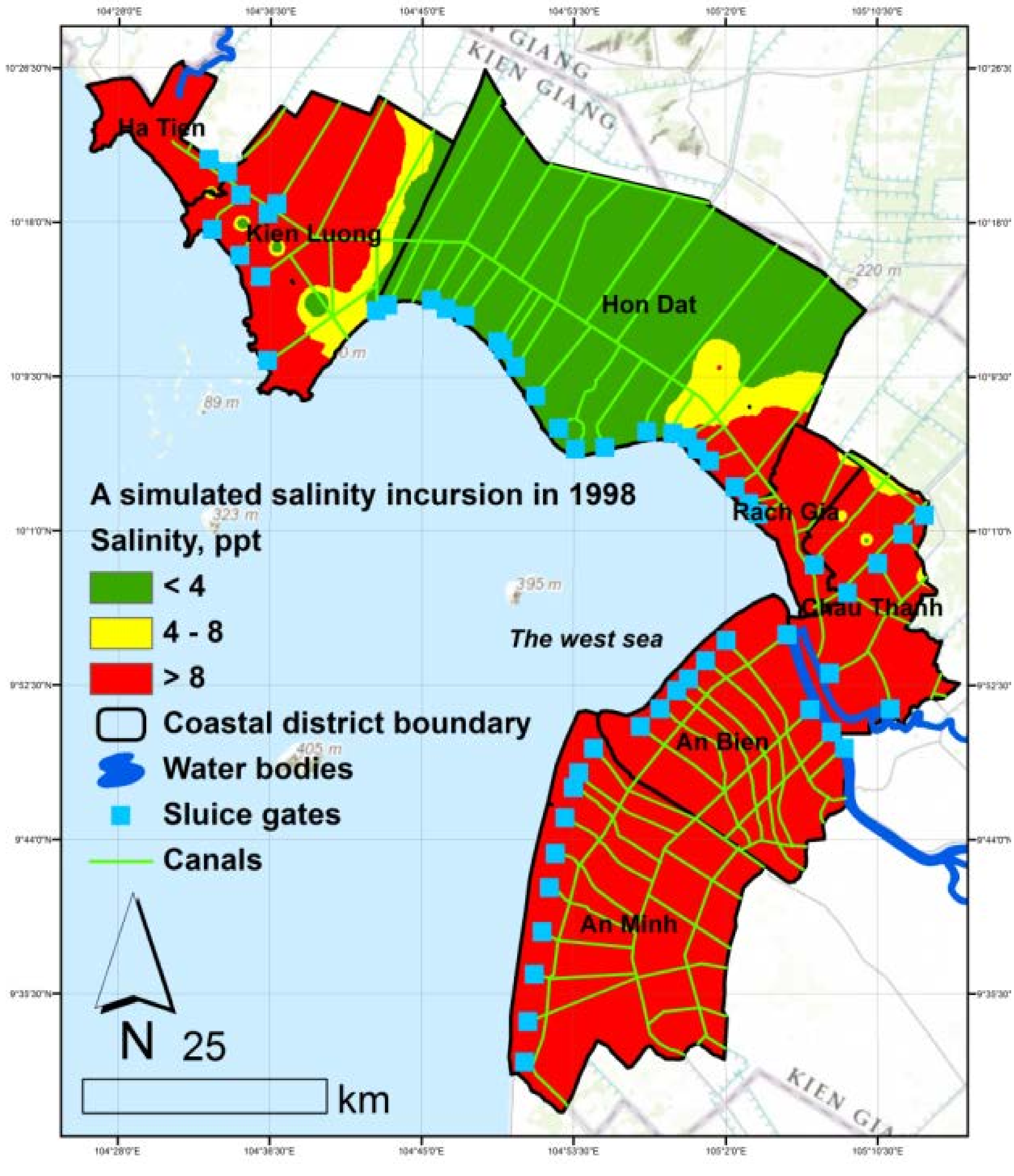
Appendix 8c.2 A projected simulation of flood depth of 15 cm sea-level rise in an A2 emission scenario by 2030 (m) classification in the seven coastal districts, derived from Tran et al. (2013).



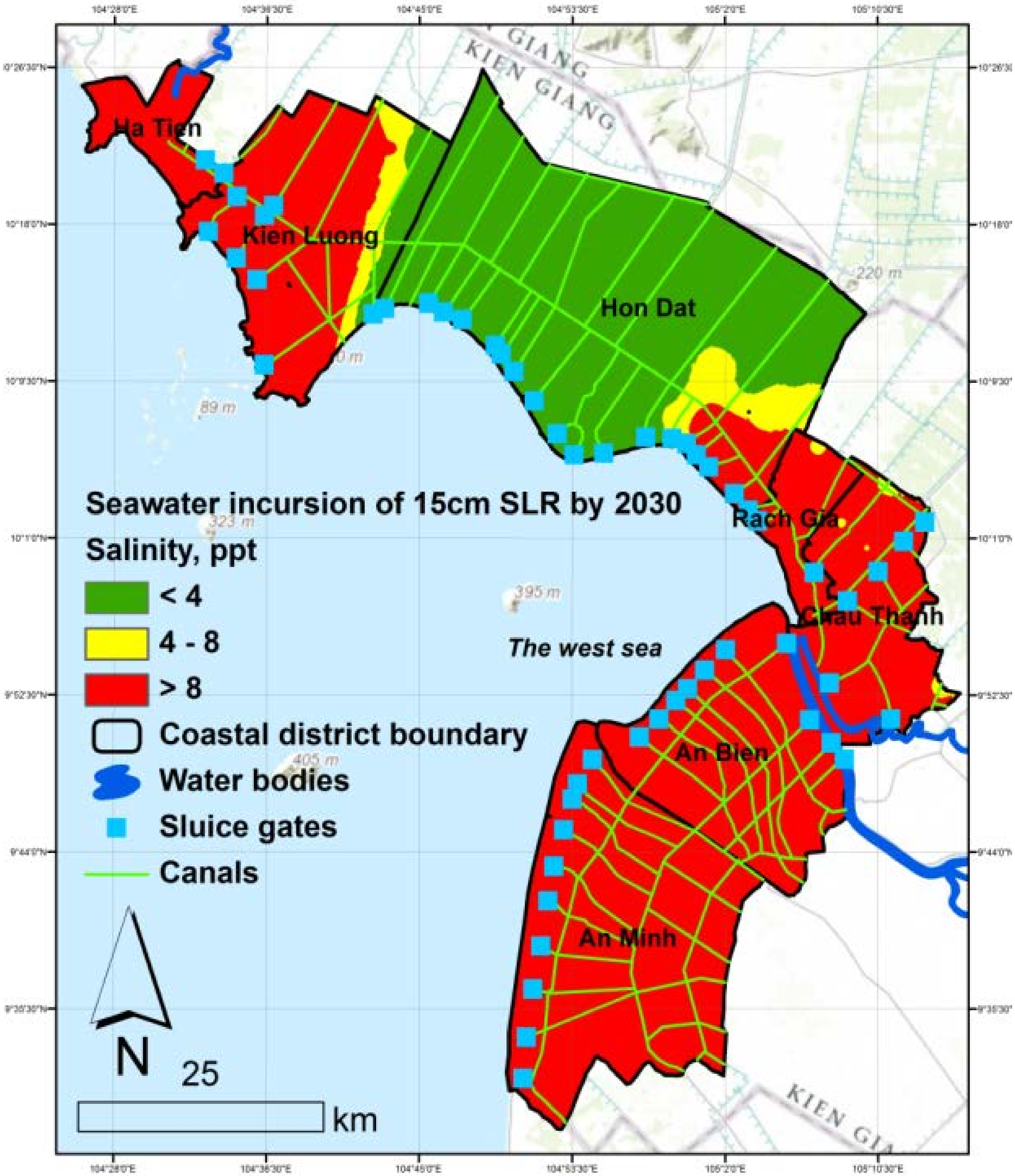
Appendix 8c.3 A projected simulation of flood depth of 30 cm sea-level rise in an A2 emission scenario by 2050 (m) classification in the seven coastal districts, derived from Tran et al. (2013).



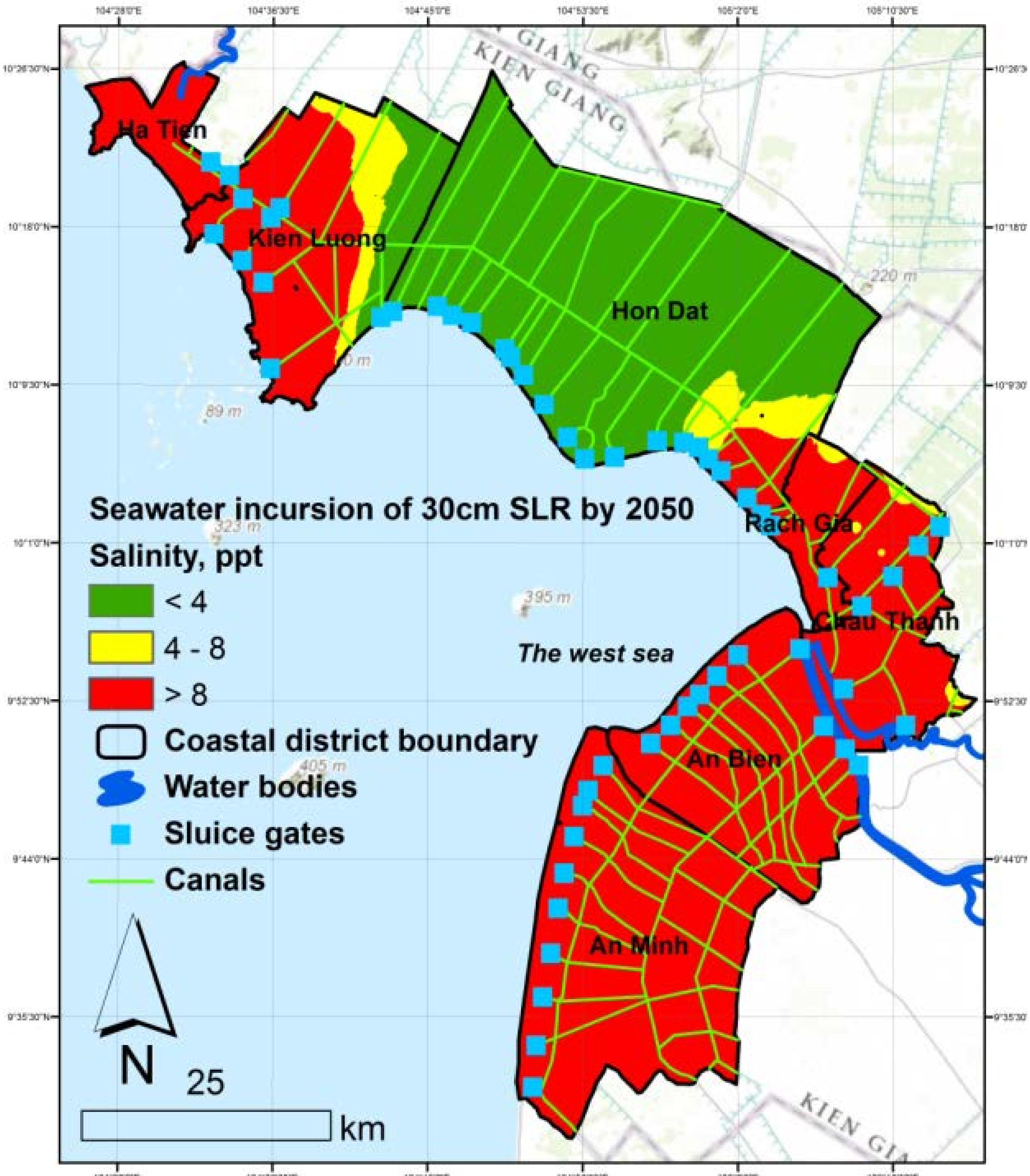
Appendix 8d.1 A simulated extreme historical drought and salinity incursion in 1998 (ppt) classification in the seven coastal districts, derived from Mackey and Russell (2011).



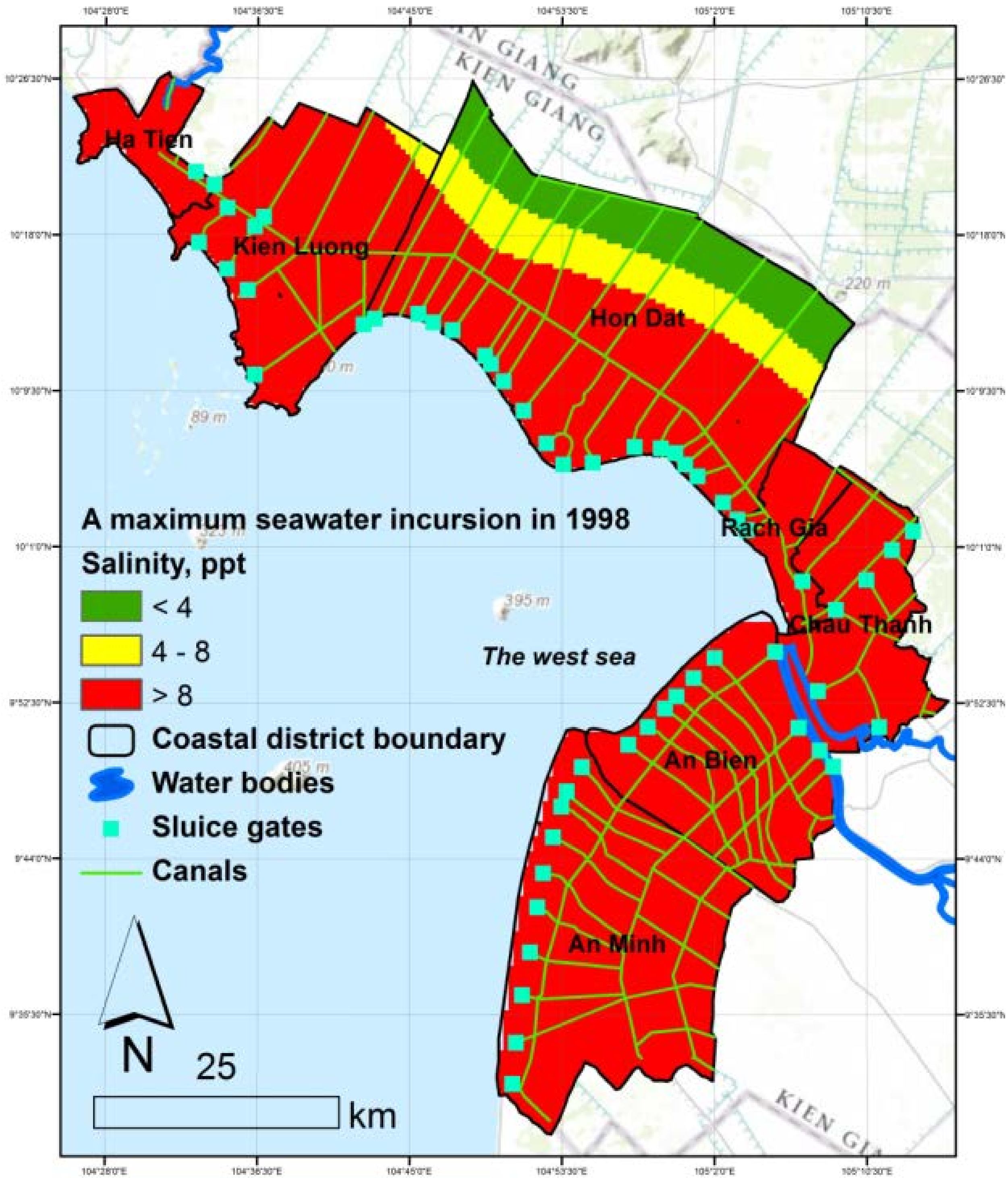
Appendix 8d.2 A projected simulation of salinity incursion of 15 cm sea-level rise by May 2030 (ppt) classification in the seven coastal districts, derived from Mackey and Russell (2011).



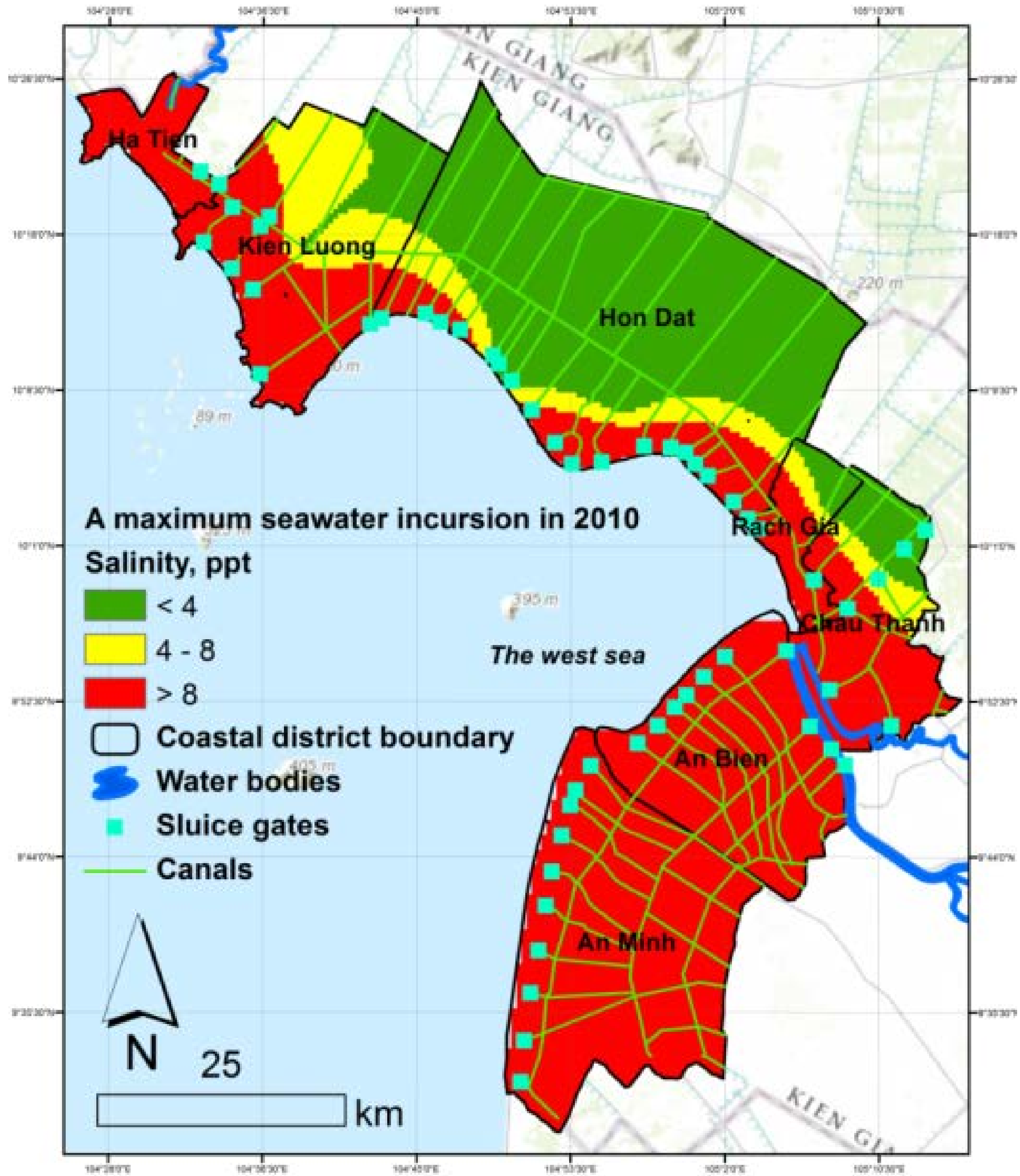
Appendix 8d.3 A projected simulation of salinity incursion of 30 cm sea-level rise by May 2050 (ppt) classification in the seven coastal districts, derived from Mackey and Russell (2011).



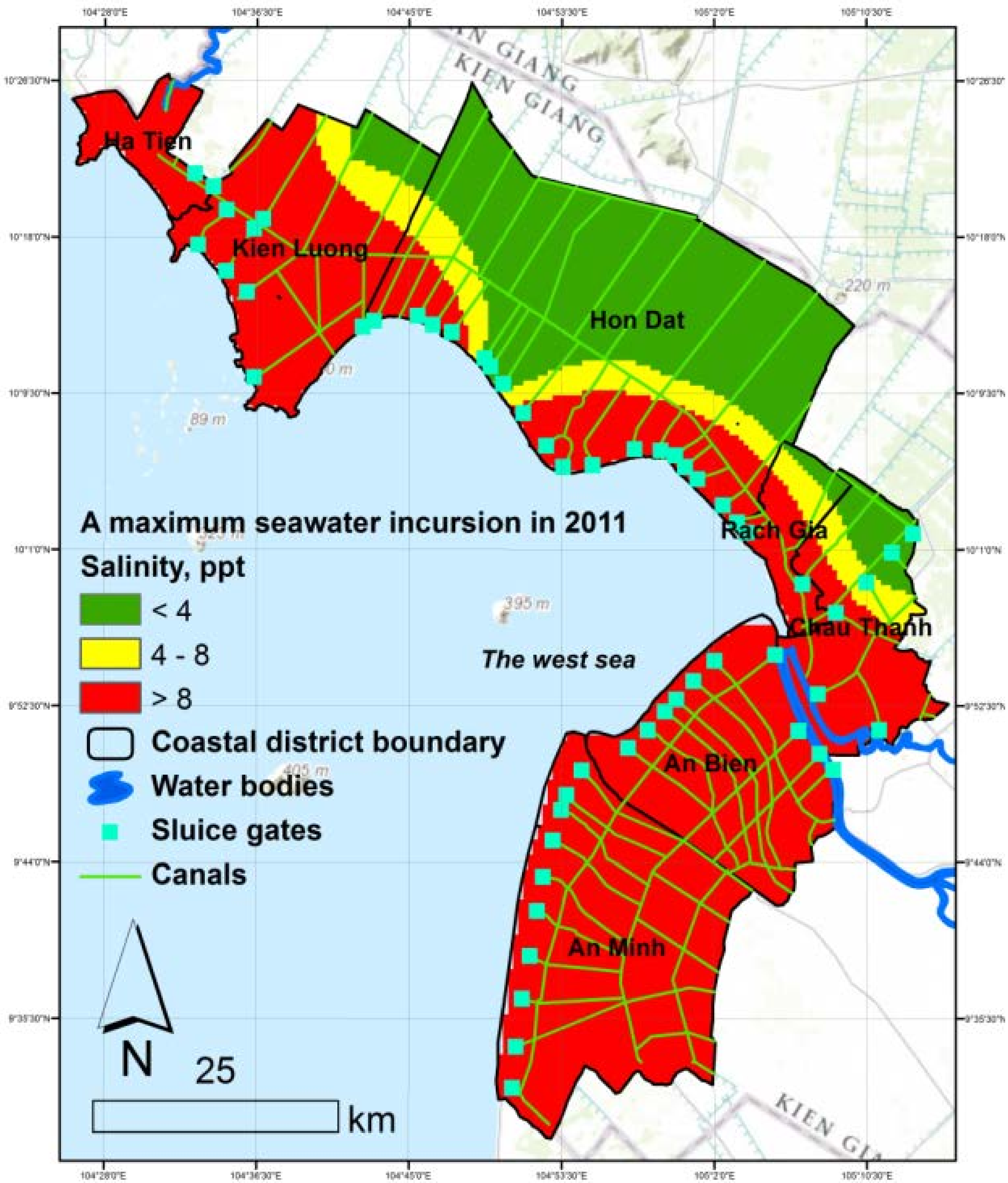
Appendix 8d.4 A maximum seawater incursion map in 1998 (ppt) classification in the seven coastal districts, derived from Le and Le (2013).



Appendix 8d.5 A maximum seawater incursion map in 2010 (ppt) classification in the seven coastal districts, derived from Le and Le (2013).

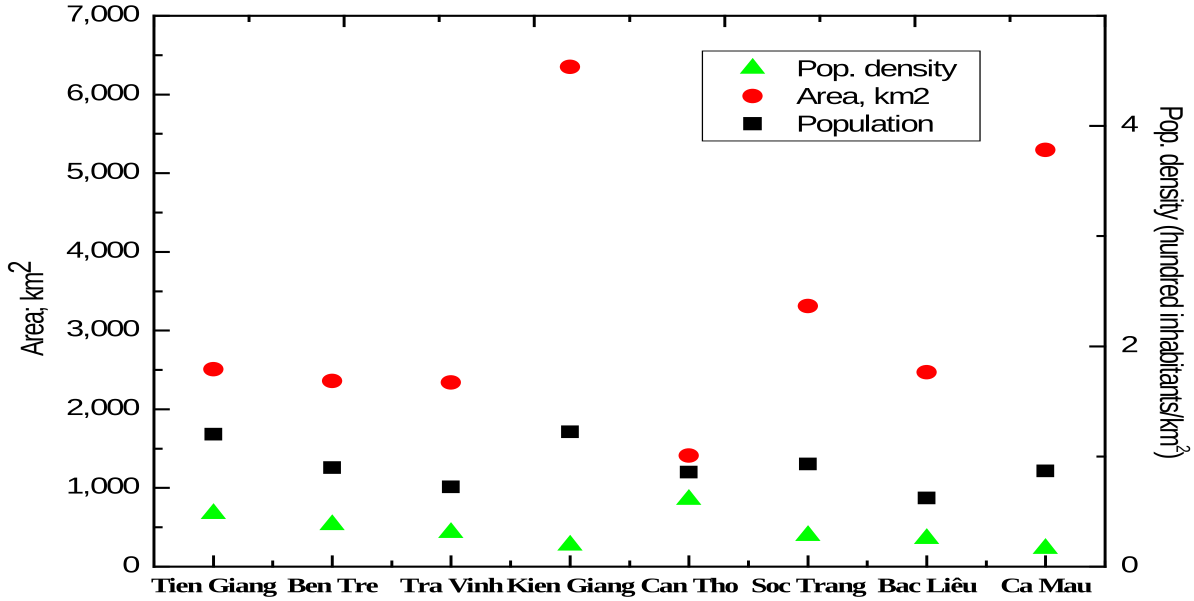


Appendix 8d.6 A maximum seawater incursion map in 2011 (ppt) classification in the seven coastal districts, derived from Le and Le (2013).

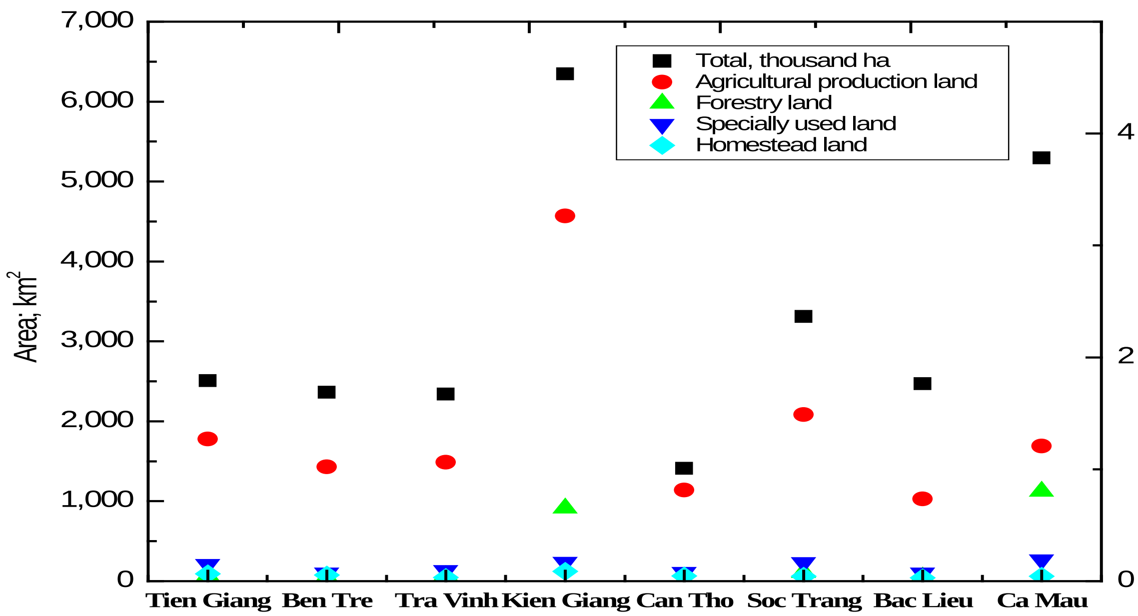


Appendix 9 Social factors in coastal provinces, especially Kien Giang, and Can Tho City in the MRD.

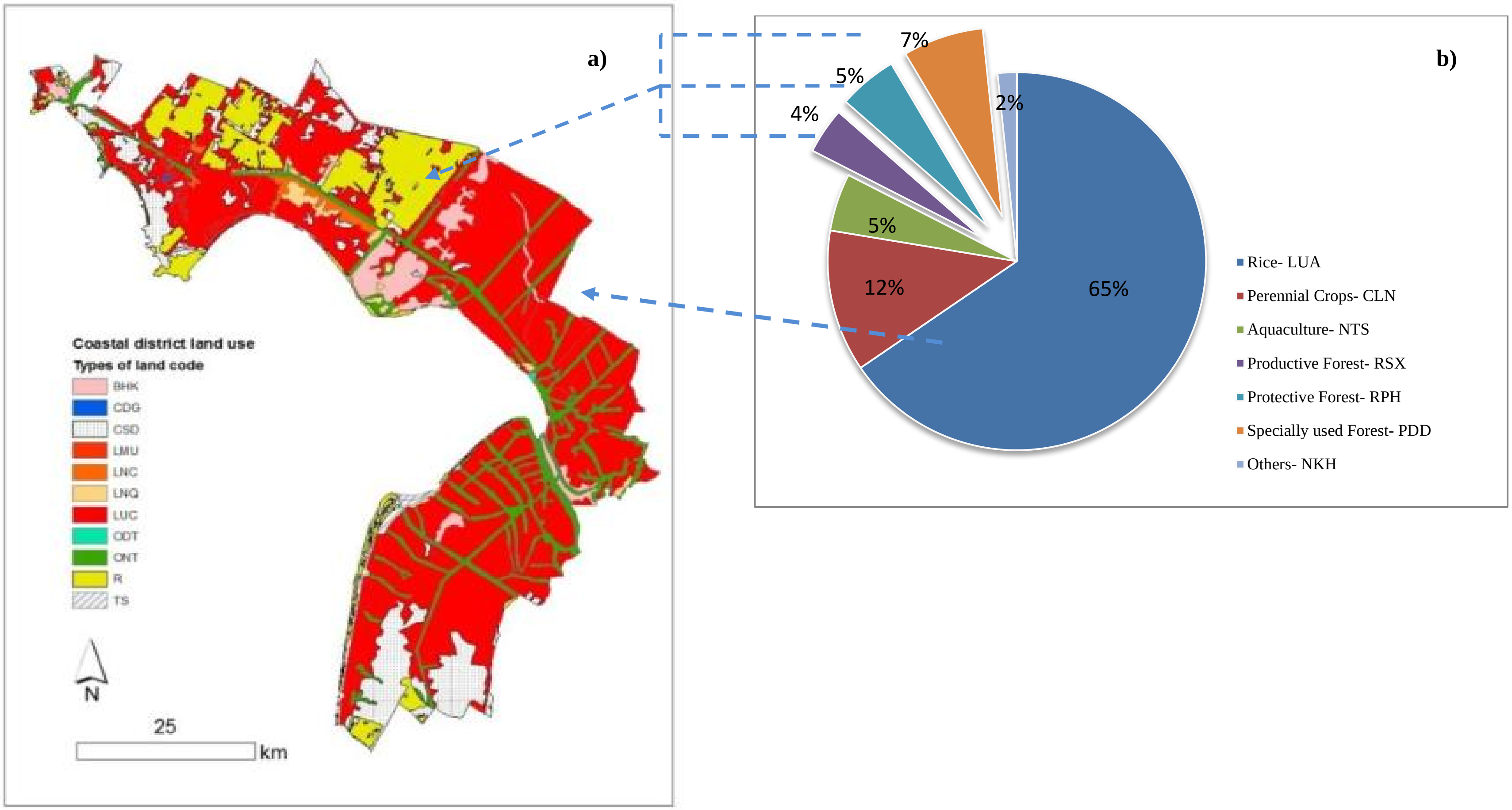
Appendix 9a Area and population in coastal provinces, and Can Tho City in the MRD, derived from GSO (2011).



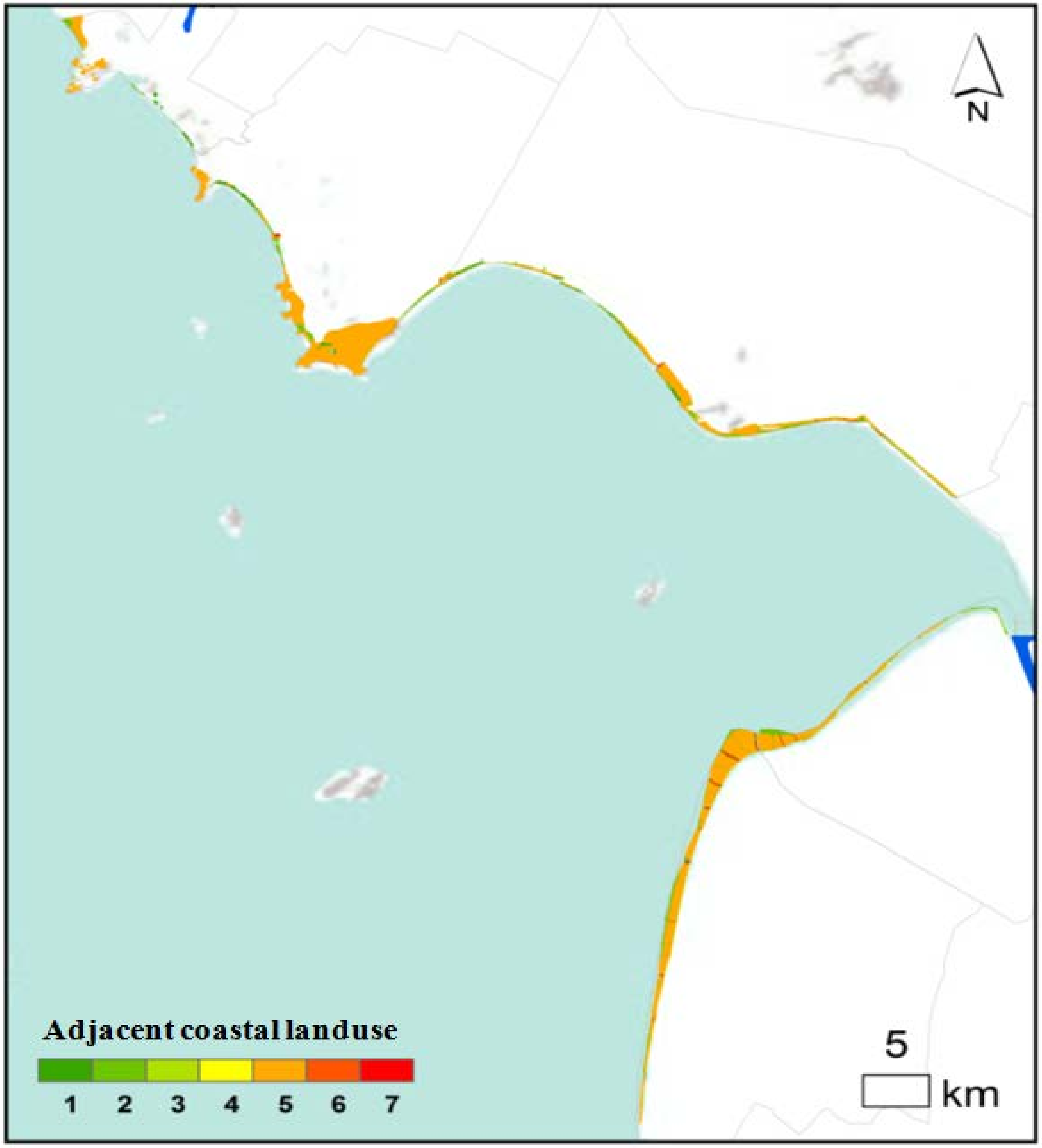
Appendix 9a.1 Landuse in coastal provinces, and Can Tho City in the MRD, derived from GSO (2011).



Appendix 9a.2 Landuse in Kien Giang province: a) The map of landuse in the seven coastal districts, derived from MONRE (2008); and b) Proportions of landuse, with regard to agricultural landuse categories in 2011, derived from the Kien Giang Statistical Office 2012.

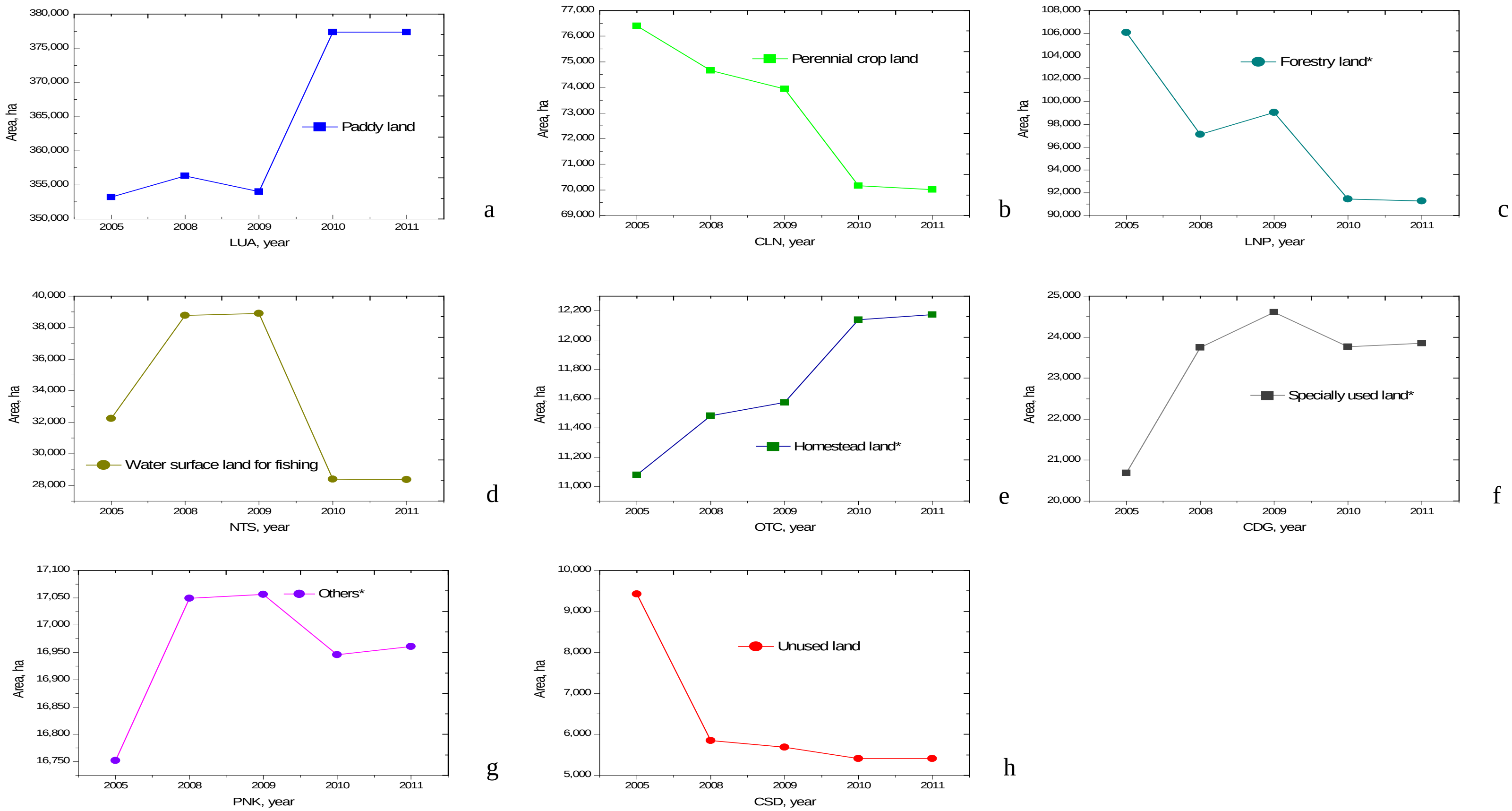


Appendix 9a.2 c) Adjacent coastal landuse along the Kien Giang coast, derived from the GIS database of MARD in 2010.



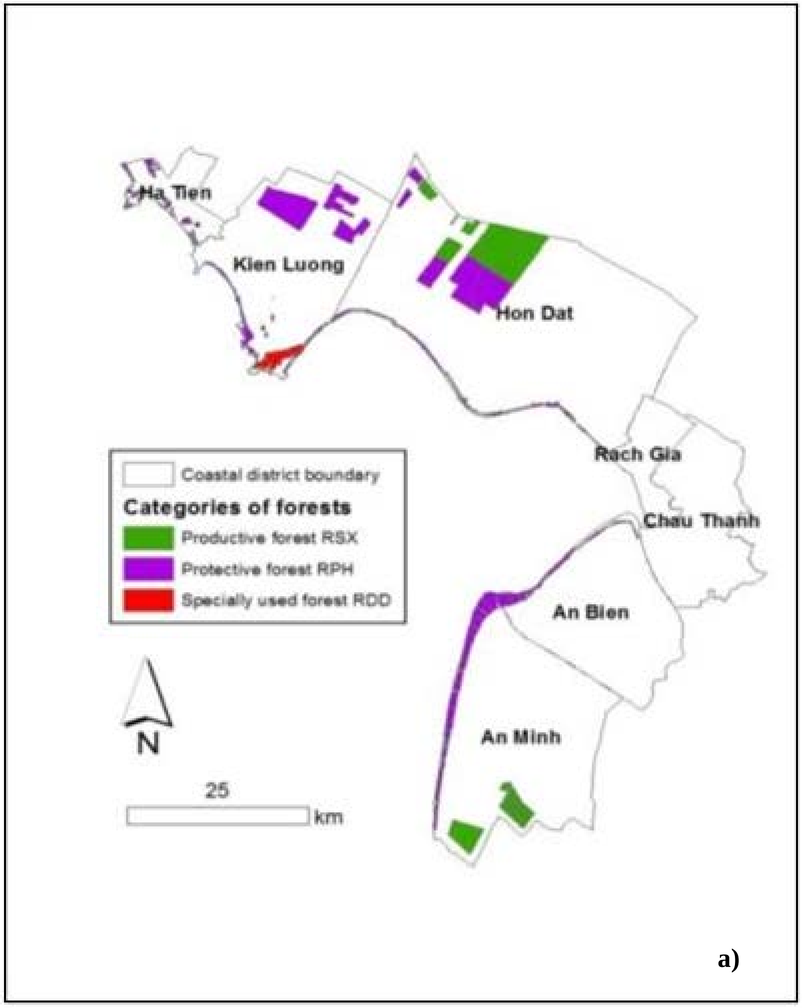
Very low [1-2]	**Low [**3- 4]	**Moderate [5**]	**High [**6]	**Very high [**7]
Mangroves (natural & planted), grass land, etc and water bodies	Man-made infrastructure (sluice gates, dykes)	Fishery farming (Farming with forest & other forests)	Agriculture (Farming and crops)	Built-up (rural and urban settlements)

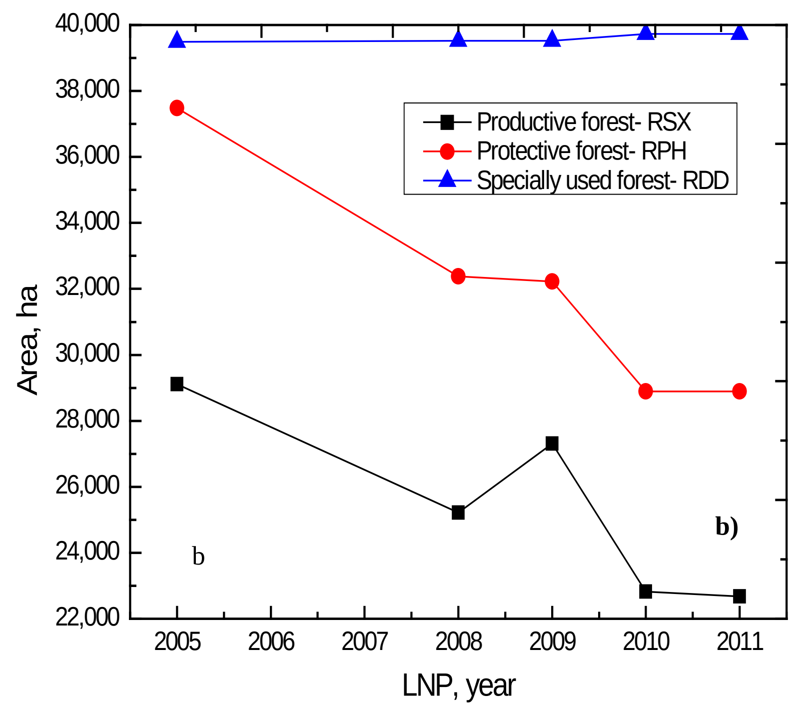
Appendix 9a.3 Trends of three categories of landuse: agricultural land, non-agricultural, and unused land categories in Kien Giang from 2005 to 2011, derived from the Kien Giang Statistical Office 2012.



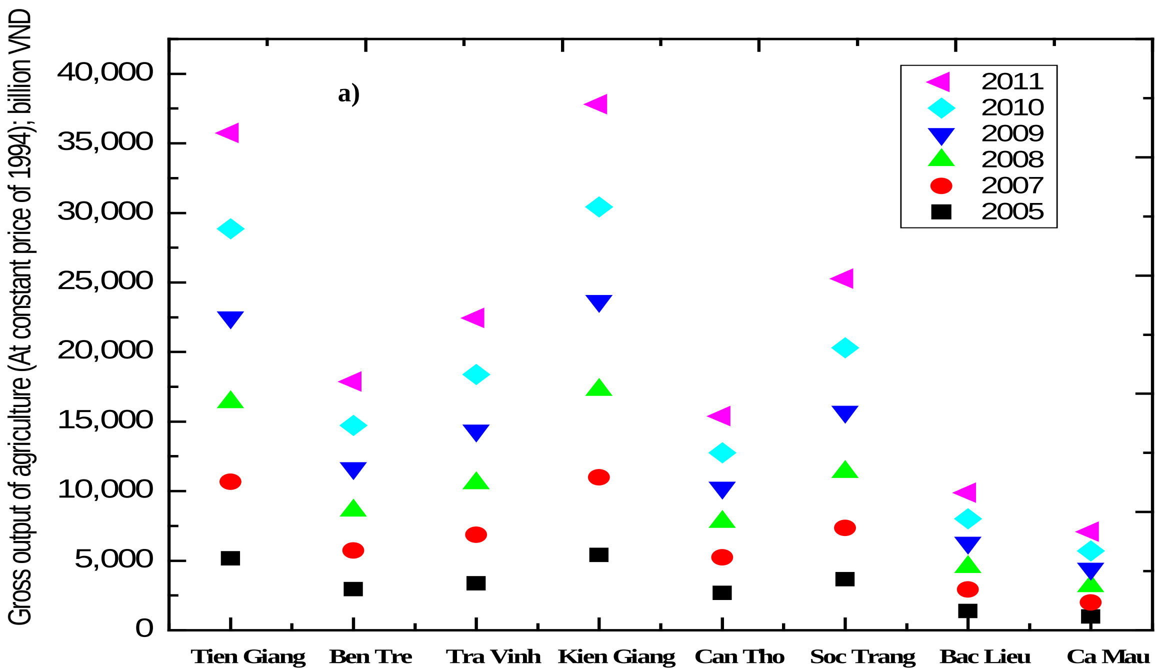
Note: Agricultural land includes: (a) paddy land, (b) perennial cropland, (c) forestry land, (d) water surface land for fishing; (e) Non-agricultural land includes homestead land, (f) specially used land, and (g) others; and (h) Unused land.

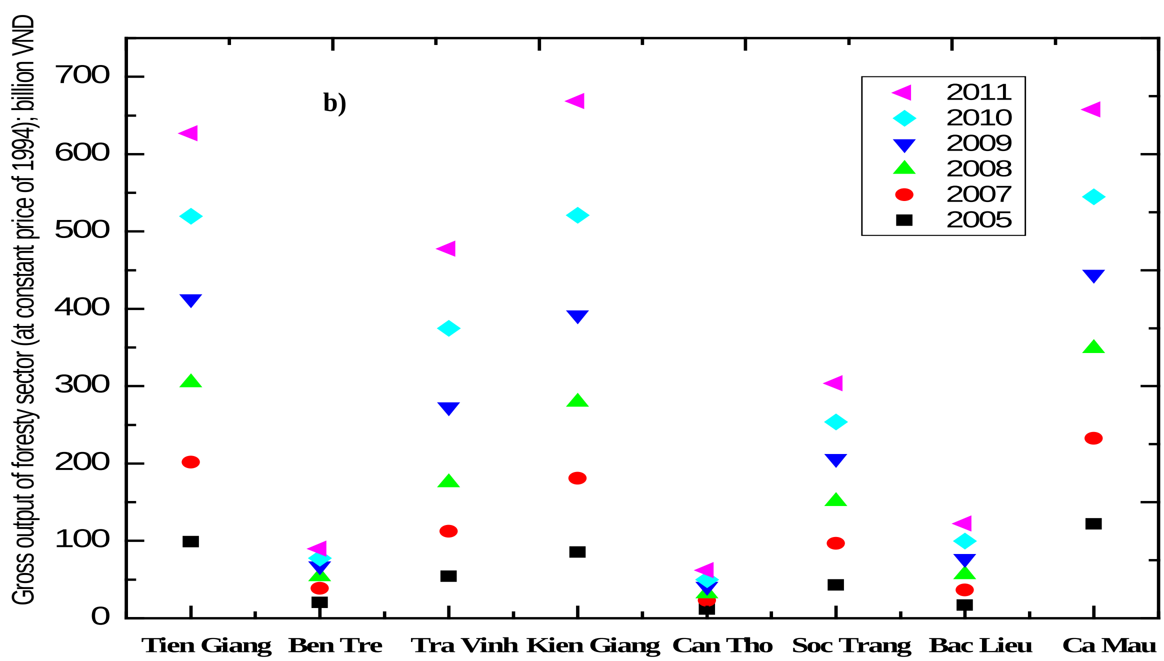
Appendix 9a.4 Forests in Kien Giang: a) A map of forest distribution in the seven coastal districts, obtained from the Sub-FIPI (2008); and b) Trends of forestry land, consisting of three categories: productive forest land, protective forest land, and specially used forest land in Kien Giang province from 2005 to 2011, derived from the Kien Giang Statistical Office 2012.

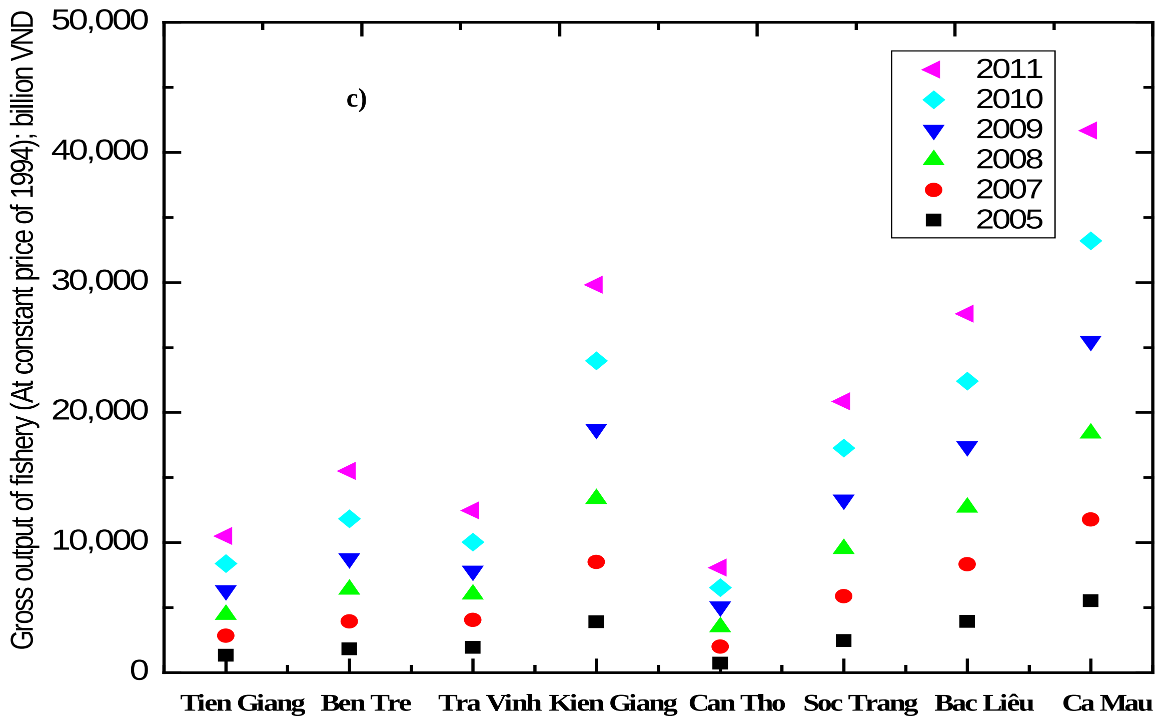


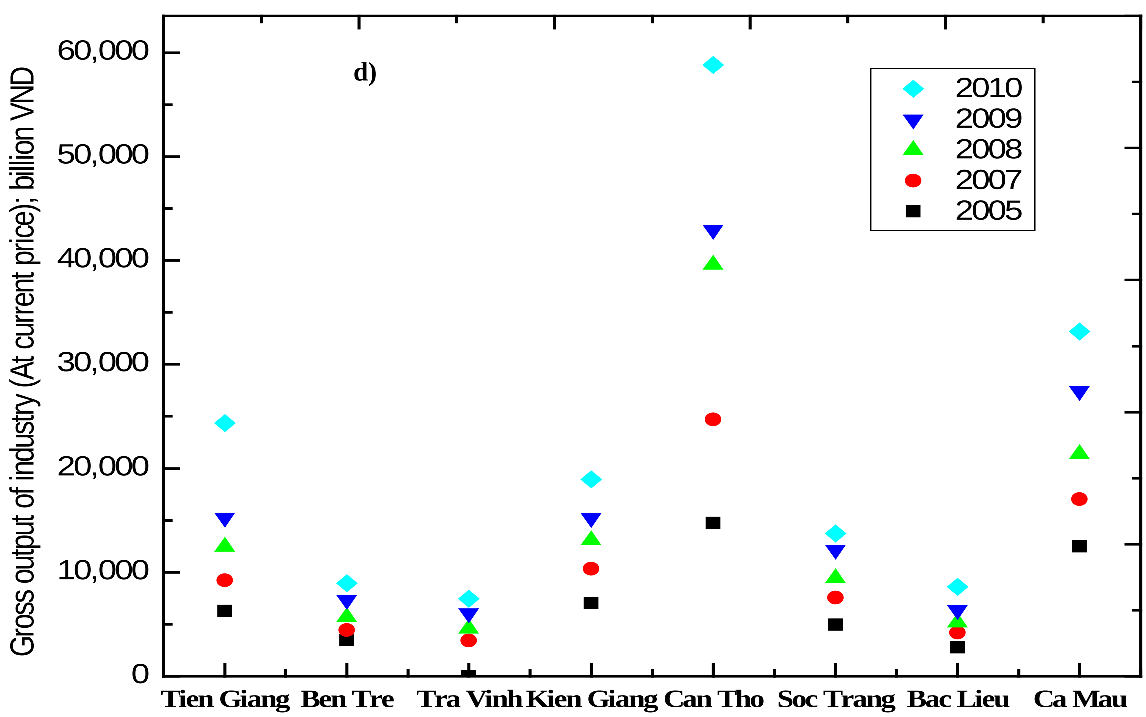


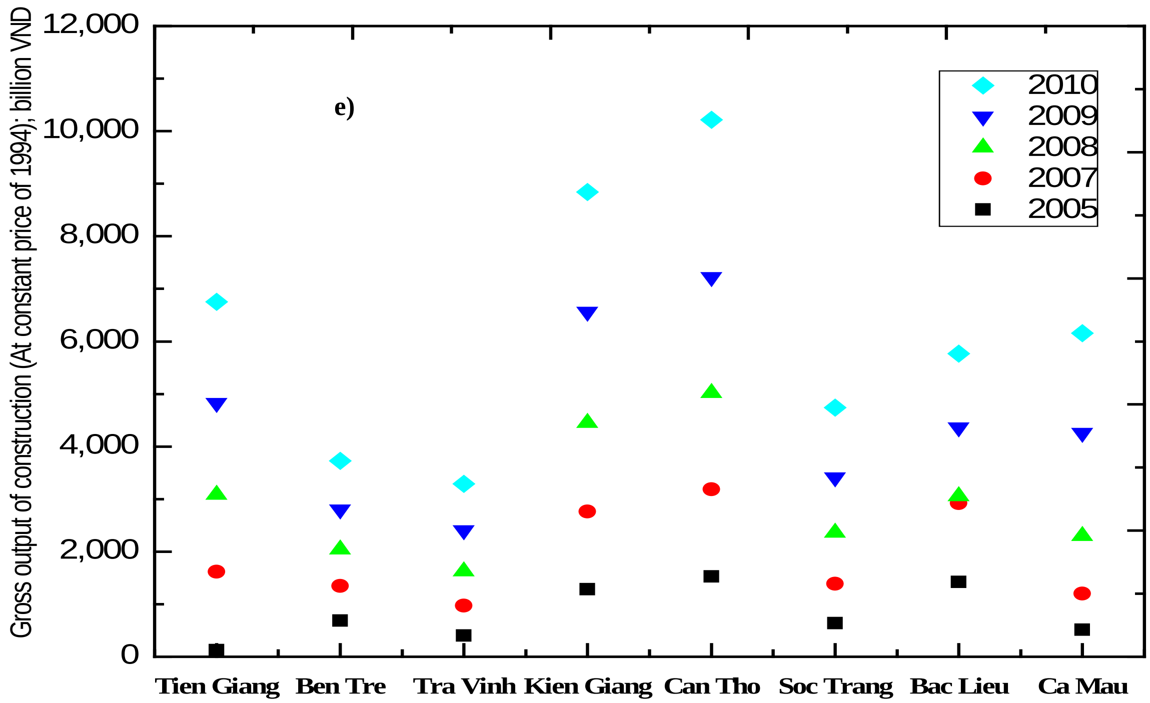
Appendix 9b.1 Trends of Gross output of: a) Agriculture; b) Forestry; c) Fishery sector; and d) Industry sector; e) Construction and f) Retail sales of goods and services in coastal provinces and Can Tho City in the MRD from 2005 to 2011, derived from GSO 2011.

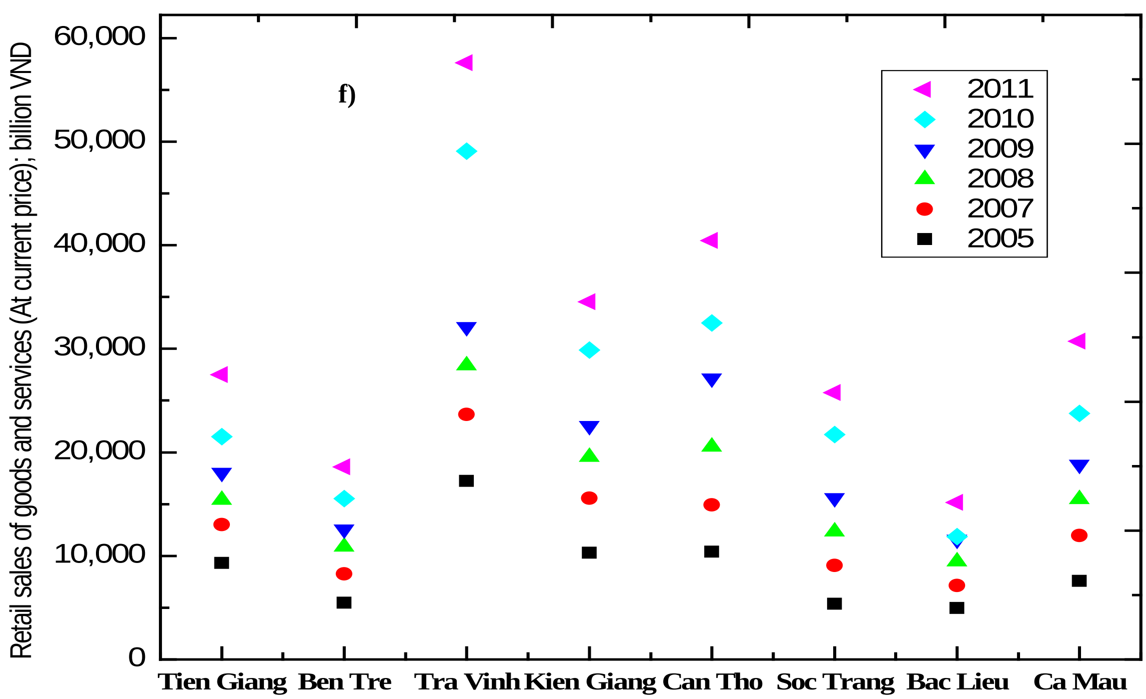




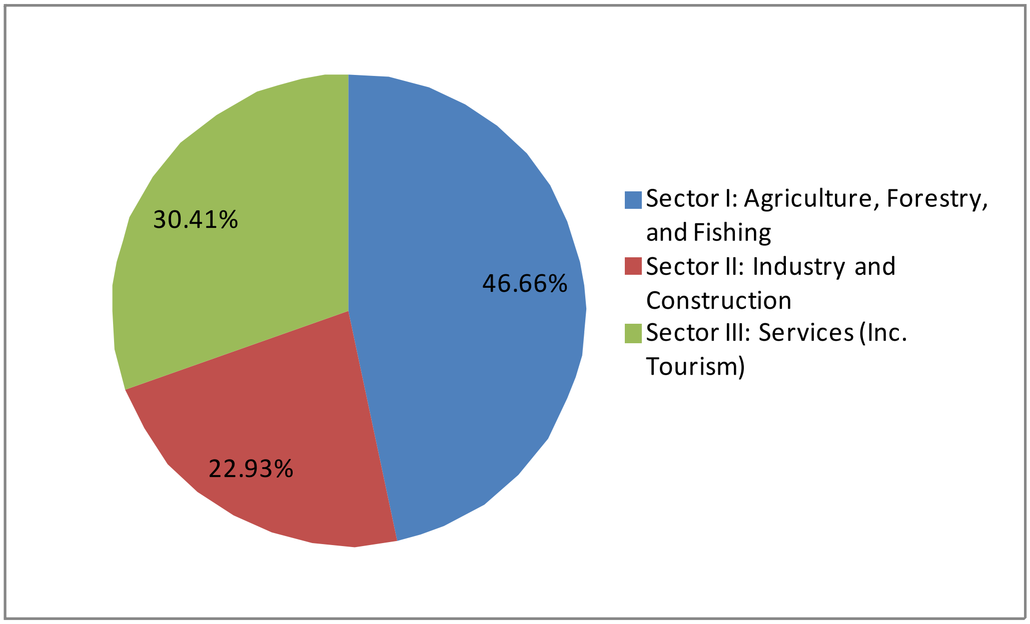

Gross output of fishery (At constant price of 1994); billion VND
50,000
40,000
30,000
20,000
10,000
0
c)
2011
2010
2009
2008
2007
2005
Tien Giang
Ben Tre
Tra Vinh
Kien Giang
Can Tho
Soc Trang
Bac Liêu
Ca Mau


Gross output of industry (At current price); billion VND
60,000
50,000
40,000
30,000
20,000
10,000
0
d)
2010
2009
2008
2007
2005
Tien Giang
Ben Tre
Tra Vinh
Kien Giang
Can Tho
Soc Trang
Bac Lieu
Ca Mau

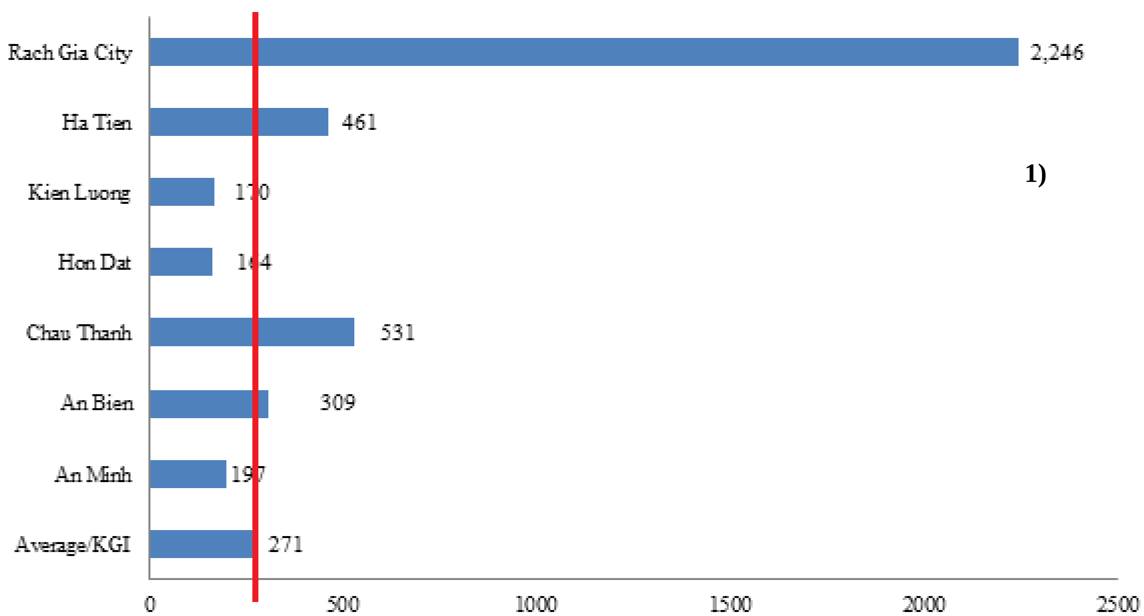

e)
Gross output of construction (At constant price of 1994); billion VND
12,000
10,000
8,000
6,000
4,000
2,000
0
2010
2009
2008
2007
2005
Tien Giang
Ben Tre
Tra Vinh
Kien Giang
Can Tho
Soc Trang
Bac Lieu
Ca Mau

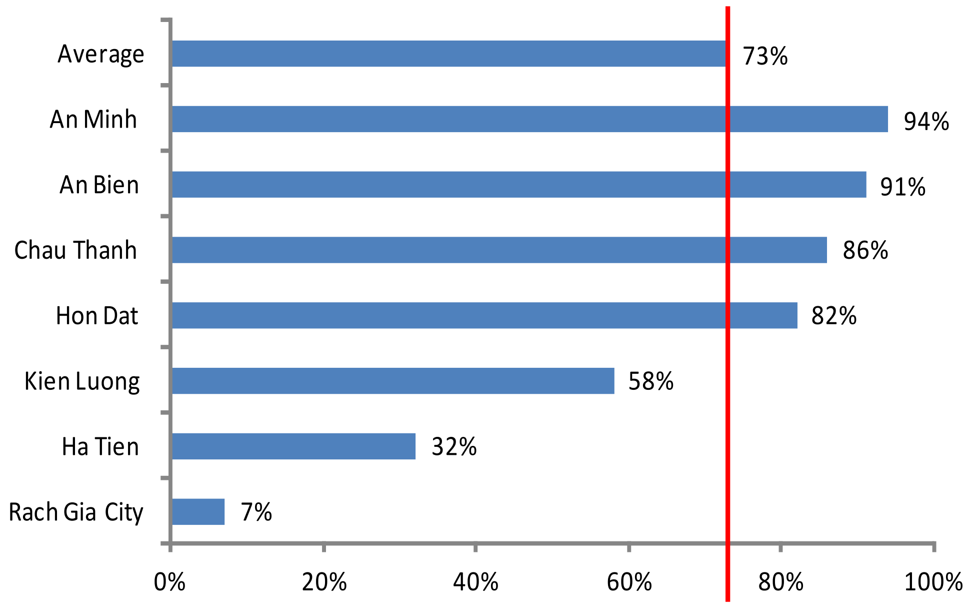

f)
Retail sales of goods and services (At current price); billion VND
60,000
50,000
40,000
30,000
20,000
10,000
0
2011
2010
2009
2008
2007
2005
Tien Giang
Ben Tre
Tra Vinh
Kien Giang
Can Tho
Soc Trang
Bac Lieu
Ca Mau

Appendix 9b.2 Structure of Gross domestic product by three main economic sectors (%) in 2011 in Kien Giang, derived from the Kien Giang Statistical Office 2012.

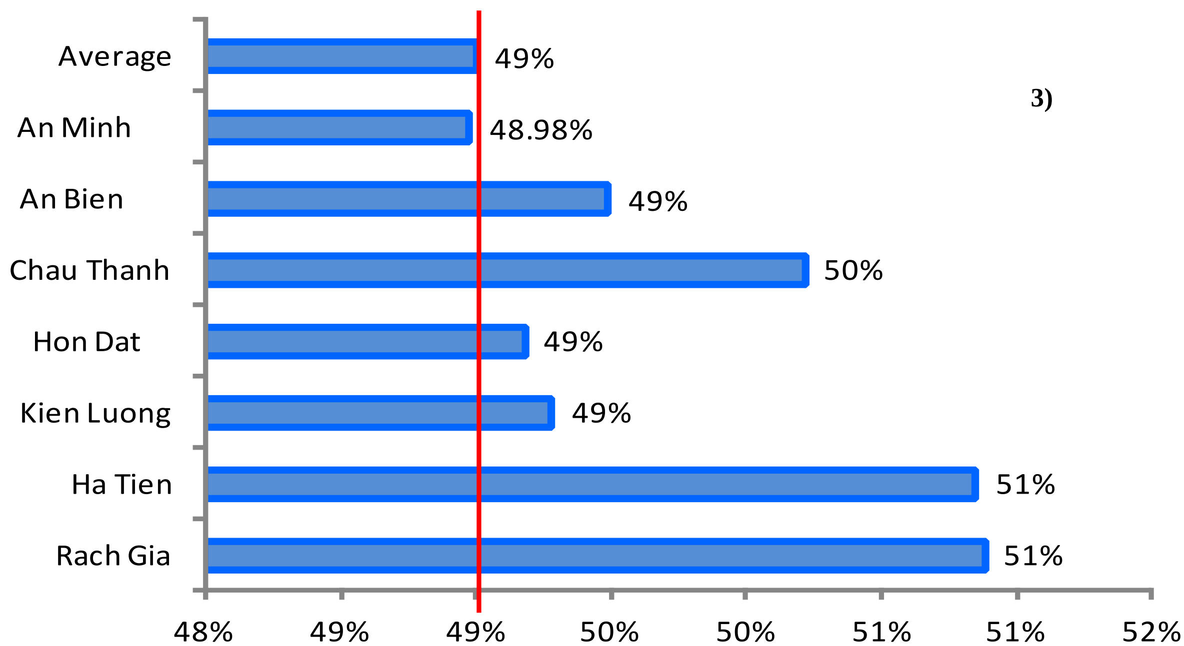


Appendix 9c Societal impacts of the seven coastal districts: 1) Population density (inhabitants/ km^2); 2) Rural population (%); 3) Female population (%) in 2011, derived from the Kien Giang Statistical Office 2012; and 4) Ethnic population (%) in 2010, derived from the Kien Giang District survey 2011.

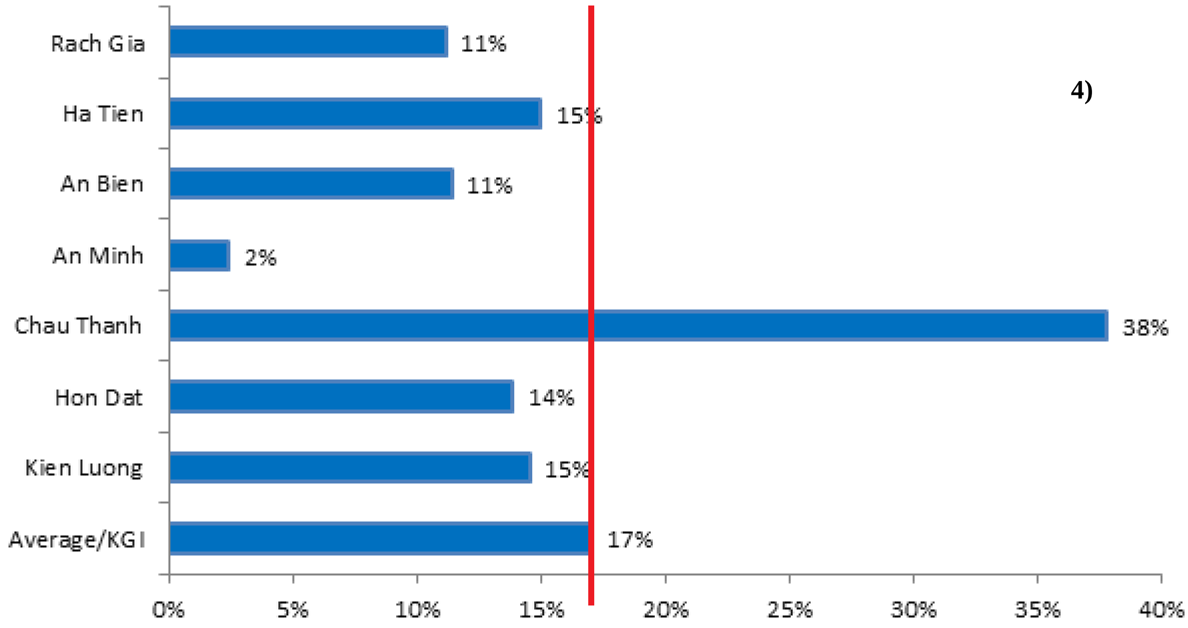



Average
An Minh
An Bien
Chau Thanh
Hon Dat
Kien Luong
Ha Tien
Rach Gia City
73%
94%
91%
86%
82%
58%
32%
7%
0%
20%
40%
60%
80%
100%

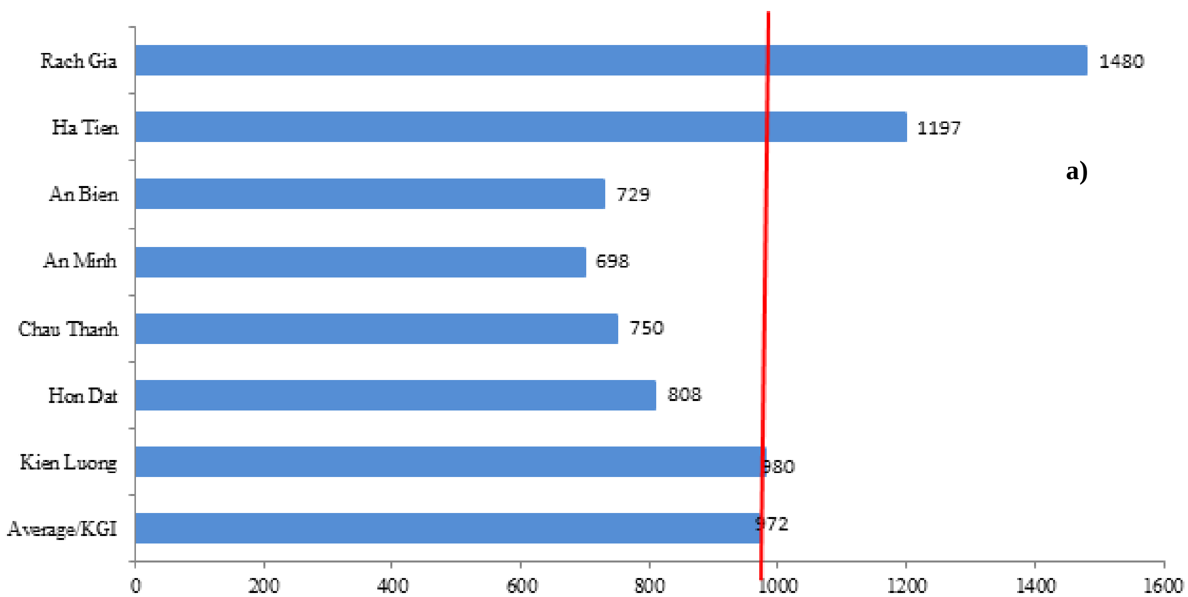
2)

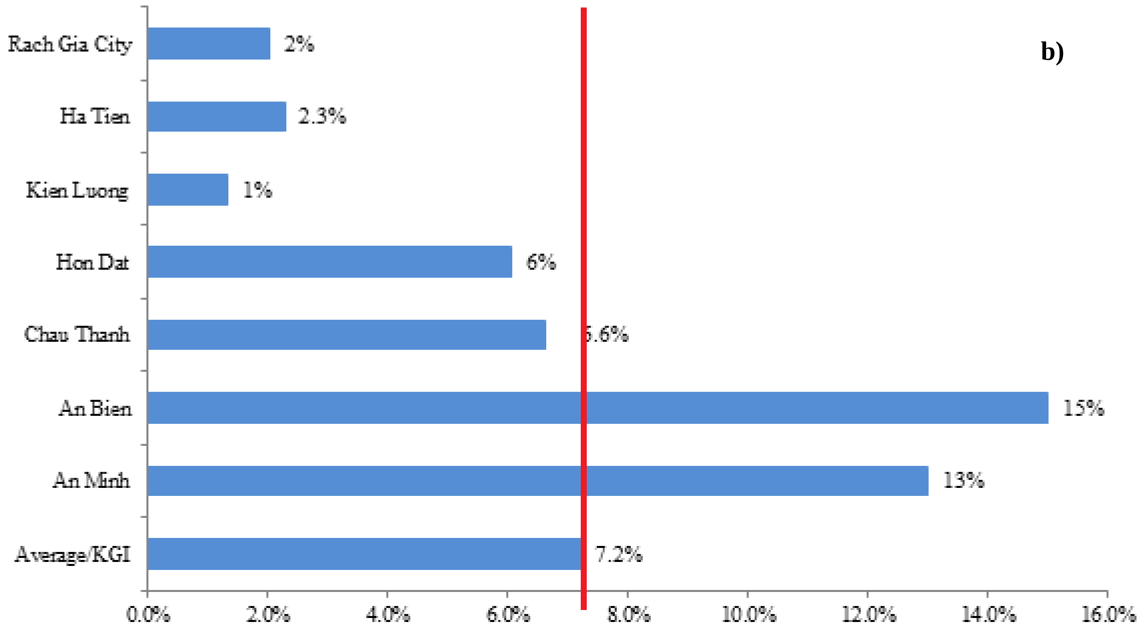

Average
An Minh
An Bien
Chau Thanh
Hon Dat
Kien Luong
Ha Tien
Rach Gia
49%
48.98%
49%
50%
49%
49%
51%
51%
48%
49%
49%
50%
50%
51%
51%
52%

3)



Appendix 9d.1 Socioeconomic factors in the seven coastal districts: a) GDP/capita per district (US$) 2010, derived from the Kien Giang district survey 2011; b) Poverty ratio (%) per district in 2011; c) District key health variables; and d) District key education variables in 2011, derived from the Kien Giang Statistical Office 2012.

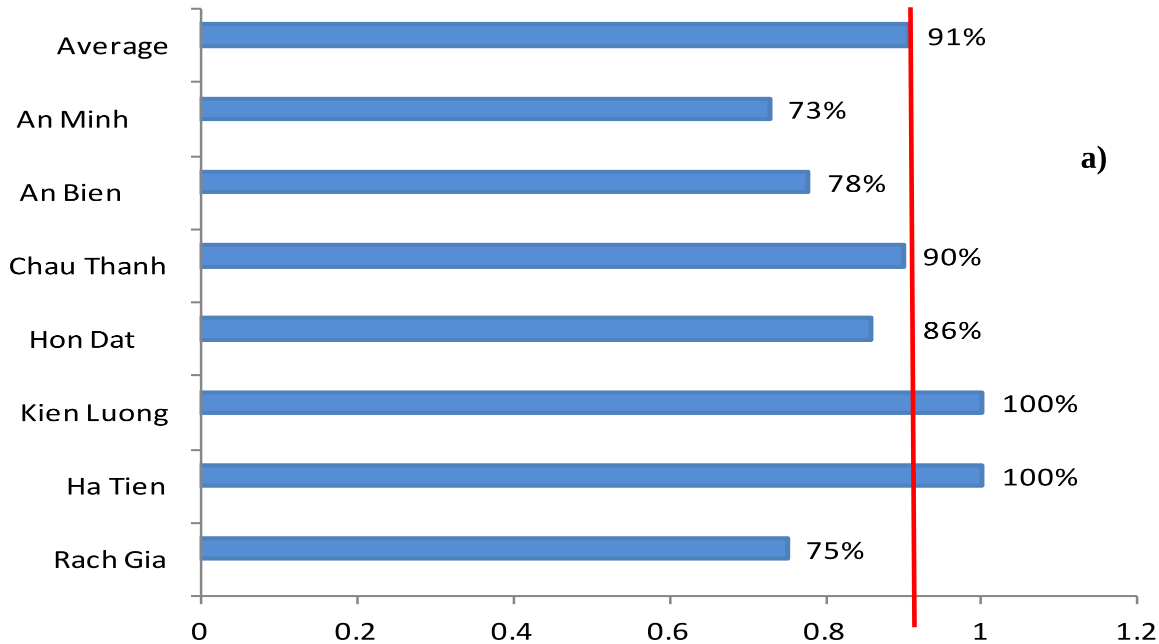


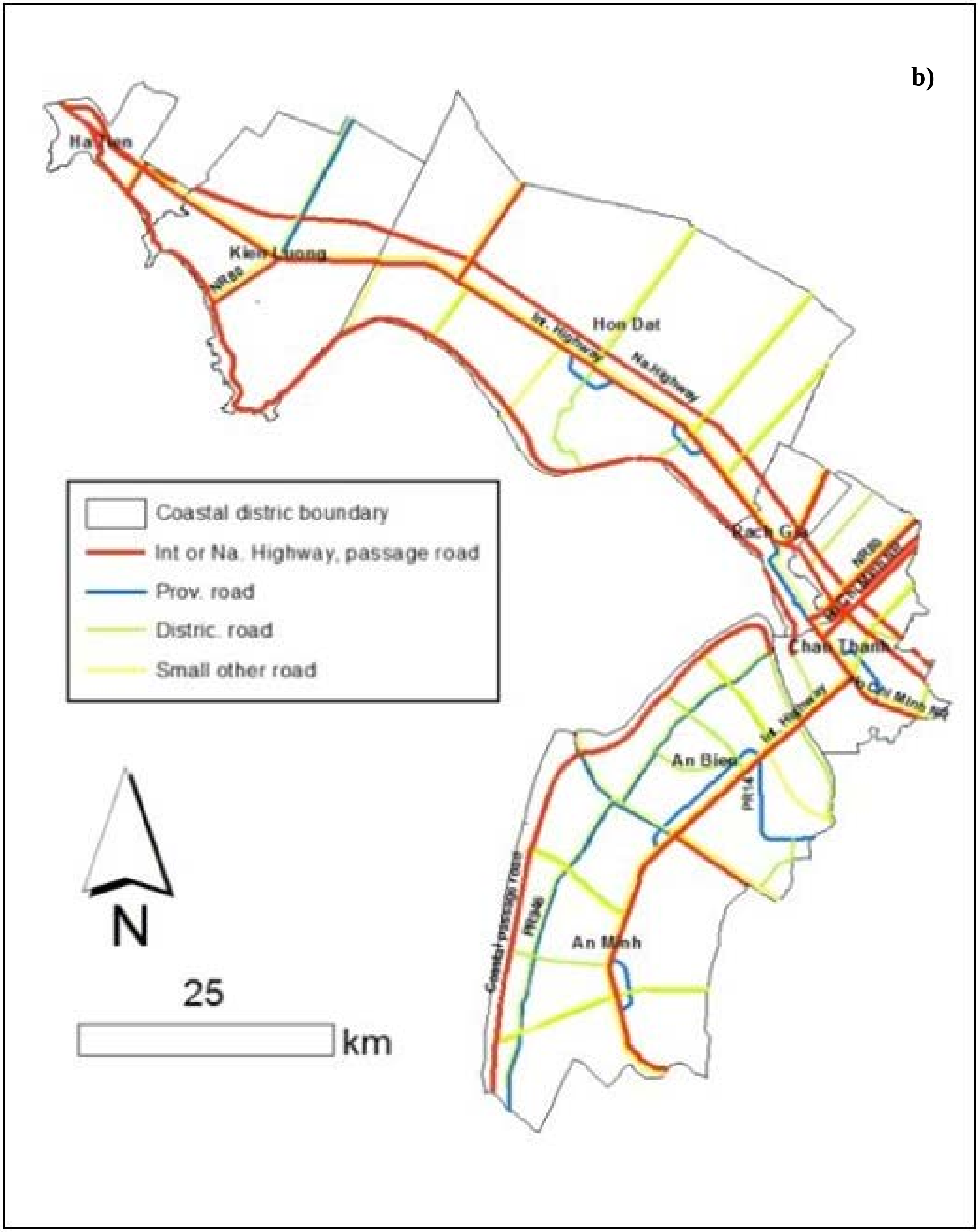


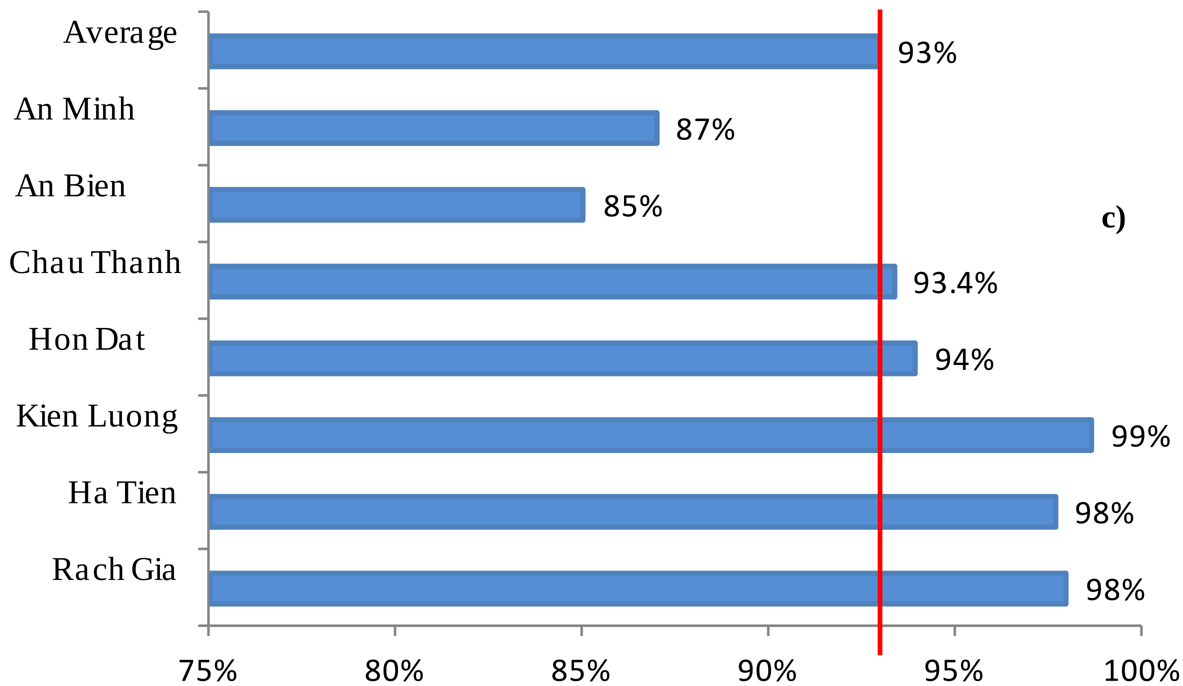
c	Districts	Health establishments	Per # inhabitants	Medical and pharmacy staffs	Per # inhabitants
	Rach Gia City	15	15,502	2,283	102
	Ha Tien	8	5,734	151	304
	Kien Luong	9	8,945	211	382
	Hon Dat	15	11,364	262	651
	Chau Thanh	11	13,778	194	781
	An Bien	10	12,379	224	553
	An Minh	12	9,689	205	567
	Average/KGI	11	10,435	347	331

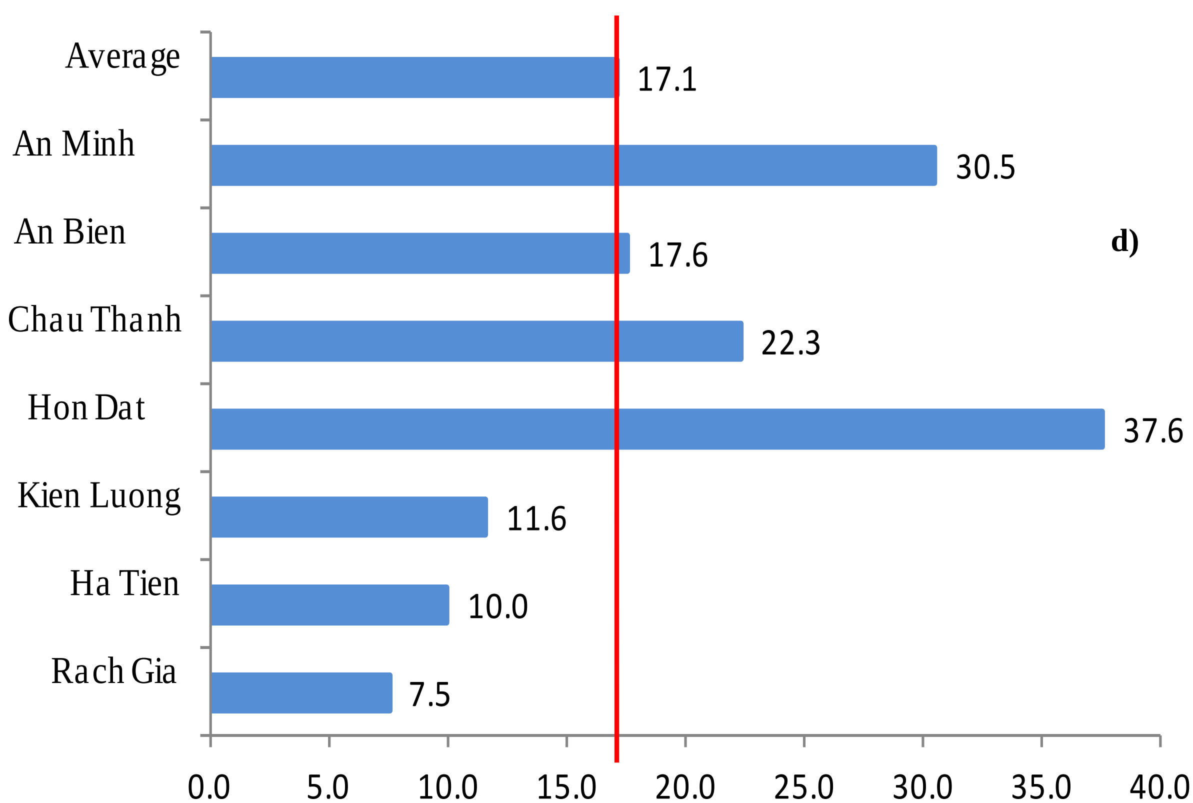
d	Districts	Kindergarten				Primary and secondary			
		Schools	Per # kids	Teachers	Per # kids	Schools	Per # pupils	Teachers	Per # pupils
	Rach Gia City	11	514	284	20	46	838	1,832	21
	Ha Tien	1	653	29	23	16	480	402	19
	Kien Luong	5	327	58	28	18	692	637	20
	Hon Dat	15	256	149	26	51	549	1,629	17
	Chau Thanh	7	384	133	20	41	567	1,306	18
	An Bien	2	1,351	125	22	35	533	1,149	16
	An Minh	2	829	68	24	43	415	1,023	17
	Average/KGI	5	468	101	23	35	535	1,072	17

Appendix 9d.2 Infrastructure in the seven coastal districts: a) Rate of communes having communication routine in 2011, derived from the Kien Giang Statistical Office 2012; b) a map of transport network for study area, obtained from Tran et al. (2013); c) Percentage household having solid houses; and d) Numbers of inhabitants per telephone subscriber in 2011, derived from the Kien Giang Statistical Office 2012.

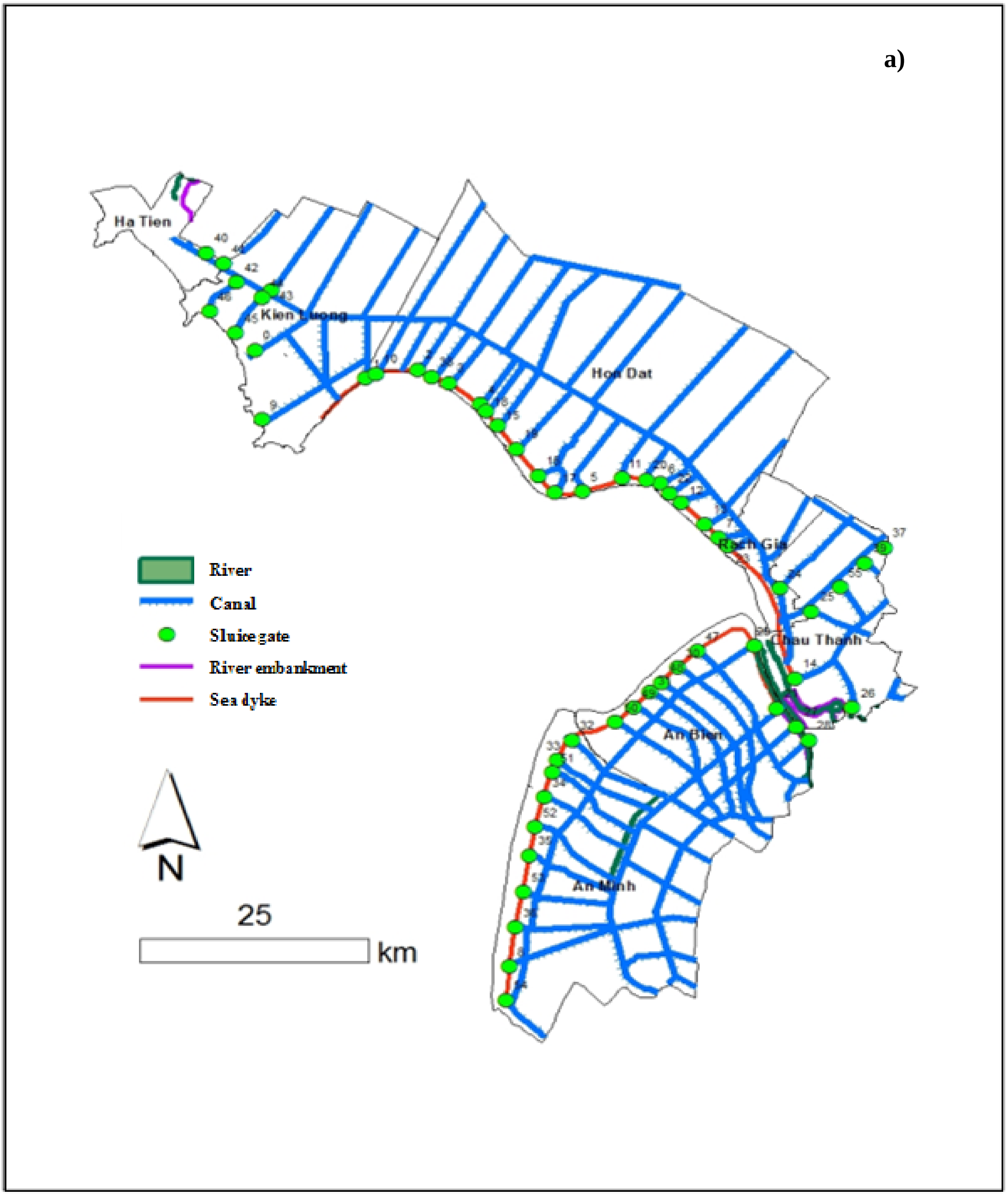


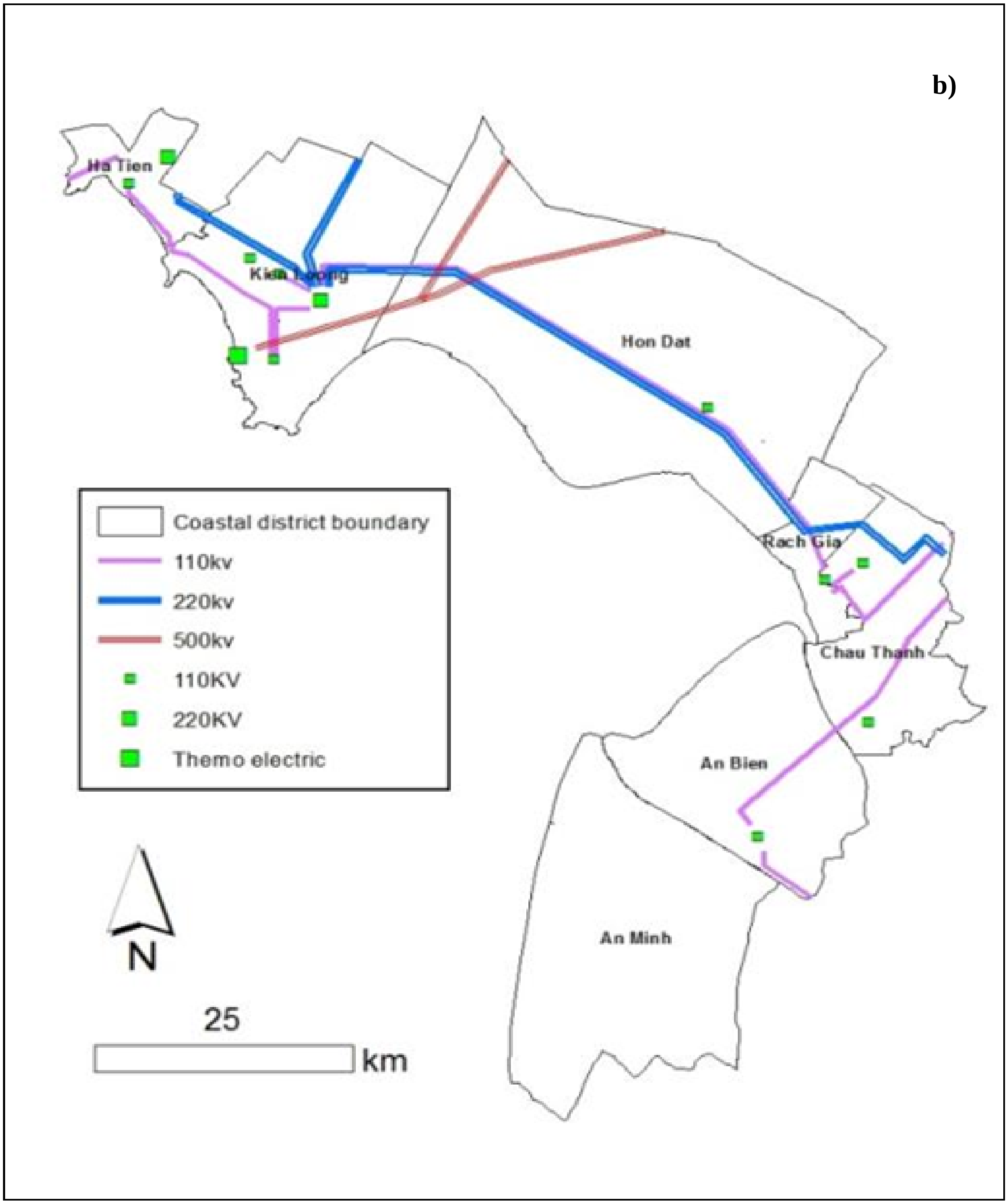

b)
Ha Tien
Kien Luong
NR80
Hon Dat
Int. Highway
Na.Highway
Rach Gia
Chau Thanh
An Bien
PR14
Int. Highway
Coastal passage road
PR96
An Minh
Coastal distric boundary
Int or Na. Highway, passage road
Prov. road
Distric. road
Small other road
N
25
km


Average
An Minh
An Bien
Chau Thanh
Hon Dat
Kien Luong
Ha Tien
Rach Gia
93%
87%
85%
93.4%
94%
99%
98%
98%
c)
75%
80%
85%
90%
95%
100%


Average
An Minh
An Bien
Chau Thanh
Hon Dat
Kien Luong
Ha Tien
Rach Gia
17.1
30.5
17.6
22.3
37.6
11.6
10.0
7.5
d)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0

Appendix 9d.3 Technology in the seven coastal districts: a) A map of irrigation and drainage system for study area from SIWRP (2010); b) A map of electricity network for study area, obtained from Tran et al. (2013).




b)
Ha Tien
Kien Luong
Hon Dat
Rach Gia
Chau Thanh
An Bien
An Minh
Coastal district boundary
110kv
220kv
500kv
110KV
220KV
Themo electric
N
25
km

Appendix 10 A summary of preliminary outcomes for the study area.

No.	Component	Sub-com	Variable	Explanation	The delta	Kien Giang	Seven coastal districts	Note
1	The scenarios of an increase in temperature (°C), rainfall (%) by the 2100, relative to 1980 - 1999, based on the IPCC SRES B2 in 13 provinces in the MRD;				Appendix 7a, c	The annual temperature in Kien Giang is projected to *increase* (see Appendix 7b) Rainfall will tend to *increase slightly in rainy months*; rainfall will tend to *decrease slightly in dry months* (Appendix 7d)		
2	The scenarios of sea-level rise (cm) by 2100, relative to 1980 - 1999, based on the SRES B1, B2, and A1FI along the Vietnam coast;				Appendix 7e			
3	Scenarios for Kien Giang for the two time periods 2030 and 2050, relative to 1980 - 1999 based on SRES B2 and A2 are simulated.					The predicted *rising sea levels* of 15 cm by 2030 and 30 cm 2050 under A2 (Appendix 7f)		
E	**Exposure**			3 sub-components, 6 variables				
	A.1	***Seawater incursion***		2 variables				
	A.1.1		Salinity, ppt Maximum 2010; Simulation 15cm of SLR in 2030, & 30 cm of SLR in 2050	< 4ppt (rice & veg); 4 - 8 (rice & shrimp); >8 (special shrimp)	-	-	The 2010 observed, and 15cm of SLR in 2030, & 30cm of SLR in 2050 modelling based on the 1998 drought event (based on the maximum isohaline). These maps of seawater incursion for the study area was used to assess where could be the most exposed, which will be explained in Chapter 5, sub-section 5.3.1.1	R
	A.1.2		Soil type	alluvisols; PASS; AASS; seasonal saline soils; regular saline soil	-	-	These results obtained will be explained in Chapter 5, sub-section 5.3.1.2	P, V
	A.2	***Flood risk***		2 variables				
	A.2.1		Flood depth, m 2000, 15 cm of SLR in 2030, & 30 cm of SLR in 2050 SRES A2	[0 -0.2; 0.2-0.5; 0.5-1.0; 1-2; >2]	-	-	The 2000 flood- an extreme event observed and 15cm of SLR in 2030, & 30cm of SLR in 2050 SRES A2 modeling. These maps of flood depth for the study area were used to assess where could be the most exposed, that will be explained in Chapter 5, sub-section 5.3.2.1	R
	A.2.2		Elevation, m	[< 0.3; 0.3-0.5; 0.5-0.8; 0.8-1; 1-1.2; 1.2-2; >2]	-	-	83% of the total area is below 1 m above MSL: 1) Ha Tien, Kien Luong, Hon Dat, and Rach Gia, average elevations of 0.8 - 1.2m, known as the flood openings; 2) Plains are largely distributed in districts *Chau Thanh, An Bien, An Minh;* 3) Low hills are scattered in some parts of districts Ha Tien, Kien Luong and Hon Dat. These results obtained will be explained in Chapter 5, sub-section 5.3.2.2	P, R
	A.3	***Shoreline change***		2 variables				

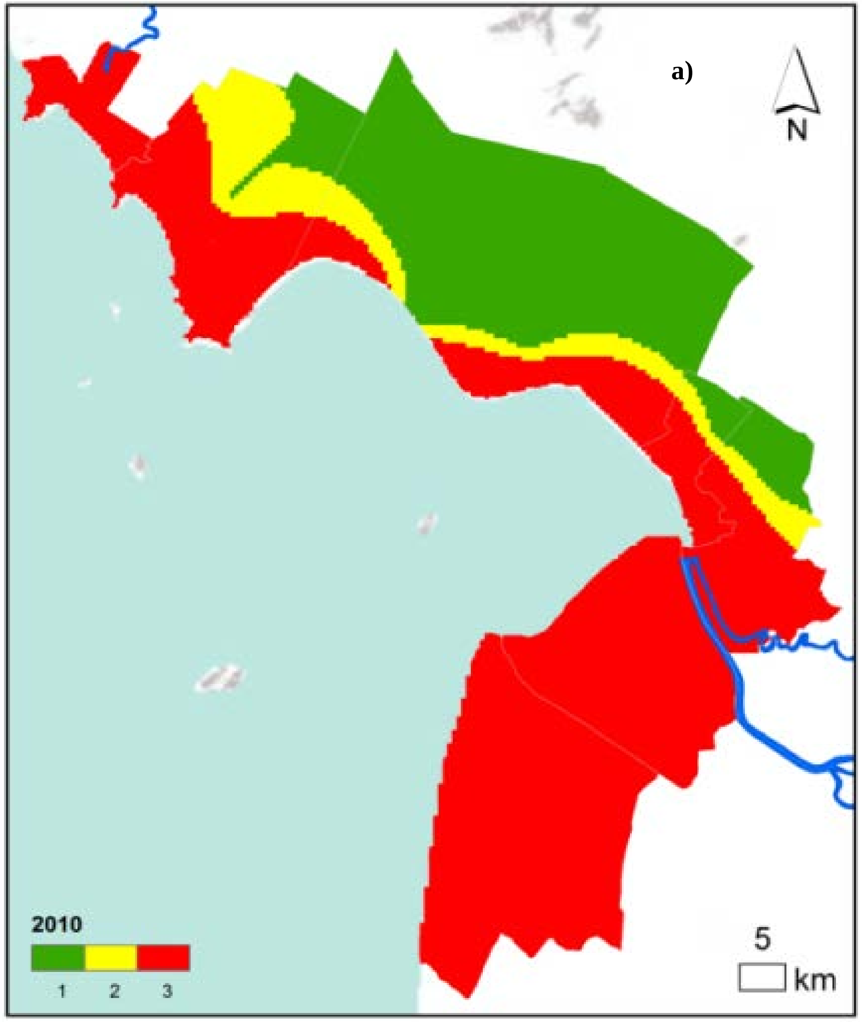
	A.3.1		Shoreline displacement- (buffer, 1 km), m/yr	[-37- -15; -15- -5; -5-5; 5-15; >15]	-		Overall, the west coast of the MRD is undergoing less shoreline change than other sections of the delta. The shoreline of Kien Giang (208 km) is characterised by mangrove fringes, covered with about 65% of the coast's length. These results obtained will be explained in Chapter 5, sub-section 5.3.3.1	L
	A.3.2		Adjacent coastal landuse	[Highest level aged MF/ water/ wetland/ grass; Mangroves forest (natural & planted); Sluice gate; Dyke; Farming with forest & other forests; Farming & crop; Settlement]	-	-	There was a steady decrease of area of protective mangrove forests. These results obtained will be explained in Chapter 5, sub-section 5.3.3.2	V
S	**Sensitivity**			2 sub-components, 7 variables	-	-		
	S.1	***Societal factors***		4 variables	< 20 mil	1.7 mil	Population of coastal districts: 920,979 in 2011 (54.7% of the provincial population)	
	S.1.1		Population density, inhabitants/ km^2	Entire district level	429	271	308; in which *Rach Gia* experienced the most sensitive area (the most densely populated district at 2,246 inhabitant/ km2)	F, V
	S.1.2		Rural people, %	Entire district level	75	73	62; in which *An Minh* experienced the most sensitive area in terms of rural people (94%)	F, V
	S.1.3		Ethnic groups, %	Entire district level	-	17	15; in which *Chau Thanh* experienced the most sensitive area in terms of ethnic groups (38%)	F, V
	S.1.4		Female, %	Entire district level	> 50	> 50	> 50	F, V
	S.2	***Landuse factors***		3 variables	Statistical data in 2011	Statistical data in 2011	Area: 300,000 ha (47% of the total area of Kien Giang) in 2008	F, V
	S.2.1		Unused land (CSD)		1	0.9	11.4; These results obtained will be explained in Chapter 5, sub-section 5.4.2	
	S.2.2		Agri. Land (NNP)		89.7	90.8	77.8	
				LU for agri.production	64.5	71.9		
				LU for forests	7.7	14.4		
	S.2.3		Non Agri. Land (PNN)		9.3	8.3	10.8	
				Urban land	-	1.9		
				Rural land	-	3.8		
A	**Adaptive capacity**			3 sub-components, 9 variables				
	A.1	***Socioeconomic***		4 variables				
	A.1.1		Income, $USD/ capita	Entire district level	747	972	949; Particularly *An Minh* (698), An Bien (729) experienced the most lowest income	F, V

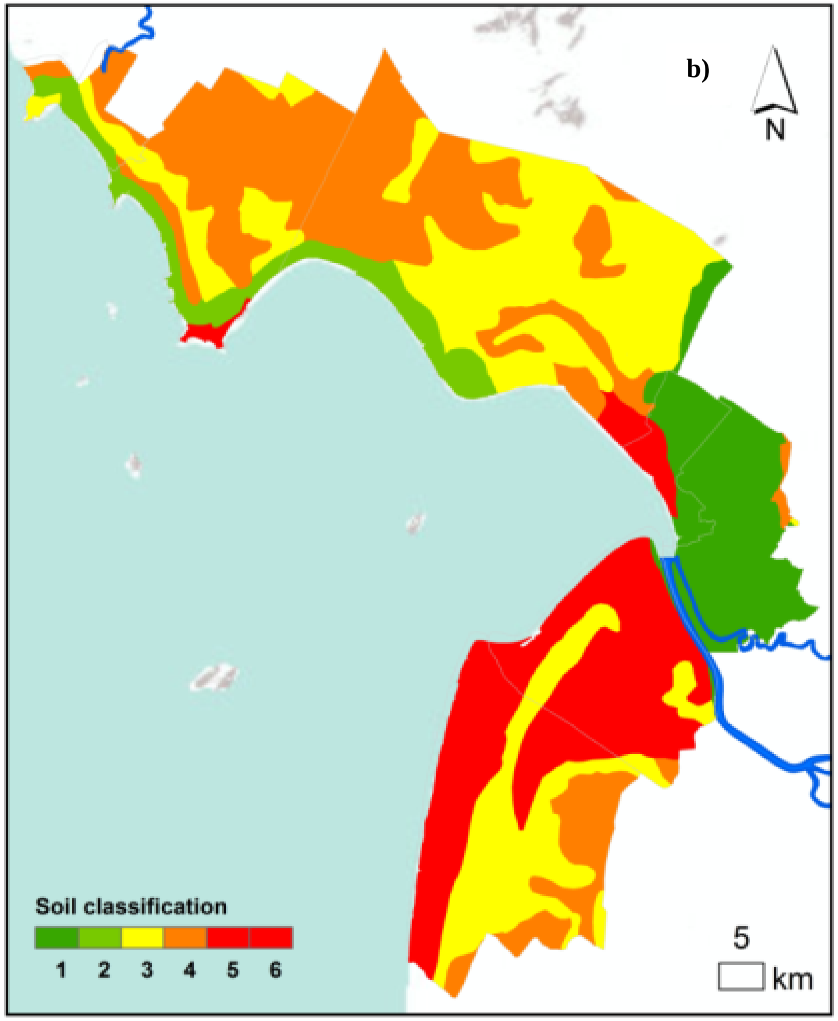
A.1.2		Education	Entire district level	-	Education in coastal districts experienced stronger than education in the province		F, V
			Kids/ kindergarten	-	468	616; the lowest capacity of a kindergarten was in *Hon Dat* at 256 kids	
			Kids/teacher at kindergarten	-	23	23.2; the highest figure of kids under a teacher's supervision in terms of kindergarten was in *Kien Luong* at 28 kids	
			Pupils/primary & secondary school	-	535	582; the lowest capacity of a primary and secondary school was in *An Minh* at 415 pupils	
			Pupils/teacher at primary & secondary school	-	17	18.3; the highest figure of pupils under a teacher's supervision in terms of primary and secondary school was in *Rach Gia* at 21 pupils	
A.1.3		Health	Entire district level	-	-		F, V
			Inhabitants/health establishment	-	10,435	11,056; *Ha Tien* experienced the lowest capacity of a health establishment (5,734 inhabitants)	
			Inhabitants/health staff	-	331	477; *Chau Thanh* experienced the highest deficiency that a health staff had to take care of 781 inhabitants	
A.1.4		Poverty ratio, %	Entire district level	12.5	7.2	6.6; Particularly *An Bien* (15), An Minh (13) experienced the most highest poverty ratios	F, V
A.2	***Technological***		2 variables				
A.2.1		Irrigation & drainage network	a system of rivers, & river embankments, sea dykes, canals, & sluice gates	-	-	These results obtained will be explained in Chapter 6, sub-section 6.3.2.1	V
A.2.2		Electricity network	electricity transformer stations, & high voltage power lines	-	100% at district level	100% at district level; These results obtained will be explained in Chapter 6, sub-section 6.3.2.2	F, V
A.3	***Infrastructure***		3 variables				
A.3.1		Solid house, % households having solid houses	Entire district level	78	93	93.3; Particularly *An Bien* (85), An Minh (87) experienced the most lowest capacities in terms of households having solid houses	F, V
A.3.2		Road network		-	91% at communal level	86% at communal level; Particularly *An Minh* (73), Rach Gia (75) experienced the lowest road densities at communal level. These results obtained will be explained in Chapter 6, sub-section 6.3.3.1	F, V
A.3.3		Fixed-line telephone subscribers, pers per telephone subscriber	Entire district level	17.9	17.1	14.2; the lowest capacity of a fixed-line telephone subscriber was in *Hon Dat* at 37.6 inhabitants	F, V

Note: (-): NA, beyond of this study; (P): the potential variable; (R): raster; (L): Landsat images; (V): vector; (F): Figure.

Appendix 11 Mapping of the exposure component for the study area.

Appendix 11a.1 Mapping of seawater incursion sub-component for the study area.





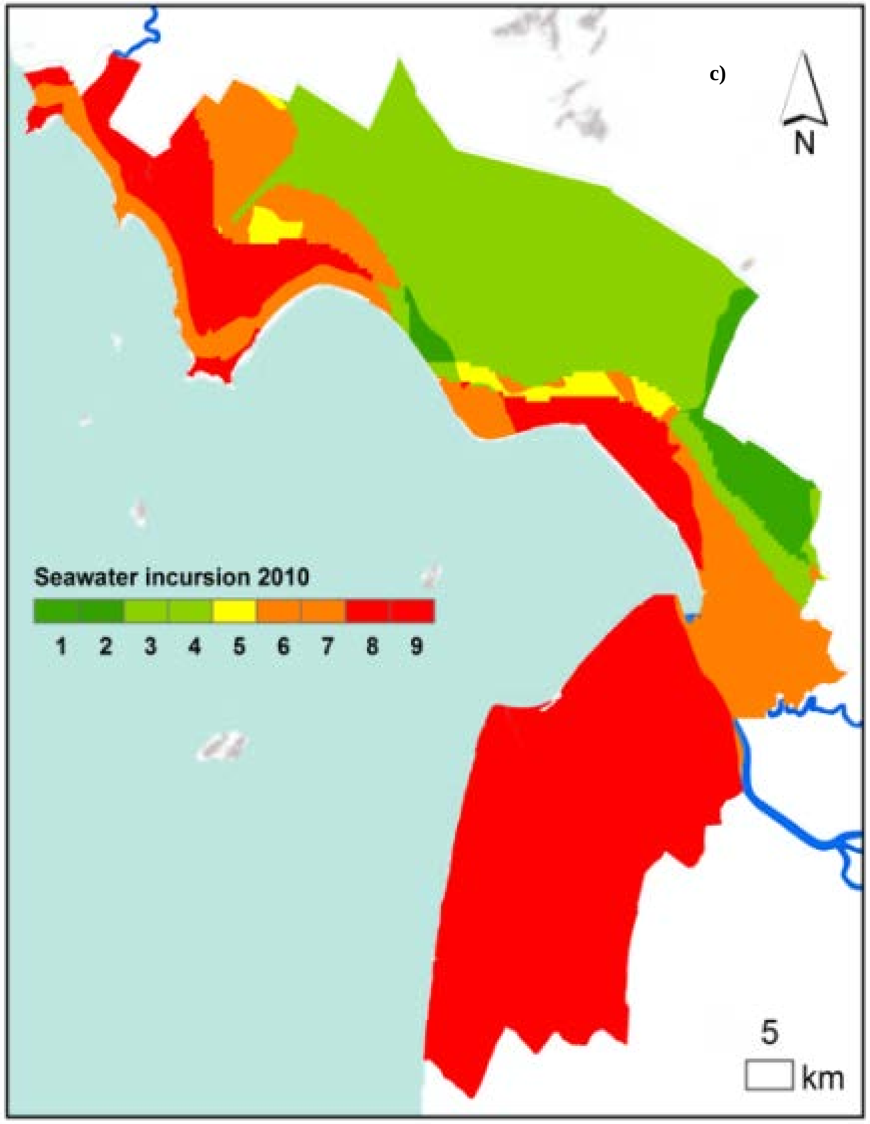


Figure a + b → Figure c by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
k7dvd_sal_re k7dvd_sal_re
k7_sal2010_re k7_sal2010_re

[Preference Matrix]

	k7dvd_sal_re	k7_sal2010_re
k7dvd_sal_re	1	0.3333
k7_sal2010_re	3	1

[*****AHP results*****]
[Eigenvalues]
1.9999
0.0001

[Eigenvector of largest Eigenvalue]
0.3162
0.9487

[criteria weights]
0.25 (k7dvd_sal_re)
0.75 (k7_sal2010_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 11a.2 Proportions of the study area classed as low to high, obtained from seawater incursion variable, from [1] to [3], and proportions classed as very low to very high, obtained from seawater incursion sub-component, from [4] to [6].

Coastal district [1]	Seawater incursion observed in 2010, % of area		
	Low < 4 ppt	Moderate 4 - 8	High > 8
An Bien			100
An Minh			100
Chau Thanh	21.8	12.48	65.72
Hon Dat	75.34	9.5	15.16
Ha Tien			100
Kien Luong	15.84	31.71	52.45
Rach Gia	23.58	13.4	63.02
7 coastal districts	*31.6*	*9.83*	*58.57*

Coastal district [2]	Seawater incursion modelled in 2030, % of area		
	Low < 4 ppt	Moderate 4 - 8	High > 8
An Bien			100
An Minh			100
Chau Thanh	0	2.54	97.46
Hon Dat	86.32	6.91	6.77
Ha Tien			100
Kien Luong	10.83	10.12	79.05
Rach Gia	0	1.8	98.2
7 coastal districts	*31.66*	*4.26*	*64.08*

Coastal district [3]	Seawater incursion modelled in 2050, % of area		
	Low < 4 ppt	Moderate 4 - 8	High > 8
An Bien			100
An Minh			100
Chau Thanh	0	4.45	95.55
Hon Dat	88.56	6.25	5.18
Ha Tien			100
Kien Luong	18.21	15.19	66.6
Rach Gia	0	5	95
7 coastal districts	*33.57*	*5.1*	*61.33*

Note: less than 4 ppt and higher than 8 ppt is a range of classification for seawater incursion (see Table 5.1). These tables were obtained from three maps in Appendices 8d.5, 8d.2, and 8d.3, respectively.

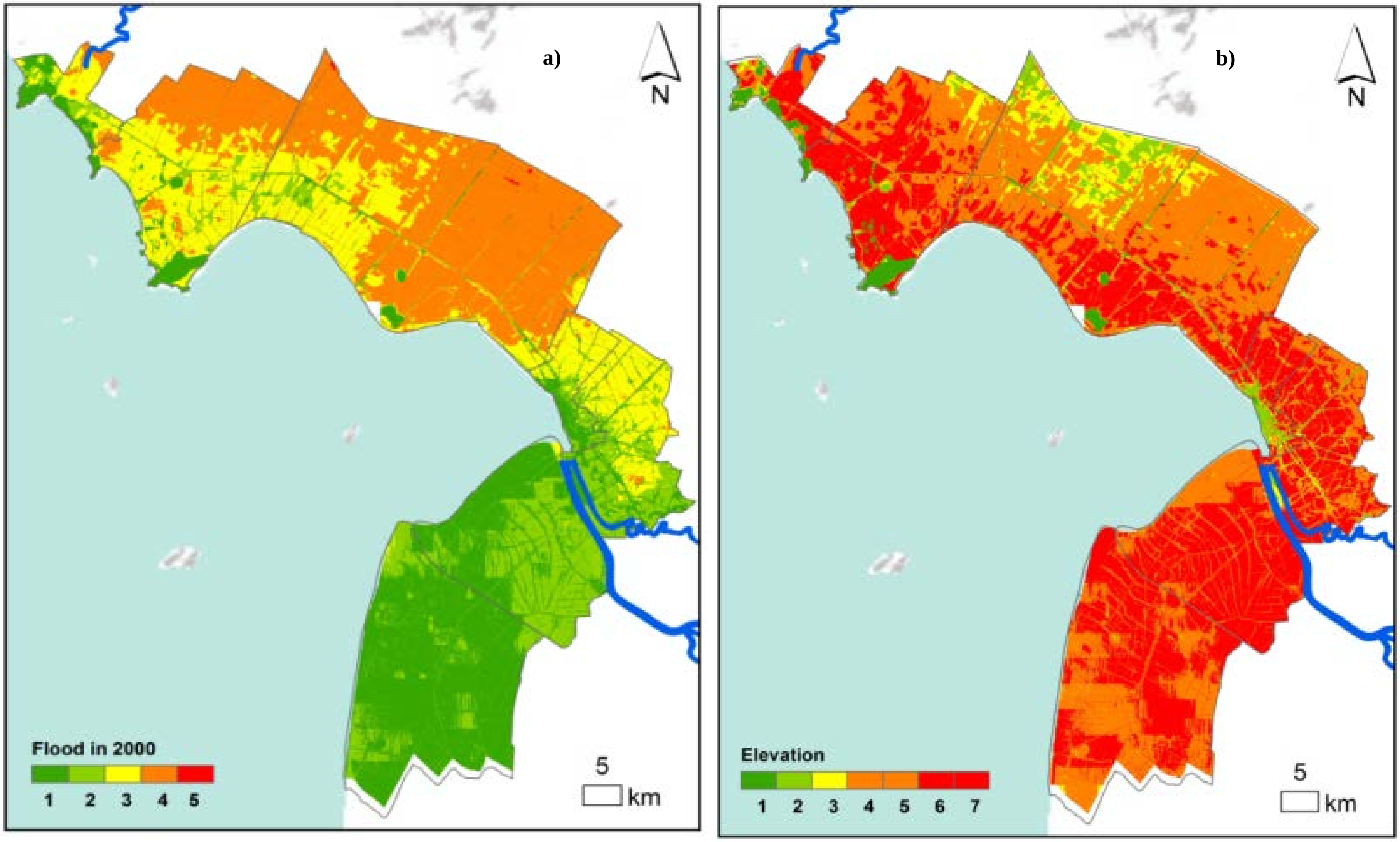
Coastal district [4]	Seawater incursion observed in 2010 using AHP, % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6-7	Very high 8- 9
An Bien					100
An Minh					100
Chau Thanh	20.38	14.4	0.07	64.82	0.32
Hon Dat	3.64	74.46	3.57	9.18	9.15
Ha Tien					100
Kien Luong	0	15.81	3.83	40.71	39.65
Rach Gia	24.64	14.17	0	33.6	27.6

Coastal district [5]	Seawater incursion modelled in 2030 using AHP, % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6-7	Very high 8- 9
An Bien					100
An Minh					100
Chau Thanh	0	2.53	0	94.29	3.18
Hon Dat	9.32	77.87	4.85	2.06	5.9
Ha Tien					100
Kien Luong	0.69	10.16	3.34	16.94	68.86
Rach Gia	0	2.27	0.02	70.09	27.62

Coastal district [6]	Seawater incursion modelled in 2050 using AHP, % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6-7	Very high 8- 9
An Bien					100
An Minh					100
Chau Thanh	0	4.24	0	92.78	2.98
Hon Dat	9.4	80.03	3.53	2.62	4.41
Ha Tien					100
Kien Luong	1.03	17.4	3.05	22.01	56.52
Rach Gia	0	5.93	0.02	66.43	27.62

Note: 1 – 9 is a range of classification: the value of “9” indicates areas very high exposure, while the value of “1” indicates areas very low exposure, in representing seawater incursion sub-component.

Appendix 11b.1 Mapping of flood risk sub-component for the study area.



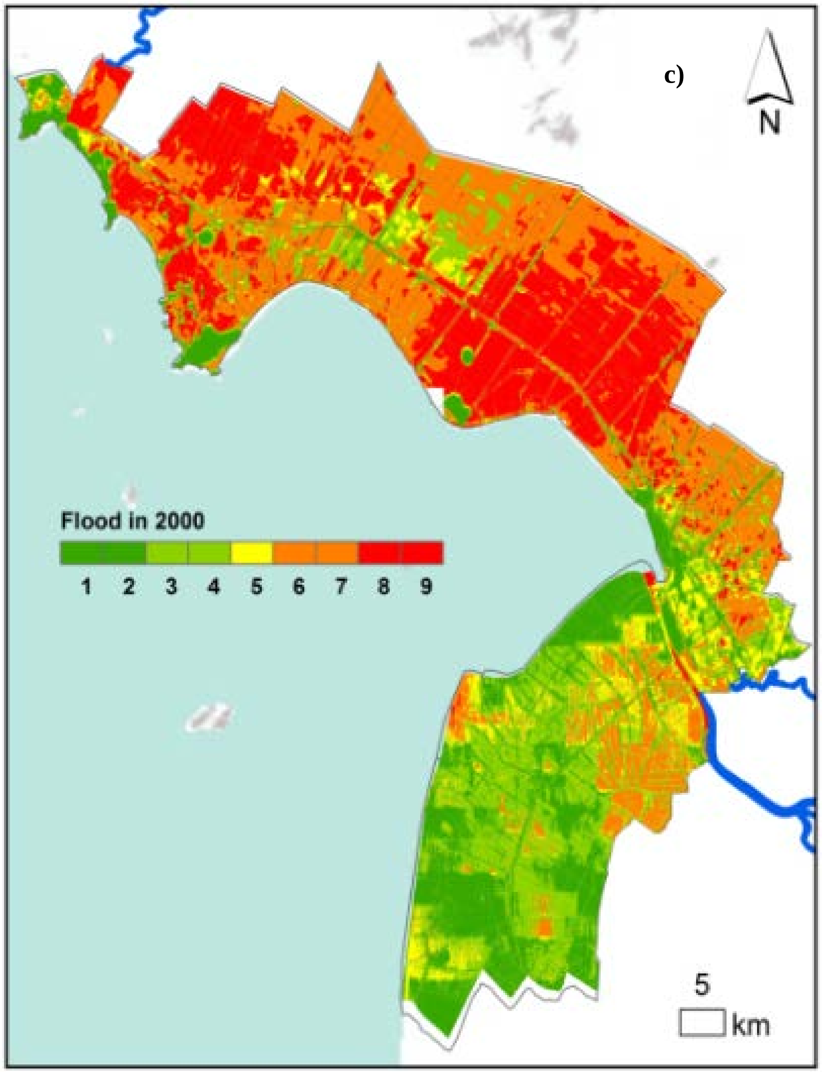


Figure a + b → Figure c by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
kgi7_dem15_re   kgi7_dem15_re
Flood depth in 2000   Flood depth in 2000

[Preference Matrix]

	kgi7_dem15_re	Flood depth in 2000
kgi7_dem15_re	1	0.4444
Flood depth in 2000	2.25	1

[*****AHP results*****]
[Eigenvalues]
1.9999
0.0001

[Eigenvector of largest Eigenvalue]
0.4061
0.9138

[criteria weights]
0.3077 (kgi7_dem15_re)
0.6923 (Flood depth in 2000)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 11b.2 Proportions of the study area classed as very low to very high, derived from flood depth variable, from [1] to [3], and flood risk sub-component, from [4] to [6].

Coastal district [1]	Flood depth observed in 2000, % of area				
	Very low 0 – 0.2 m	Low 0.2 – 0.5	Moderate 0.5 - 1	High 1 - 2	Very high > 2
An Bien	50.28	48.05	1.67	0.00	0.00
An Minh	84.45	15.20	0.35	0.00	0.00
Chau Thanh	22.02	32.88	43.44	1.65	0.00
Hon Dat	2.97	3.36	22.38	70.26	1.03
Ha Tien	29.20	16.76	39.82	14.22	0.00
Kien Luong	9.32	4.97	45.17	40.26	0.28
Rach Gia	29.15	13.87	51.39	5.60	0.00
7 coastal districts	*29.87*	*15.57*	*22.41*	*31.75*	*0.41*

Coastal district [2]	Flood depth modelled in 2030, % of area				
	Very low 0 – 0.2 m	Low 0.2 – 0.5	Moderate 0.5 - 1	High 1 - 2	Very high > 2
An Bien	22.05	61.62	16.34	0.00	0.00
An Minh	51.22	44.33	4.45	0.00	0.00
Chau Thanh	17.58	30.31	48.91	3.21	0.00
Hon Dat	2.72	3.12	19.29	73.52	1.35
Ha Tien	26.91	9.24	43.35	20.50	0.00
Kien Luong	9.72	5.16	44.54	40.23	0.34
Rach Gia	25.84	8.12	43.22	22.82	0.00
7 coastal districts	*18.93*	*22.36*	*24.36*	*33.83*	*0.53*

Coastal district [3]	Flood depth modelled in 2050, % of area				
	Very low 0 – 0.2 m	Low 0.2 – 0.5	Moderate 0.5 - 1	High 1 - 2	Very high > 2
An Bien	13.45	49.70	36.85	0.00	0.00
An Minh	27.48	61.34	11.18	0.00	0.00
Chau Thanh	12.67	13.36	39.54	34.41	0.02
Hon Dat	1.24	0.59	3.76	48.78	45.63
Ha Tien	24.53	7.50	33.88	34.01	0.08
Kien Luong	7.31	1.54	10.76	66.32	14.08
Rach Gia	19.71	5.92	14.93	58.89	0.56
7 coastal districts	*11.45*	*20.88*	*15.55*	*33.87*	*18.24*

Note: 0 – higher than 2m is a range of classification for flood depth (see Table 5.1).

Coastal district [4]	Flood observed in 2000 using AHP, % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6-7	Very high 8- 9
An Bien	23.20	32.78	15.94	26.80	1.29
An Minh	44.14	42.99	7.27	5.42	0.18
Chau Thanh	12.18	25.21	17.43	39.11	6.06
Hon Dat	2.63	8.24	4.02	41.55	43.55
Ha Tien	27.42	10.54	6.69	26.96	28.38
Kien Luong	6.51	8.04	3.17	36.91	45.37
Rach Gia	22.8	15.96	6.97	37.42	16.86
7 coastal districts	*16.59*	*20.36*	*7.60*	*30.87*	*24.59*

Coastal district [5]	Flood modelled in 2030 using AHP, % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6-7	Very high 8- 9
An Bien	11.94	25.59	27.15	23.85	11.47
An Minh	36.58	23.79	29.51	7.50	2.61
Chau Thanh	10.03	23.87	17.91	38.09	10.10
Hon Dat	2.37	7.31	3.70	40.96	45.67
Ha Tien	25.15	9.69	4.00	27.32	33.84
Kien Luong	6.78	8.18	2.89	35.65	46.50
Rach Gia	20.12	14.54	4.23	30.40	30.71
7 coastal districts	*13.16*	*15.07*	*13.23*	*30.16*	*28.38*

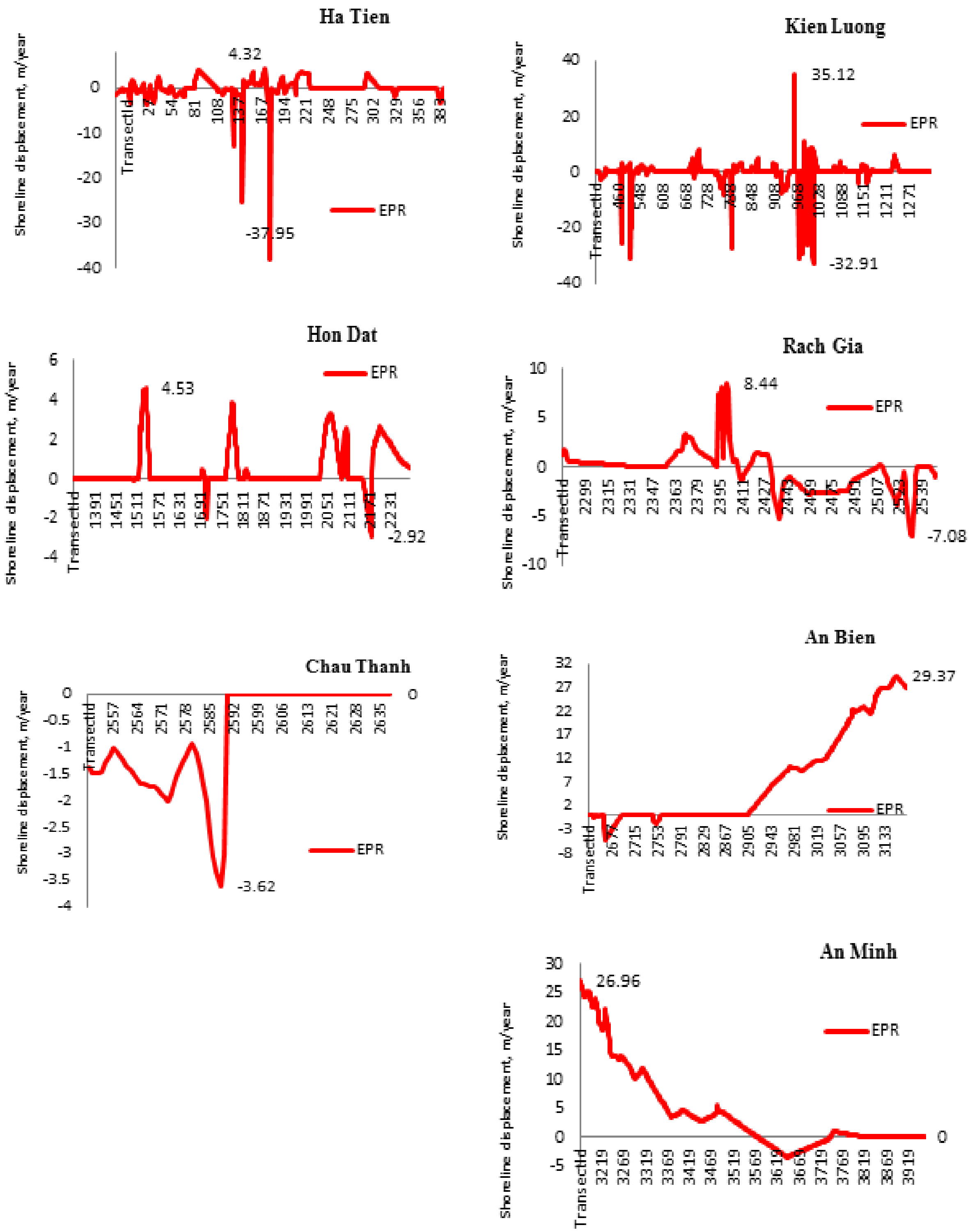
Coastal district [6]	Flood modelled in 2050 using AHP, % of area				
	Very low 1 - 2	Low 3 - 4	Moderate 5	High 6-7	Very high 8- 9
An Bien	6.49	25.75	23.83	43.93	0.00
An Minh	21.71	28.64	34.33	15.31	0.00
Chau Thanh	7.28	13.99	8.95	48.52	21.27
Hon Dat	1.14	1.12	1.27	43.00	53.46
Ha Tien	23.11	9.31	3.31	39.69	24.58
Kien Luong	5.56	2.94	2.52	37.10	51.87
Rach Gia	16.58	9.99	2.58	28.20	42.65
7 coastal districts	*8.41*	*11.95*	*11.89*	*36.64*	*31.11*

Note: 1 – 9 is a range of classification for flood risk sub-component of Jenks's Natural Breaks; The value of "1" indicates area the least flood exposure, while the value of "9" indicates area the most flood exposure in representing flood risk sub-component.

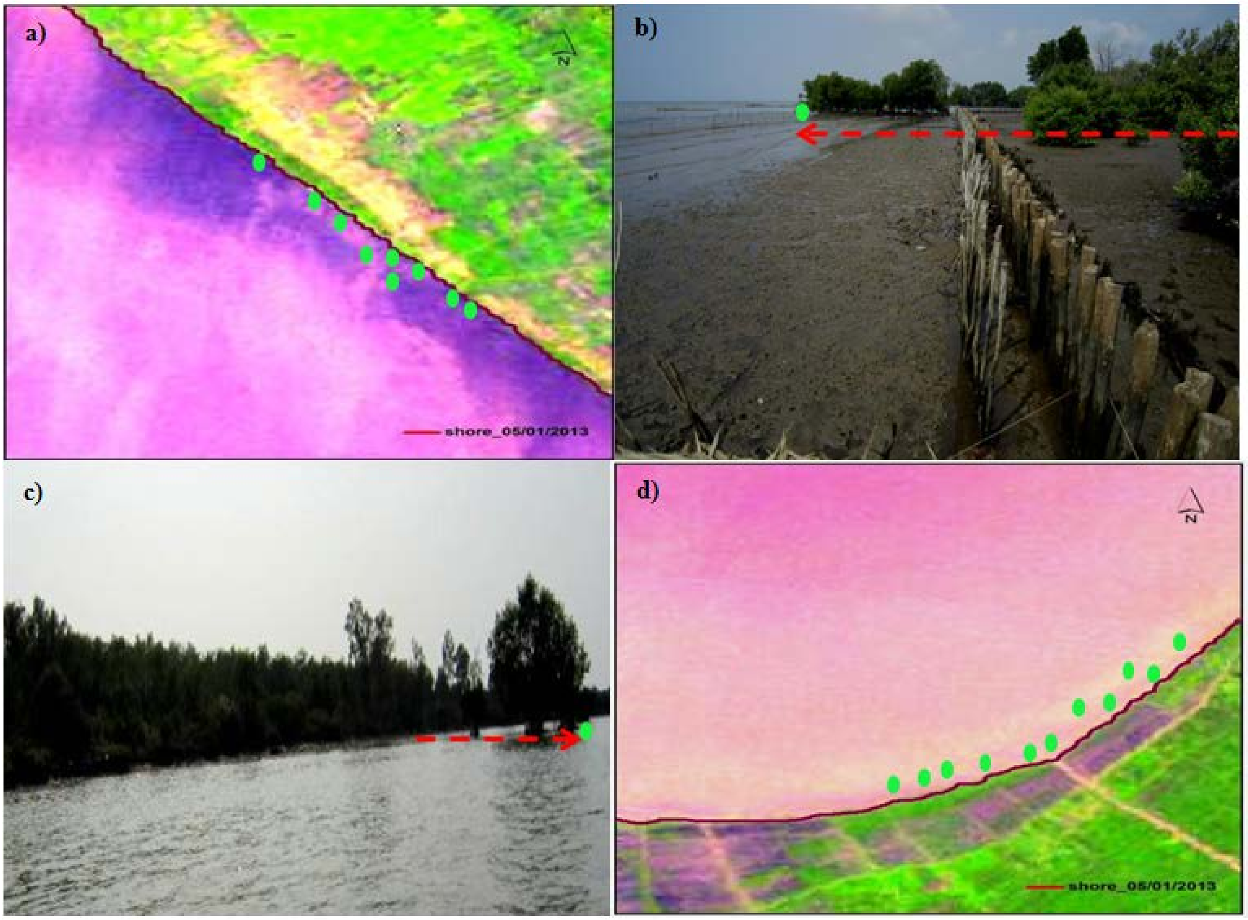
Appendix 11c.1 illustrates several patterns of the Kien Giang coast: a) Mui Nai (Deer cape) and Ha Tien bay; b) 5km far from Ha Tien town taken during the dry season in 2013; c) Dua Cape, Kien Luong; d) My Lam, Hon Dat; e) Rach Gia bay; f) Chau Thanh; g) Nam Thai A, An Bien and Thuan Hoa, An Minh; and h) An Minh, derived from Google Earth.

Note: The mangrove forests were fringed, shown in the red circle lines, mainly distributed in four coastal districts: An Bien, An Minh, Hon Dat, and Kien Luong along the Kien Giang coast.

Appendix 11c.2 The analyses of EPR showed the trends of shoreline displacement in seven coastal districts over 1973 - 2013.

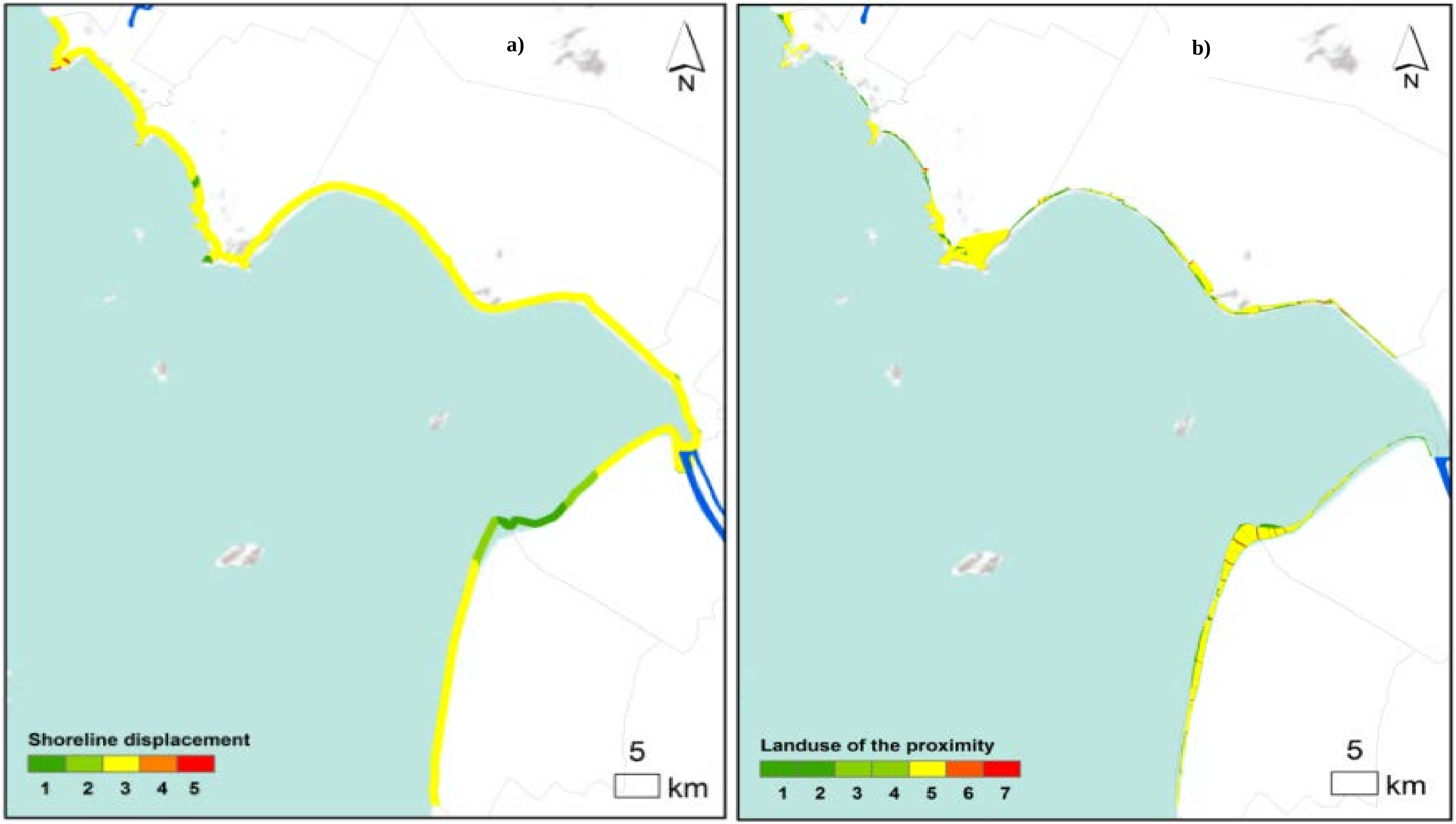


Appendix 11c.3 The digitised patterns of the shoreline a) of the Hon Dat coast, and d) of the An Bien coast extracted from the Landsat image in 2013; Photos showing the pattern c) of the Hon Dat coast, and b) of the An Bien coast, taken in field trip during the dry season in 2015.



Note: (●): Scattered mangroves seawards.

Appendix 11c.4 Mapping of shoreline change sub-component for the study area.



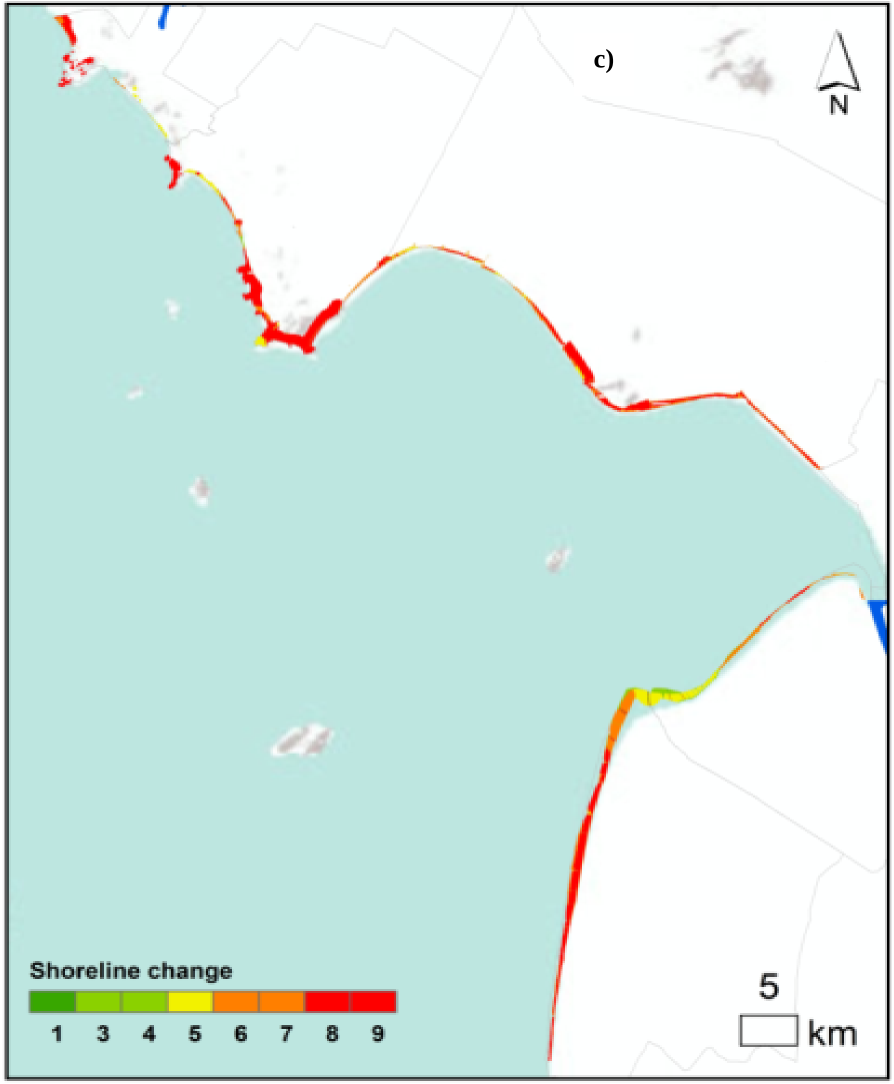


Figure a + b →Figure c by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
shorebu1km1re shorebu1km1re
k7_htr2010_re k7_htr2010_re

[Preference Matrix]

	shorebu1km1re	k7_htr2010_re
shorebu1km1re	1	2
k7_htr2010_re	0.5	1

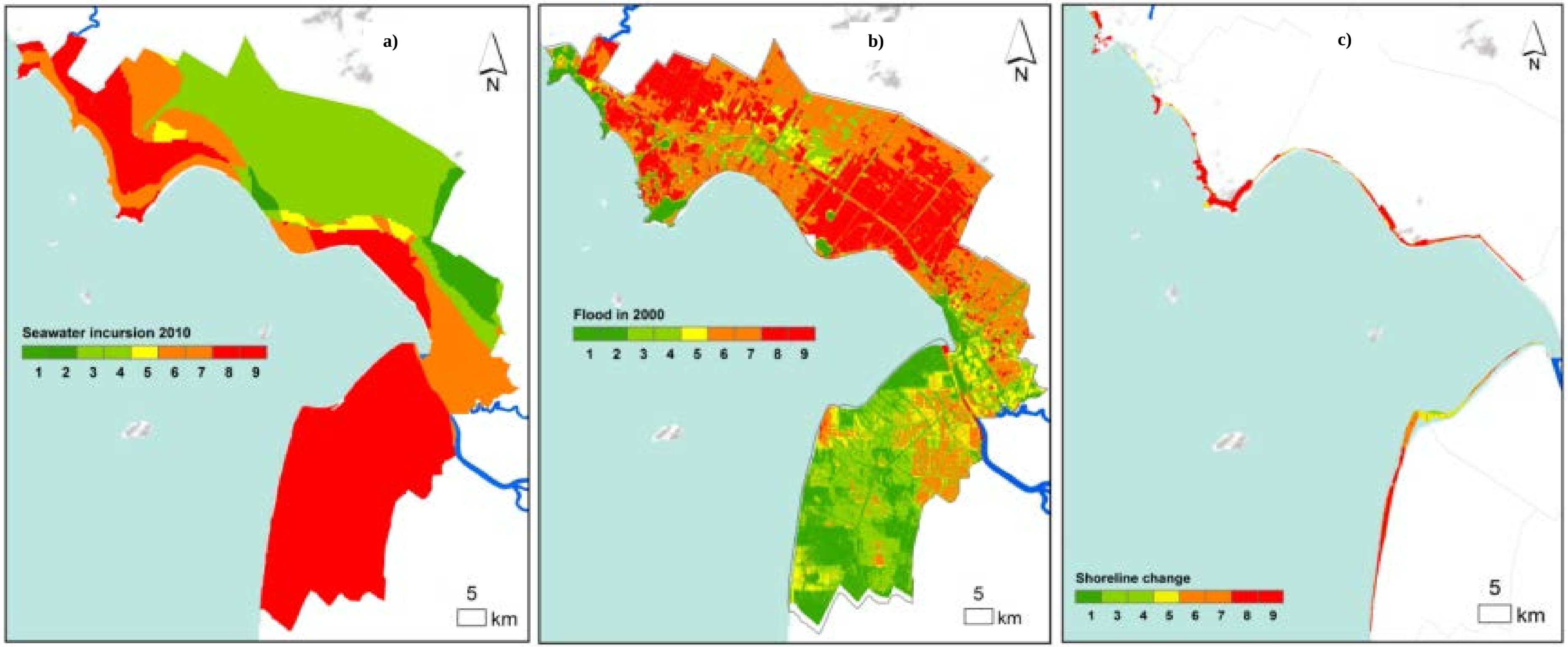
[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.8944
0.4472

[criteria weights]
0.6667 (shorebu1km1re)
0.3333 (k7_htr2010_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 11d Mapping of the exposure component for the study area.



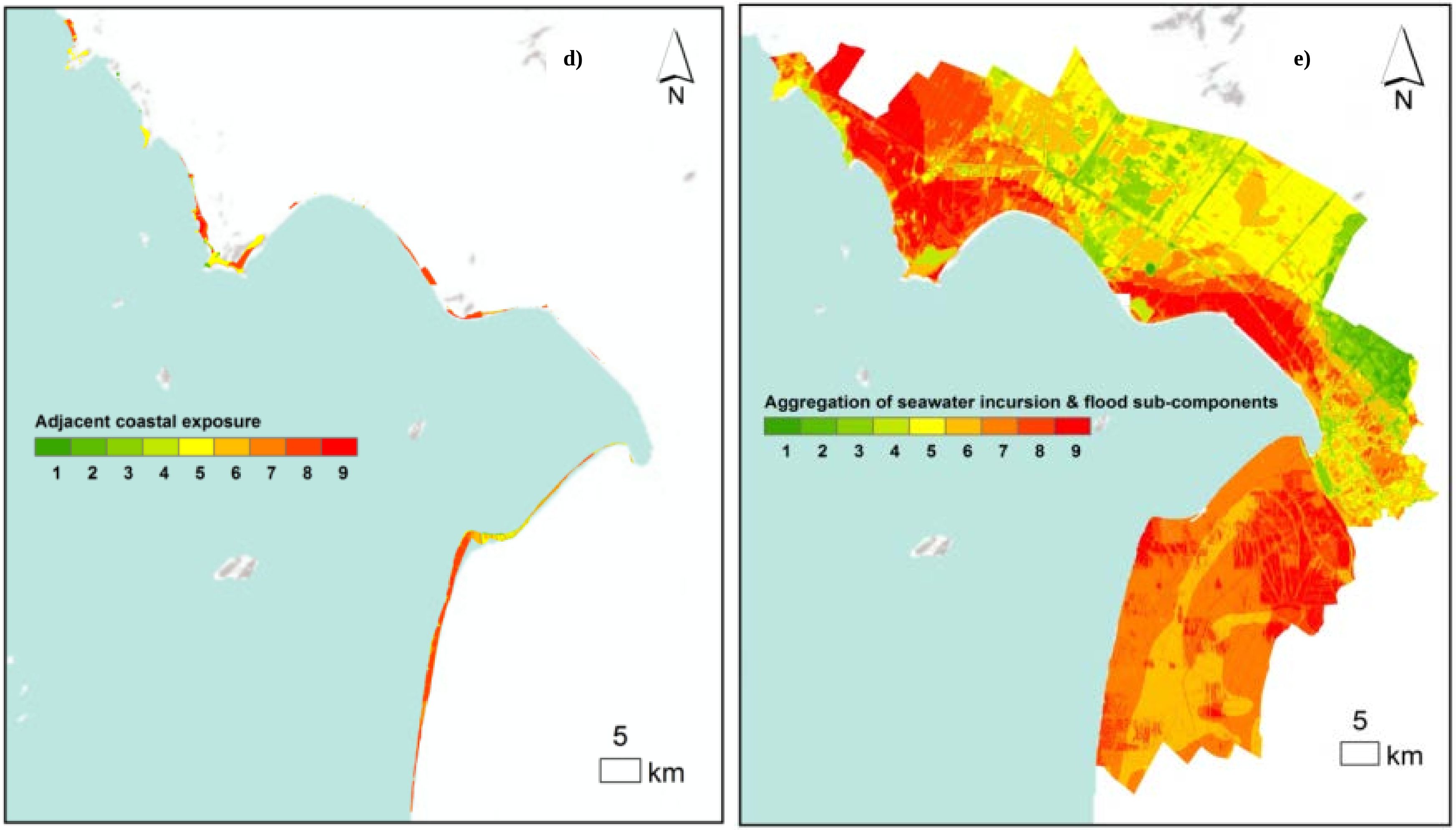

d)
N
Adjacent coastal exposure
1 2 3 4 5 6 7 8 9
5
km
e)
N
Aggregation of seawater incursion & flood sub-components
1 2 3 4 5 6 7 8 9
5
km

Figure a + b + c → Figure d by AHP (input raster)

[Criteria & LayerSource (clsfd.)]
k7inu00dem_re k7inu00dem_re
k7ahp2shkm1re k7ahp2shkm1re
k7max10dvd_re k7max10dvd_re

[Preference Matrix]

	k7inu00dem_re	k7ahp2shkm1re	k7max10dvd_re
k7inu00dem_re	1	2	0.8
k7ahp2shkm1re	0.5	1	0.3333
k7max10dvd_re	1.25	3	1

[*****AHP results*****]
[Eigenvalues]
3.0037
-0.0018
-0.0018

[Eigenvector of largest Eigenvalue]
0.5787
0.2723
0.7687

[criteria weights]
0.3573 (k7inu00dem_re)
0.1681 (k7ahp2shkm1re)
0.4746 (k7max10dvd_re)

[consistency ratio CR]
0.0035
(Revision of preference values is recommended if CR > 0.1)

Figures a & b are aggregated by AHP to generate Figure e (target raster). Finally, Mosaic was used to generate a map of exposure levels in Figure f

[Criteria & LayerSource (clsfd.)]
k7max10dvd_re k7max10dvd_re
k7inu00dem_re k7inu00dem_re

[Preference Matrix]

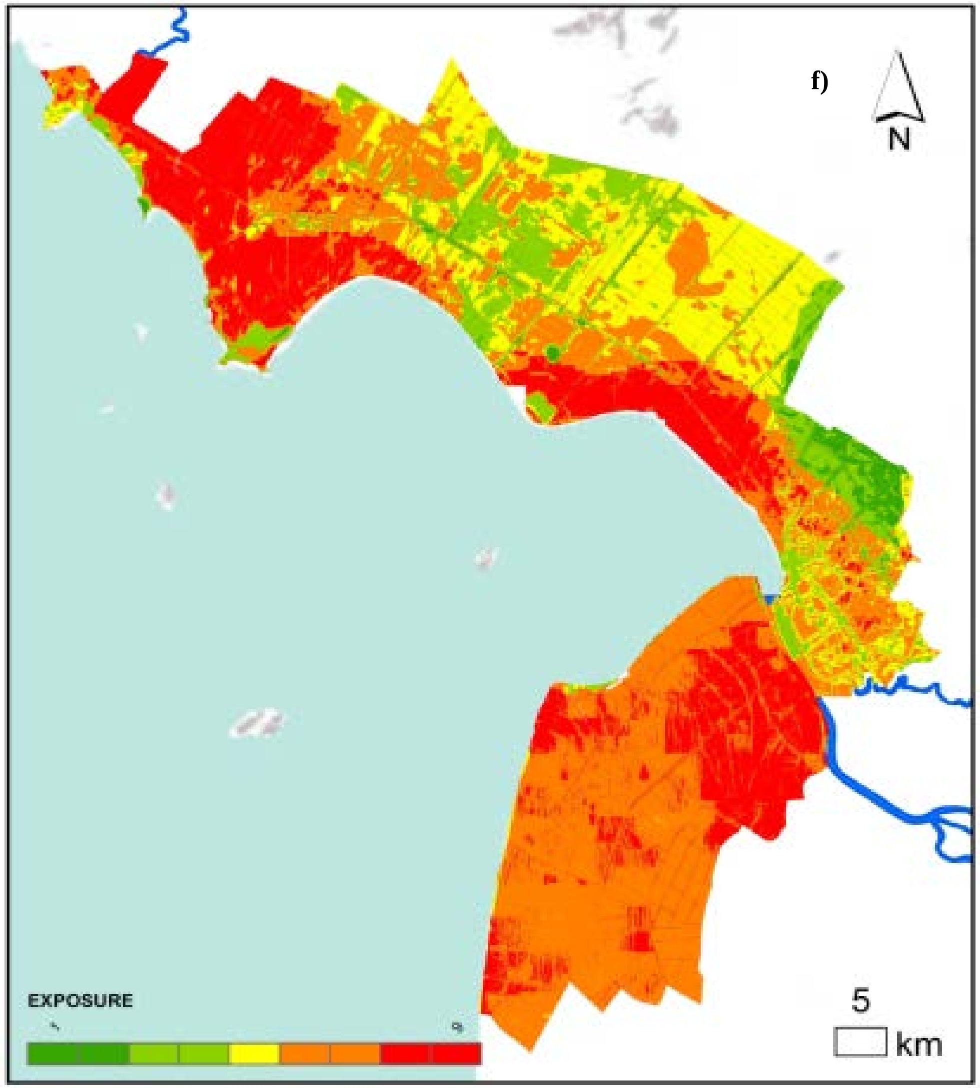
	k7max10dvd_re	k7inu00dem_re
k7max10dvd_re	1	1.285
k7inu00dem_re	0.7782	1

[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.7892
0.6142

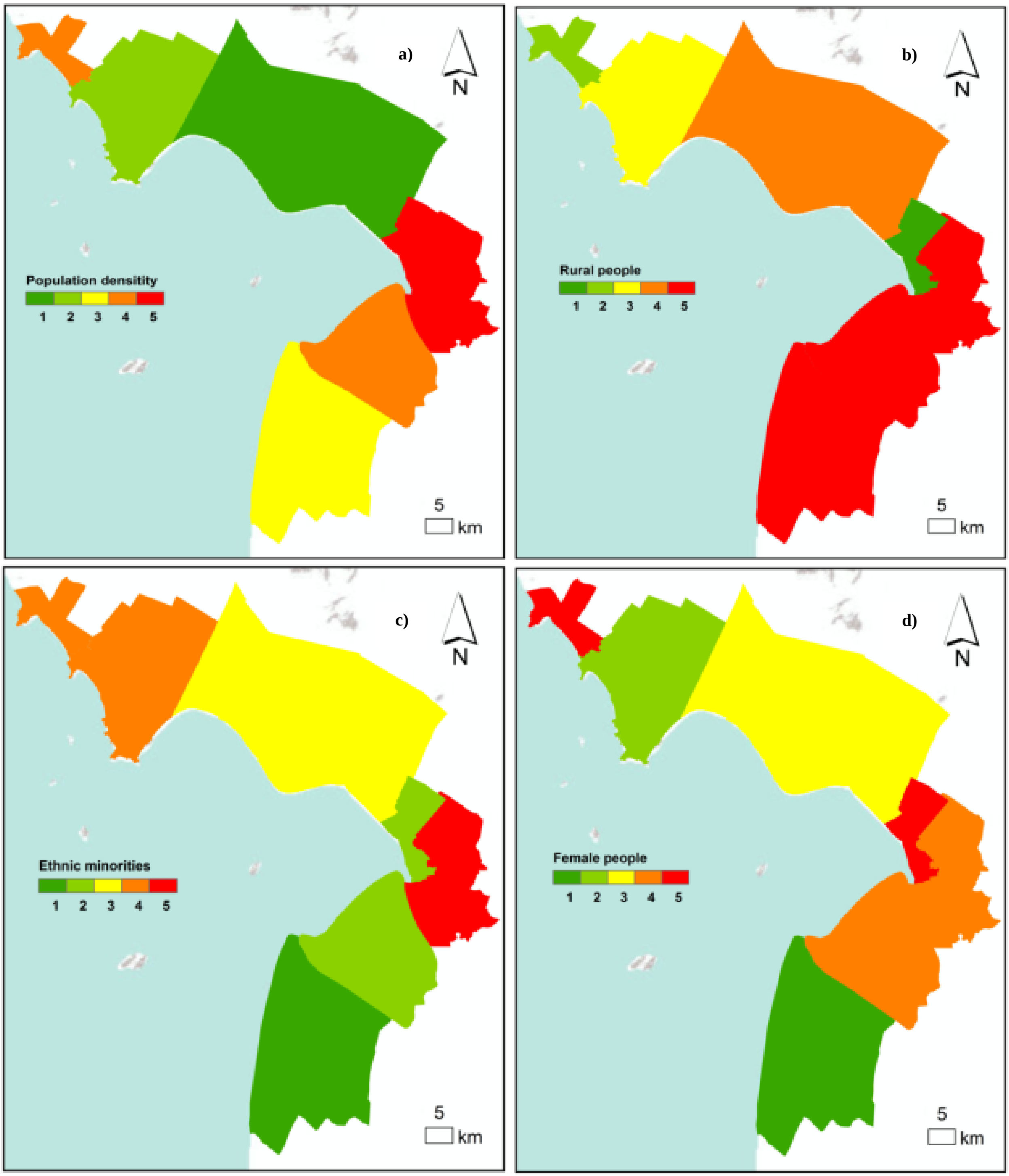
[criteria weights]
0.5624 (k7max10dvd_re)
0.4376 (k7inu00dem_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)


f)
N
EXPOSURE
5
km

Appendix 12 Mapping of the sensitivity component for the study area.

Appendix 12a Mapping of societal factors sub-component for the study area.



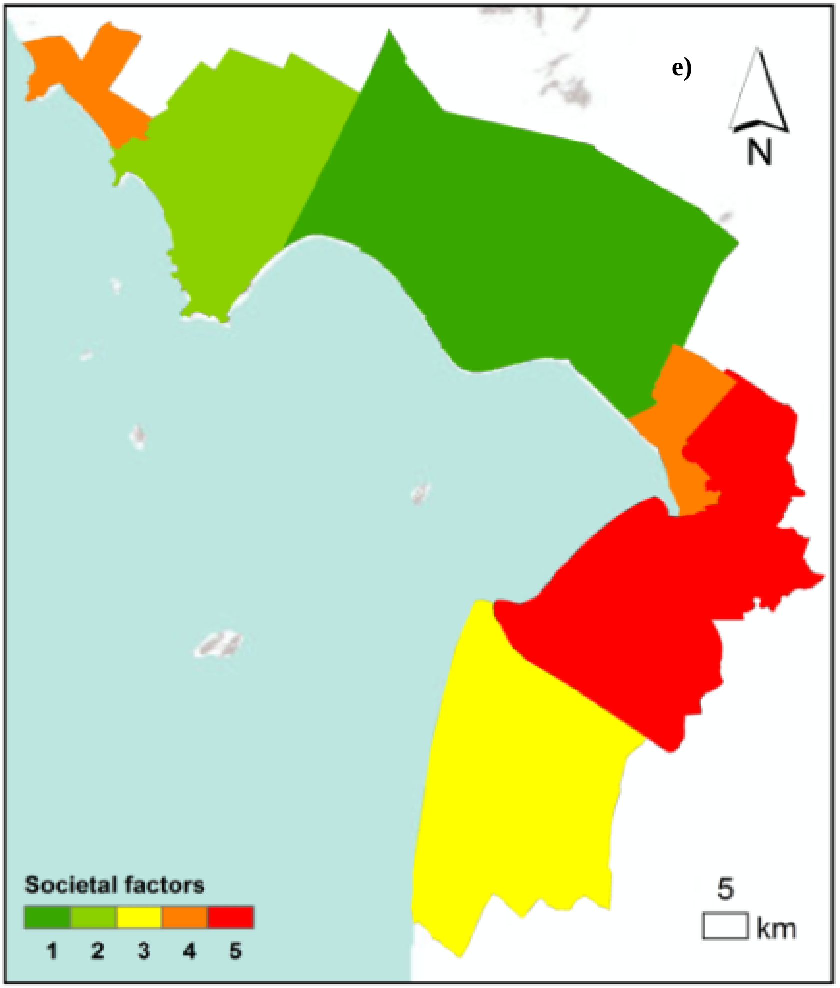


Figure a + b + c + d→ Figure e by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]

k7_pd_30414re	k7_pd_30414re
k7_ru_30414re	k7_ru_30414re
k7_eth30414re	k7_eth30414re
k7_gen30414re	k7_gen30414re

[Preference Matrix]

	k7_pd_30414re	k7_ru_30414re	k7_eth30414 re	k7_gen30414re
k7_pd_30414re	1	0.8	2.5	2.5
k7_ru_30414re	1.25	1	0.8	1.4
k7_eth30414re	0.4	1.25	1	1.8
k7_gen30414re	0.4	0.7143	0.5556	1

[*****AHP results*****]

[Eigenvalues]

4.1831
-0.0884
-0.0884
-0.0064

[Eigenvector of largest Eigenvalue]

0.6899
0.5033
0.4407
0.2766

[criteria weights]

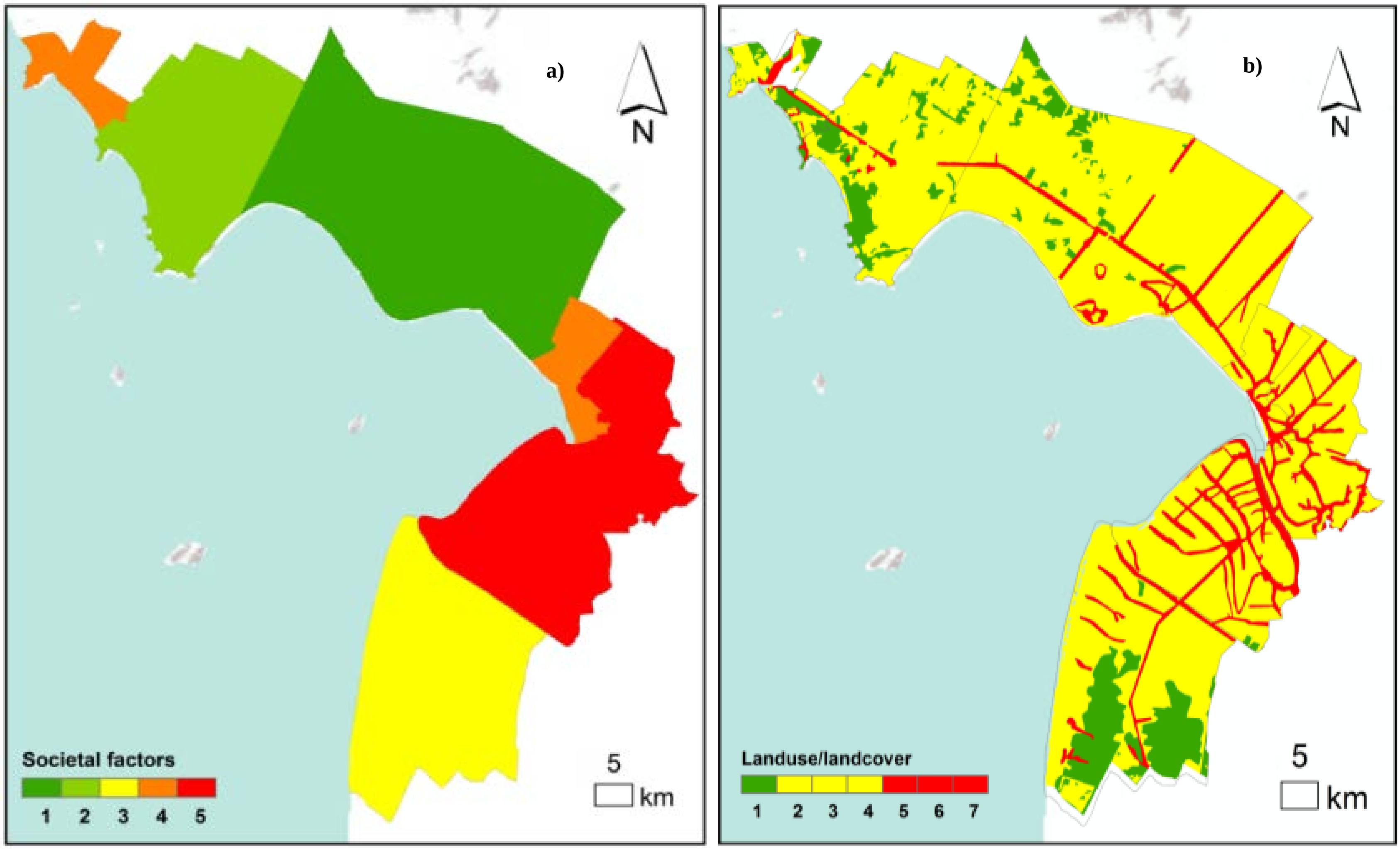
0.3611	(k7_pd_30414re)
0.2635	(k7_ru_30414re)
0.2307	(k7_eth30414re)
0.1448	(k7_gen30414re)

[consistency ratio CR]

0.0678

(Revision of preference values is recommended if CR > 0.1)

Appendix 12b Mapping of the sensitivity component for the study area.



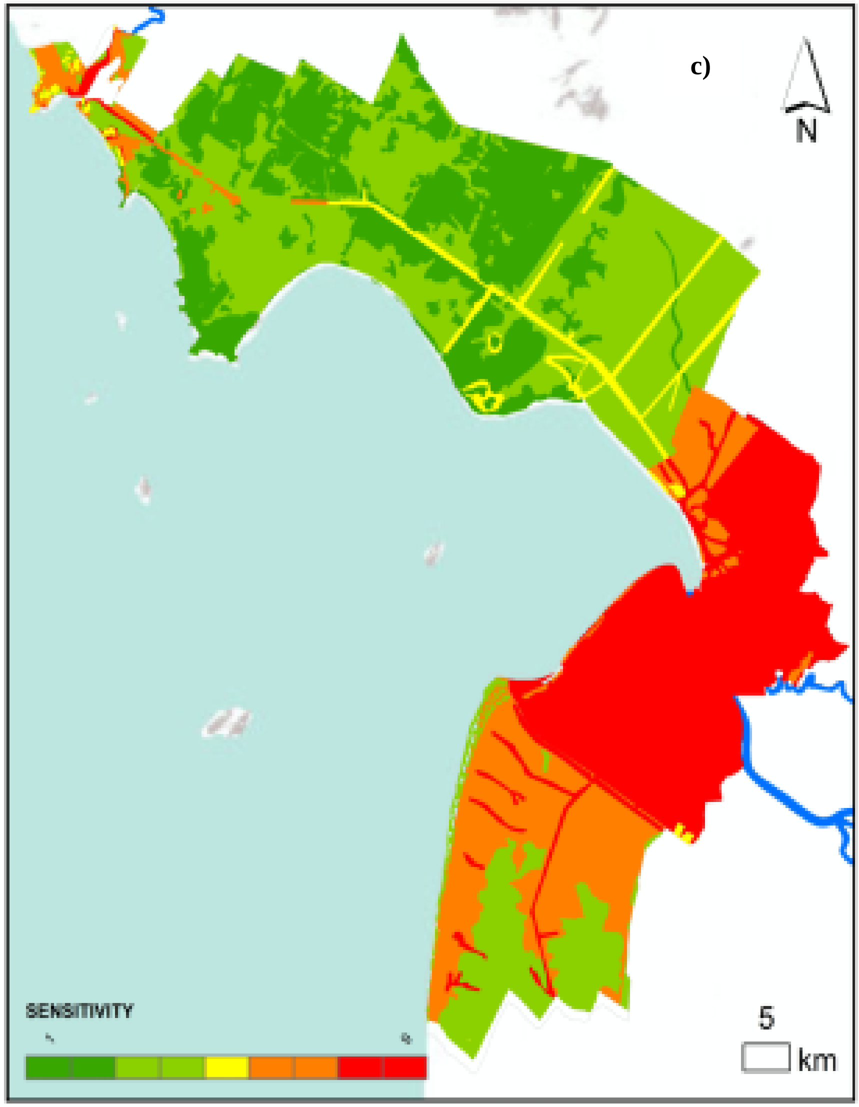


Figure a + b → Figure c by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
k7_ahp4pop_re k7_ahp4pop_re
k7_lulc_re k7_lulc_re

[Preference Matrix]

	k7_ahp4pop_re	k7_lulc_re
k7_ahp4pop_re	1	1.2857
k7_lulc_re	0.7778	1

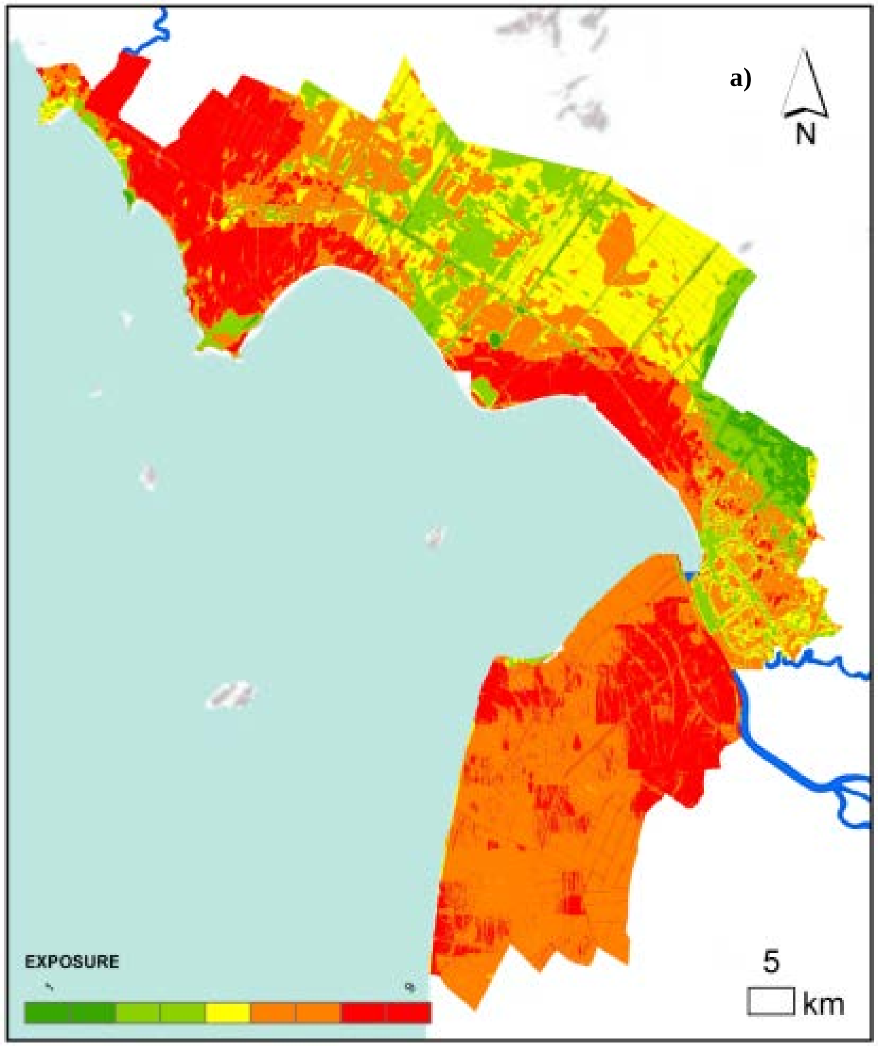
[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.7893
0.6139

[criteria weights]
0.5625 (k7_ahp4pop_re)
0.4375 (k7_lulc_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 13 Mapping of potential impacts for the study area.



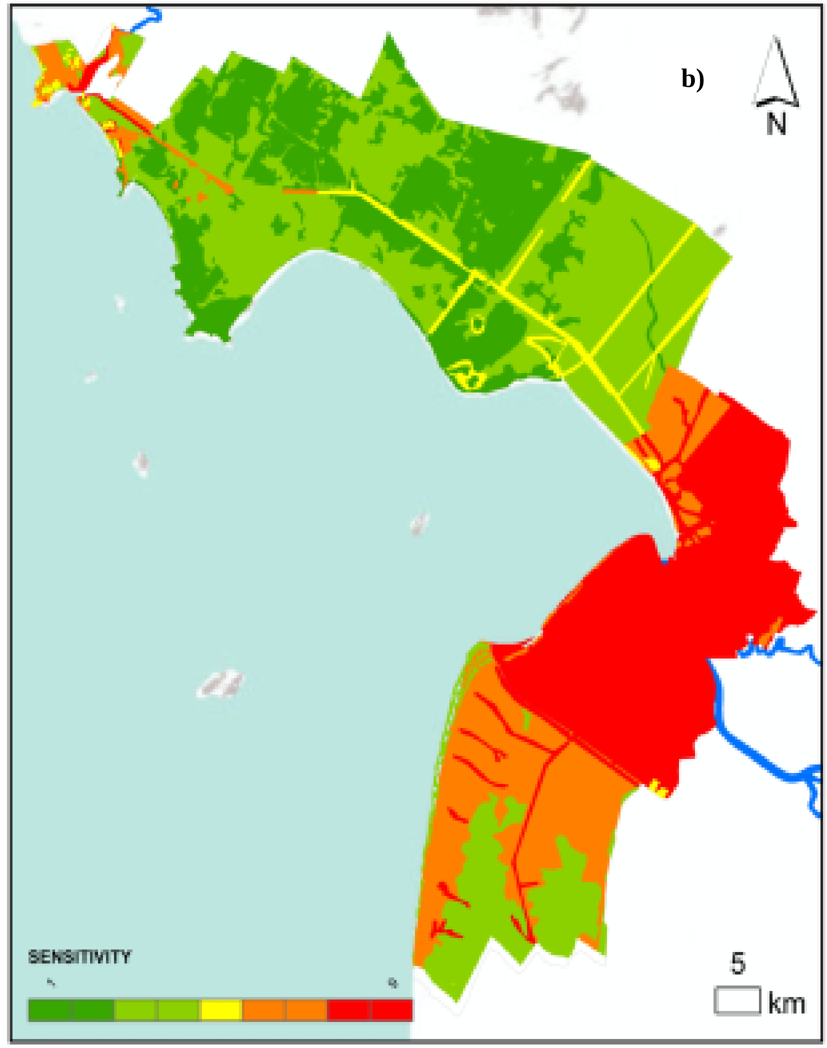


Figure a + b → Figure c by AHP
[Criteria & LayerSource (clsfd.)]
k7_ex61tes_re k7_ex61tes_re
k7_sen3ahp_re k7_sen3ahp_re

[Preference Matrix]

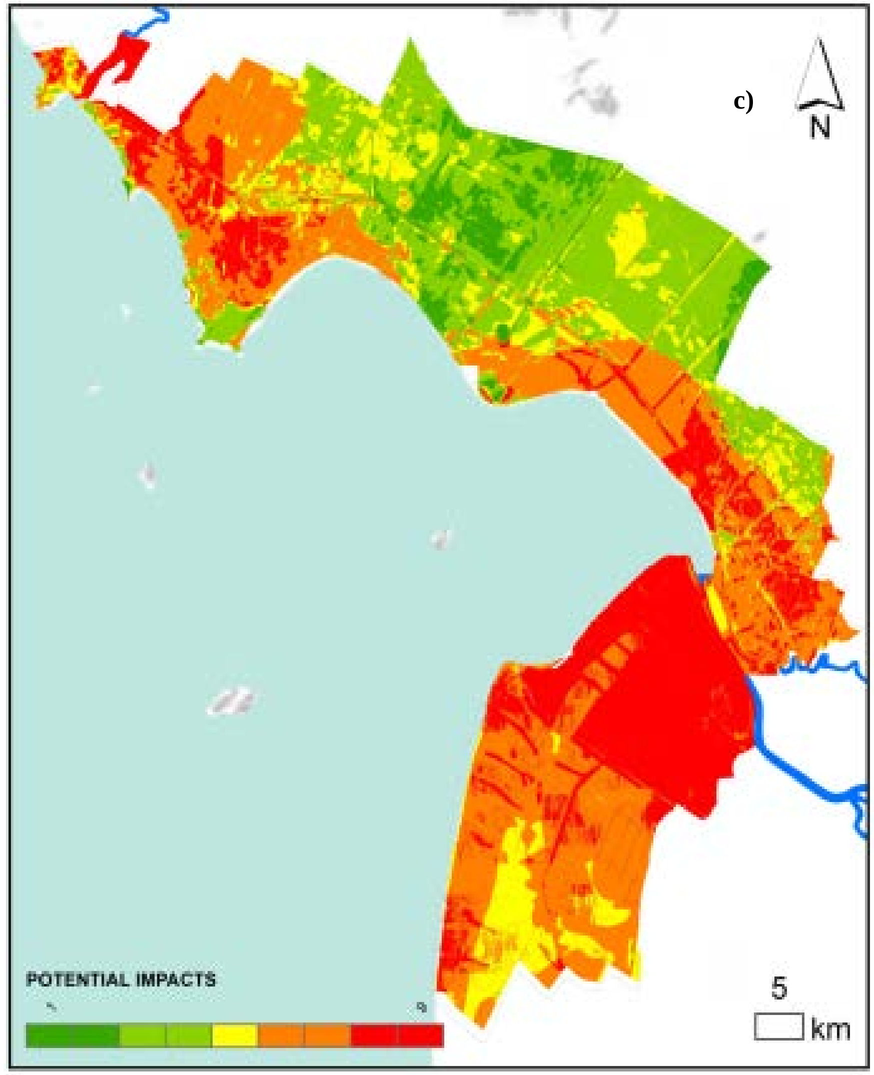
	k7_ex61tes_re	k7_sen3ahp_re
k7_ex61tes_re	1	1.8
k7_sen3ahp_re	0.5556	1

[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.8741
0.4857

[criteria weights]
0.6428 (k7_ex61tes_re)
0.3572 (k7_sen3ahp_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)



Appendix 14 Overall aggregated rankings of each coastal district within seven ones in terms of measuring coastal potential impacts study.

Rank	* Seawater incursion 2010	** Soil type undated	*Seawater incursion sub-component*	Flood depth 2000	Elevation	*Flood risk sub-component*	*** Analysis of LRR during 1973 - 2013	****Adjacent coastal landuse 2010	*Shoreline change vulnerability*	*Exposure*
1	Hon Dat	Chau Thanh	*Hon Dat*	An Minh	Hon Dat	*An Minh*	Hon Dat	Chau Thanh	*Chau Thanh*	*Hon Dat*
2	Kien Luong	Ha Tien	*Rach Gia*	An Bien	Ha Tien	*An Bien*	Ha Tien	Rach Gia	*Rach Gia*	*Chau Thanh*
3	Rach Gia	Hon Dat	*Chau Thanh*	Chau Thanh	Rach Gia	*Chau Thanh*	Rach Gia	Ha Tien	*An Bien*	*Rach Gia*
4	Chau Thanh	Kien Luong	*Kien Luong*	Rach Gia	Kien Luong	*Rach Gia*	Kien Luong	Kien Luong	*Ha Tien*	*Ha Tien*
5	Ha Tien	Rach Gia	*Ha Tien*	Ha Tien	Chau Thanh	*Ha Tien*	An Bien	An Bien	*An Minh*	*Kien Luong*
6	An Bien	An Minh	*An Bien*	Kien Luong	An Minh	*Kien Luong*	Chau Thanh	An Minh	*Kien Luong*	*An Bien*
7	An Minh	An Bien	***An Minh***	Hon Dat	An Bien	***Hon Dat***	An Minh	Hon Dat	***Hon Dat***	***An Minh***

Rank	Population density 2011	Rural population 2011	Ethnic group 2010	Female population 2011		*Societal factors*	Landuse/ landcover 2008	*Sensitivity [41%]*	*Exposure [69%]*	*Potential impacts [58%]*
1	Hon Dat	Rach Gia	An Minh	An Minh		*Hon Dat*	*Kien Luong*	*Hon Dat*	*Hon Dat*	*Hon Dat*
2	Kien Luong	Ha Tien	Rach Gia	Kien Luong		*Kien Luong*	*An Minh*	*Kien Luong*	*Chau Thanh*	*Rach Gia*
3	An Minh	Kien Luong	An Bien	Hon Dat		*An Minh*	*Ha Tien*	*Ha Tien*	*Rach Gia*	*Kien Luong*
4	An Bien	Hon Dat	Hon Dat	An Bien		*Ha Tien*	*Hon Dat*	*An Minh*	*Ha Tien*	*Chau Thanh*
5	Ha Tien	Chau Thanh	Ha Tien	Chau Thanh		*Rach Gia*	*Chau Thanh*	*Rach Gia*	*Kien Luong*	*Ha Tien*
6	Chau Thanh	An Bien	Kien Luong	Ha Tien		*Chau Thanh*	*An Bien*	*An Bien*	*An Bien*	*An Minh*
7	Rach Gia	An Minh	Chau Thanh	Rach Gia		An Bien	Rach Gia	Chau Thanh	An Minh	An Bien

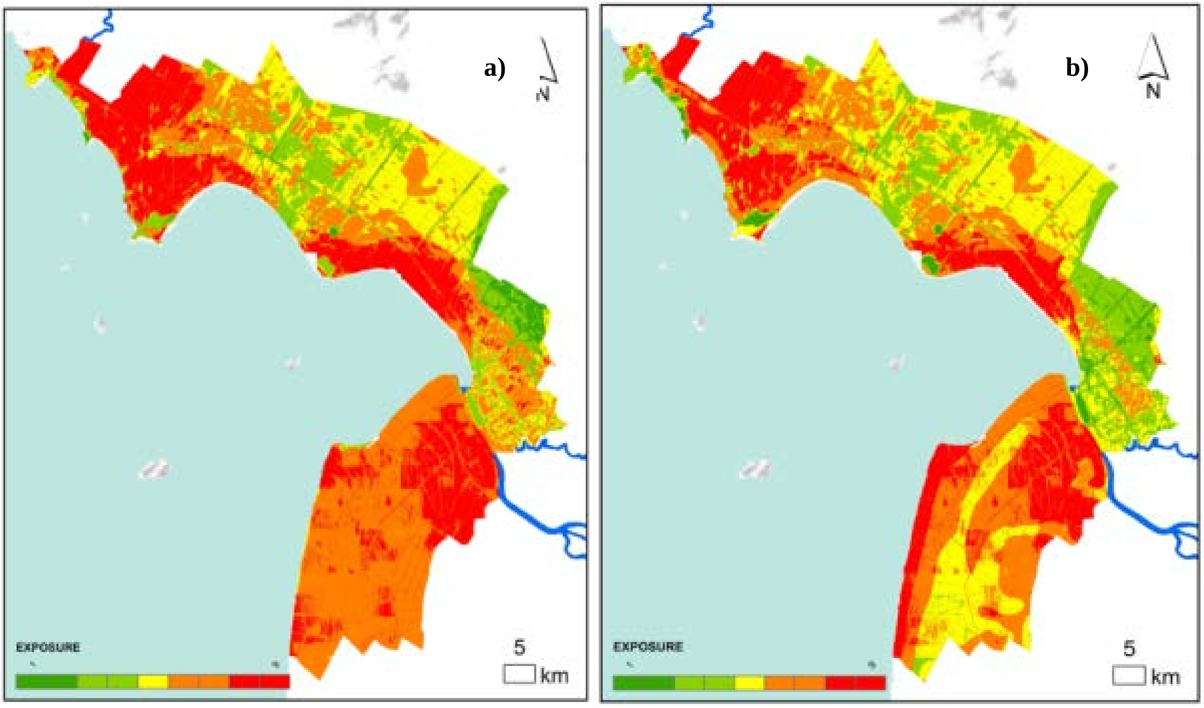
Note: The value of 7 indicates the highest rank, while the value of 1 indicates the lowest one within 7 coastal districts, in terms of representing exposure, sensitivity. Shaded red indicates districts are likely to be high exposure, sensitivity, potential impacts, shaded yellow for moderate and shaded green for low.

Appendix 15 A summary of relative weights of variables, sub-components, two components: exposure, sensitivity, and potential impacts for the study that were simultaneously obtained from AHP.

No.	Component	Sub-component	Variable	Weight	CR	Mosaic	Sub-component	Variable	Final	References
1	Exposure			***0.6428***						Appendix 13
1.1		Shoreline change		*0.1681*			0.0841		**0.0540**	Appendix 11d
1.1.1			Shoreline displacement (1km buffer)	0.6667				0.0560		Appendix 11c.3
1.1.2			Coastal adjacent landuse	0.3333				0.0280		Appendix 11c.3
					0					Appendix 11c.3
1.2		Flood		*0.3573*		*0.4376*	0.3975		**0.2555**	Appendix 11d
1.2.1			Flood depth	0.6923				0.2752		Appendix 11b.2
1.2.2			Elevation	0.3077				0.1223		Appendix 11b.2
					0					Appendix 11b.2
1.3		Seawater incursion		*0.4746*		*0.5624*	0.5185		**0.3333**	Appendix 11d
1.3.1			Salinity	0.75				0.3889		Appendix 11a.1
1.3.2			Soil type	0.25				0.1296		Appendix 11a.1
					0					Appendix 11a.1
					0.0035					Appendix 11d
2	Sensitivity			***0.3572***						Appendix 13
2.1		Societal factors sensitivity		*0.5625*			0.5625		**0.2009**	Appendix 12a
2.1.1			Population density	0.3611				0.2031		Appendix 12a
2.1.2			Rural people	0.2635				0.1482		Appendix 12a
2.1.3			Female people	0.1448				0.0815		Appendix 12a
2.1.4			Ethnicity minorities	0.2307				0.1298		Appendix 12a
					0.0678					Appendix 12a
2.2		Landuse		*0.4375*			0.4375		**0.1563**	Appendix 12b
					0					Appendix 12b
3	Potential impacts			1,000						Appendix 13
					0					Appendix 13

Note: The CR < 0.1, acceptable by Saaty (1980); and the CR< 0.05 for 3 by 3 matrices, and the CR< 0.08 for 4 by 4 matrices, acceptable by Saaty (1994), respectively.

Appendix 16 Changing priorities of variables based on pair-wise comparisons using AHP; An example for mapping the exposure component: a) the final study exposure, and b) the alternative adjusted exposure.



Simultaneously, relative weights of the variables used in aggregation, in order to represent exposure that were obtained; These are summarised as below.

a) 6 layers, 3 sub-components- final study exposure

Criteria weights-6 layers, 3 sub-components
0.3560 (k7_sal2010_re)
0.2474 (kg7_fmba_re1)
0.1187 (k7dvd_sal_re)
0.1121 (shorebu1km1re)
0.1099 (k7dem15_re2)
0.0560 (k7_htr2010_re)

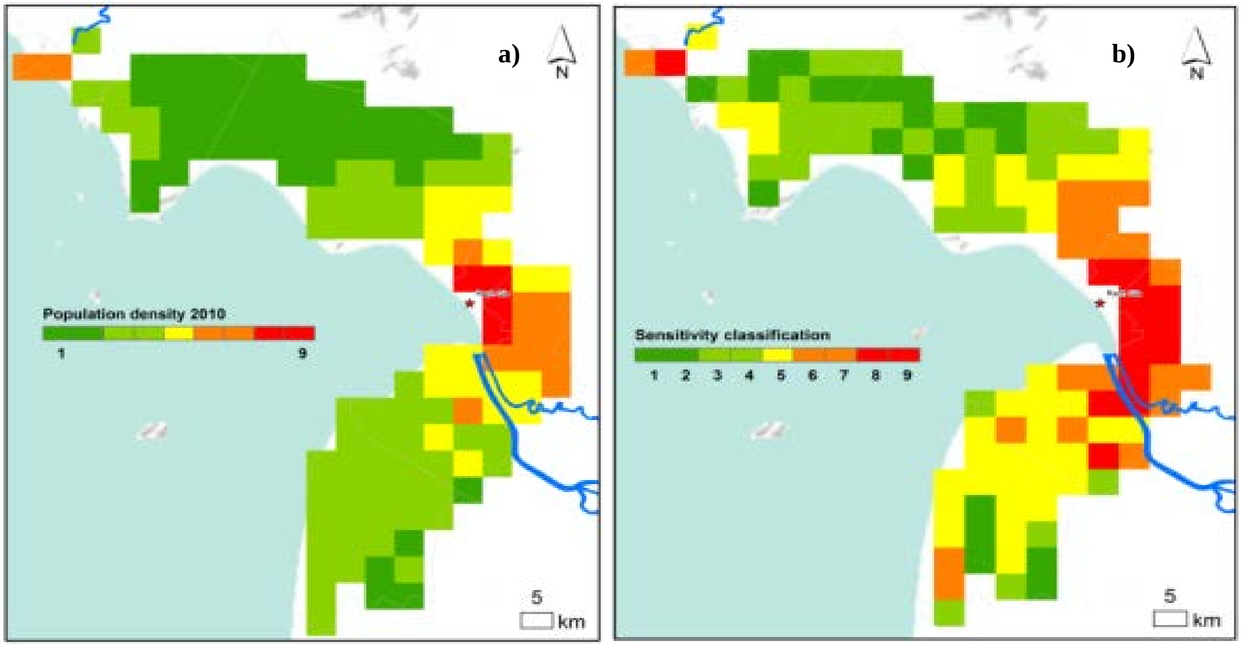
Criteria weights-4layers, 2 sub-components
0.4218 (k7_sal2010_re)
0.3030 (kg7_fmba_re1)
0.1406 (k7dvd_sal_re)
0.1346 (k7dem15_re2)
CR = 0.0035
Therefore,
0.3889 (*k7_sal2010_re*)
0.2752 (*Flood depth in 2000*)
0.1296 (k7dvd_sal_re)
0.1223 (*kgi7_dem15_re*)
0.0560 (shorebu1km1re)
0.0280 (k7_htr2010_re)

b) 6 layers- changing priorities of variables-exposure

Criteria weights-6layers _re1
0.2507 (k7_sal2010_re)
0.1958 (kg7_fmba_re1)
0.1564 (k7dvd_sal_re)
0.1607 (k7_htr2010_re)
0.1389 (shorebu1km1re)
0.0975 (k7dem15_re2)
CR = 0
Criteria weights-4layers
0.3492 (k7_sal2010_re)
0.2724 (kg7_fmba_re1)
0.2374 (k7dvd_sal_re)
0.0975 (k7dem15_re2)
CR = 0.0124
Therefore,
0.3000 (*k7_sal2010_re*)
0.2341 (*Flood depth in 2000*)
0.1969 (k7dvd_sal_re)
0.1193 (*kgi7_dem15_re*)
0.0695 (shorebu1km1re)
0.0804 (k7_htr2010_re)

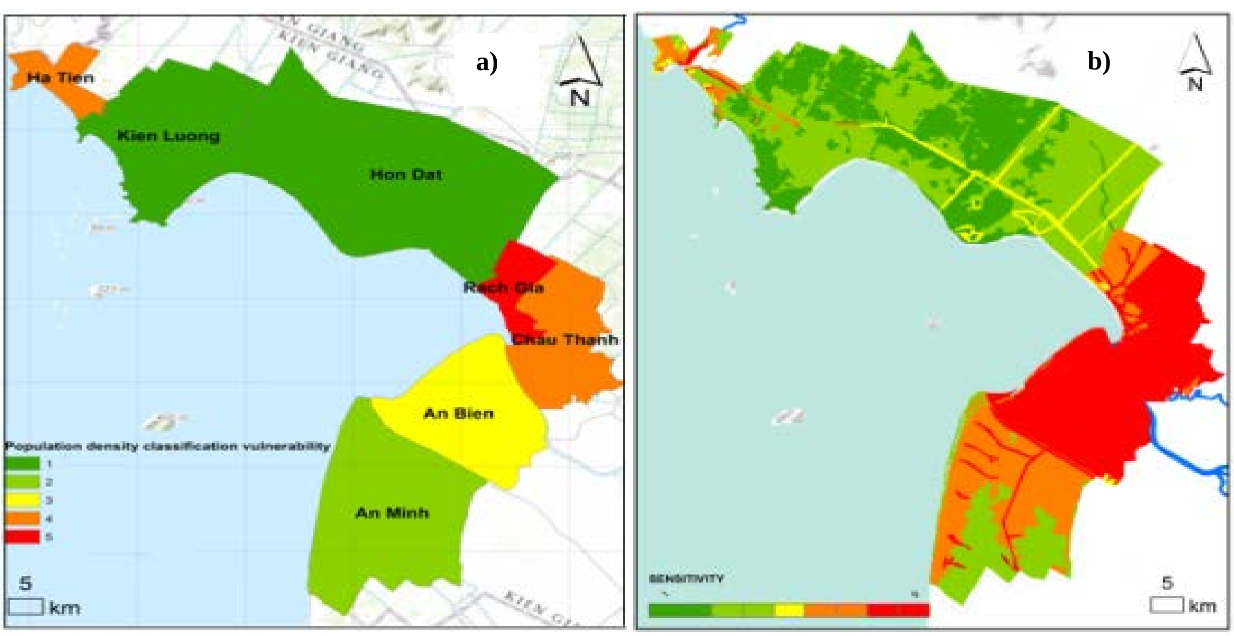
Appendix 17 Evaluation of scale-based input data in order to represent sensitivity for the study area: a) global population density; b) PD at district level; and c) PD within district level.

a. At global input data



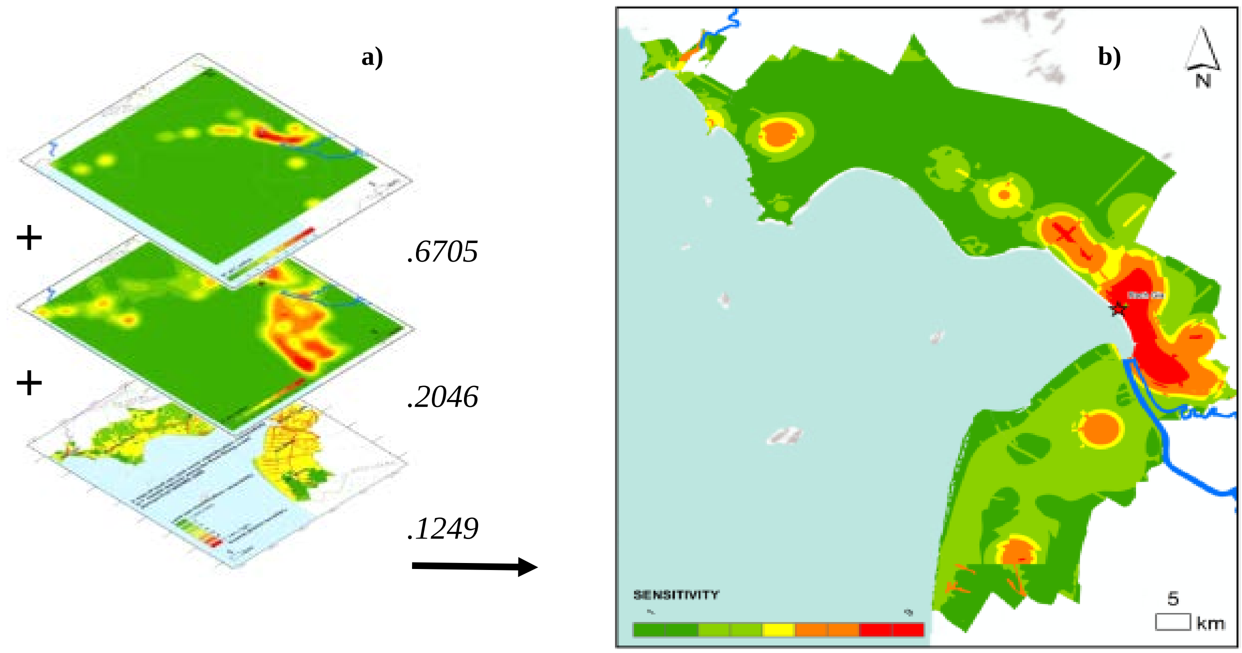
Note: Figure a) shows the population density for the study derived from the global population density (gridded PD in 2010, version 3- GPWv3), while Figure b) shows the sensitivity component derived from the aggregation of two layers the global PD and study landuse.

b. At an entire district level.



Note: Figure a) shows the study PD obtained at an entire district level, while Figure b) shows the study sensitivity component.

c. Within district level.



Note: Figure a) shows the aggregation of three layers, comprising urban people density, rural people density obtained from the GIS database of MARD (undated), and study landuse by AHP, while Figure b) shows the mapping sensitivity component generated, respectively.

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored [for 5.7a]

[Criteria & LayerSource (clsfd.)]
k7ds10ag_re k7ds10ag_re
k7_lulc_re k7_lulc_re

[Preference Matrix]

	k7ds10ag_re	k7_lulc_re
k7ds10ag_re	1	1.2857
k7_lulc_re	0.7778	1

[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.7893
0.6139

[criteria weights]
0.5625 (k7ds10ag_re)
0.4375 (k7_lulc_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored [for 5.7c]

[Criteria & LayerSource (clsfd.)]
k7_lulc_re k7_lulc_re
k7_dc1_rurdre k7_dc1_rurdre
k7_dc1_urdre k7_dc1_urdre

[Preference Matrix]

	k7_lulc_re	k7_dc1_rurdre	k7_dc1_urdre
k7_lulc_re	1	0.5	0.2273
k7_dc1_rurdre	2	1	0.25
k7_dc1_urdre	4.4	4	1

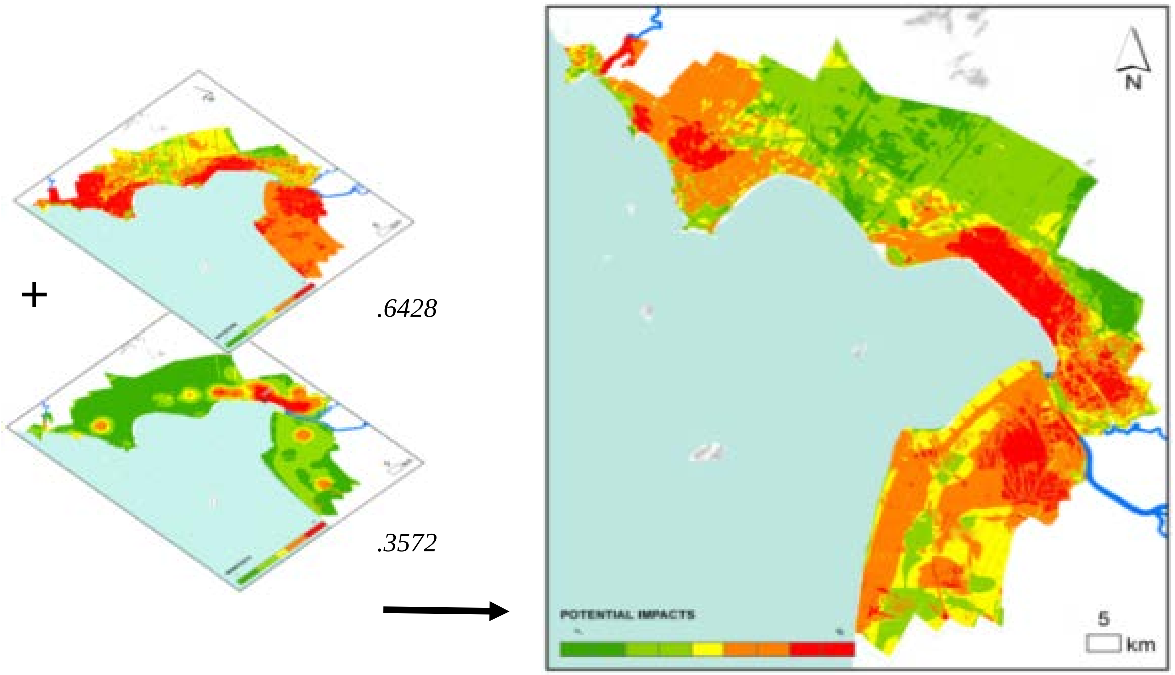
[*****AHP results*****]
[Eigenvalues]
3.0399
-0.0199
-0.0199

[Eigenvector of largest Eigenvalue]
0.1754
0.2873
0.9416

[criteria weights]
0.1249 (k7_lulc_re)
0.2046 (k7_dc1_rurdre)
0.6705 (k7_dc1_urdre)

[consistency ratio CR]
0.0384

Appendix 18 Exposure and sensitivity within district level were used in order to represent potential impacts for the study area.



Note: See in detail for sensitivity within district level in Appendix 5.7c.

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
k7_ex61tes_re k7_ex61tes_re
k7_sen3ahp_re k7_sen3ahp_re

[Preference Matrix]

	k7_ex61tes_re	k7_sen3ahp_re
k7_ex61tes_re	1	1.8
k7_sen3ahp_re	0.5556	1

[*****AHP results*****]
[Eigenvalues]
2
0

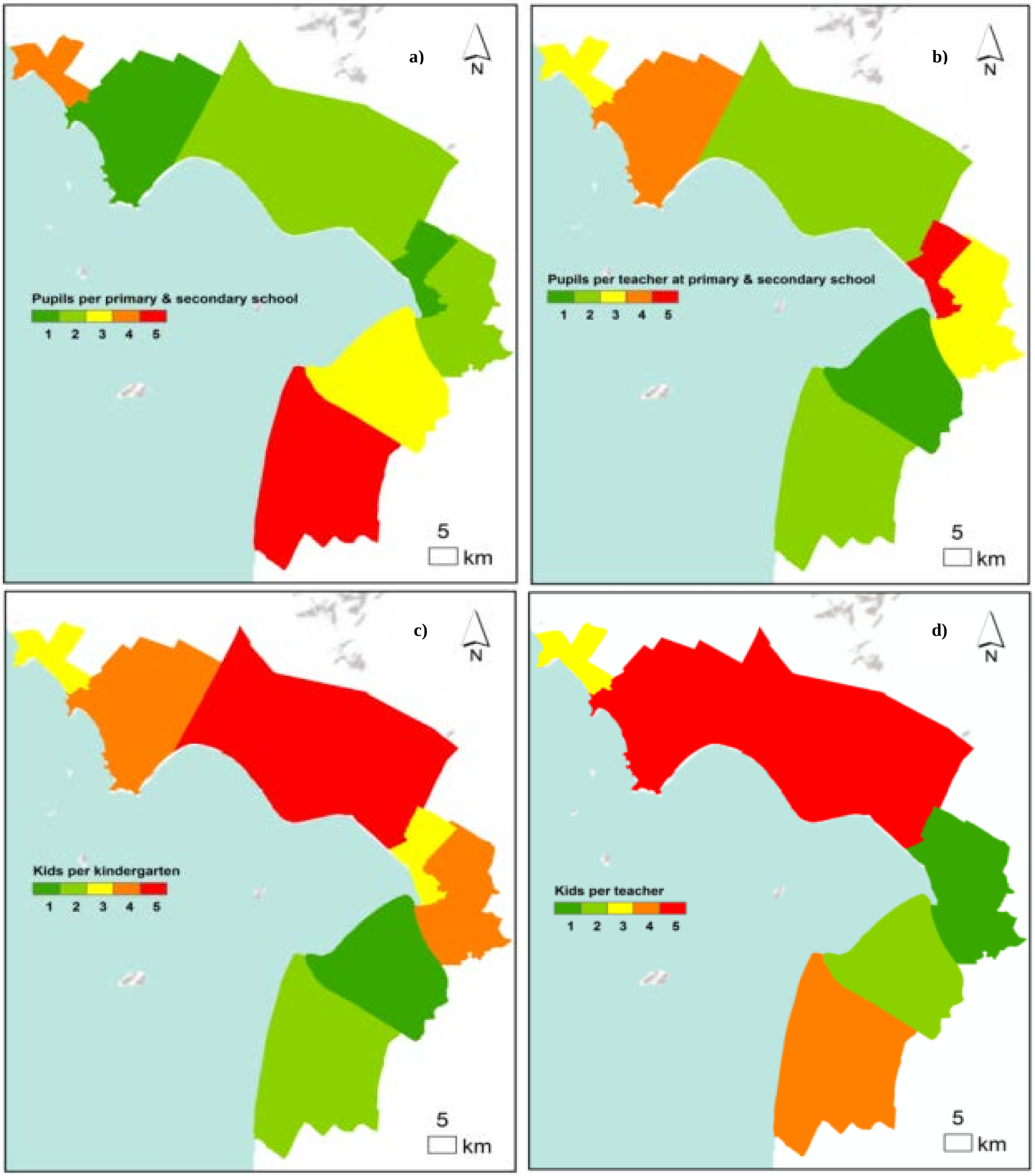
[Eigenvector of largest Eigenvalue]
0.8741
0.4857

[criteria weights]
0.6428 (k7_ex61tes_re)
0.3572 (k7_sen3ahp_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 19 Mapping of the adaptive capacity component for the study area.

Appendix 19a.1 Mapping of education capability for the study area.



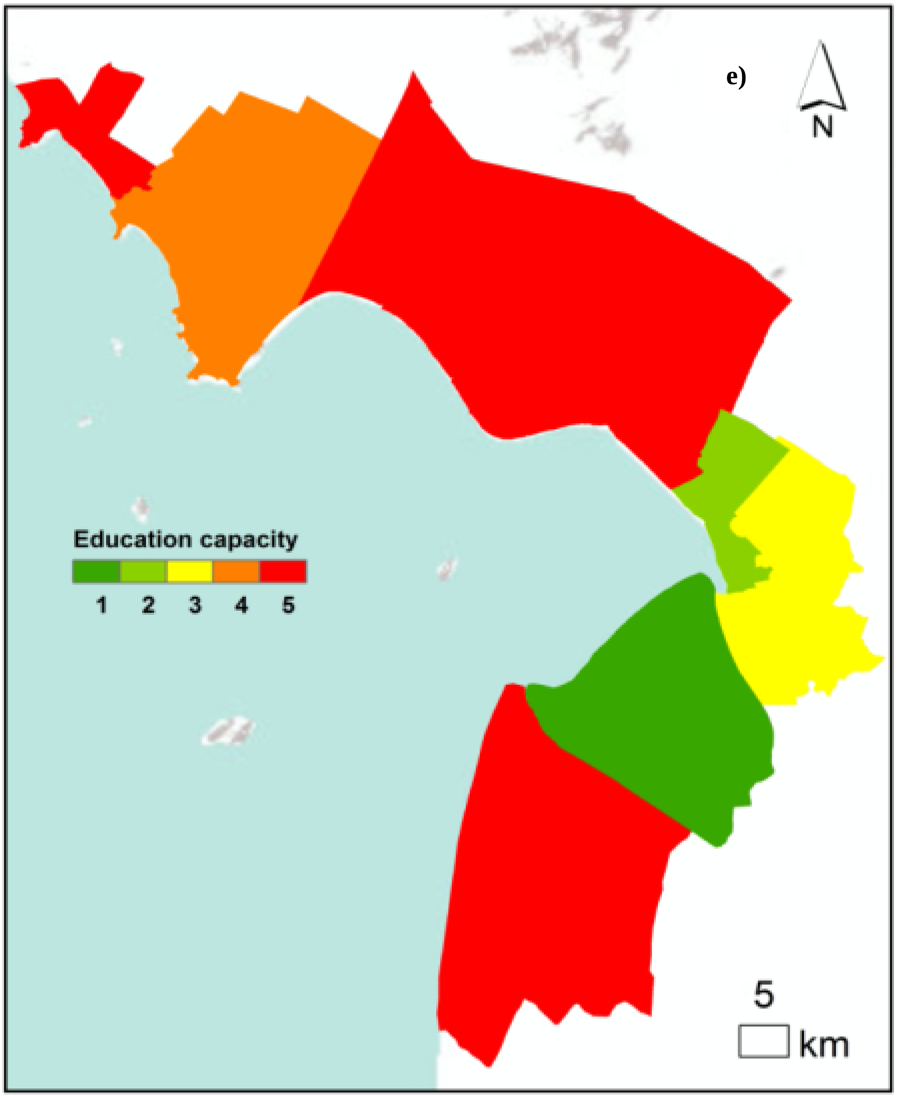


Figure a + b + c + d → Figure e by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]

k7_puptea_re1	k7_puptea_re1
k7_pupsch_re1	k7_pupsch_re1
k7_kidtea_re1	k7_kidtea_re1
k7_kidsch_re1	k7_kidsch_re1

[Preference Matrix]

	k7_puptea_re1	k7_pupsch_re1	k7_kidtea_re1	k7_kidsch_re1
k7_puptea_re1	1	0.7778	2	1
k7_pupsch_re1	1.2857	1	1.8	1.2857
k7_kidtea_re1	0.5	0.5556	1	0.7143
k7_kidsch_re1	1	0.7778	1.4	1

[*****AHP results*****]

[Eigenvalues]

4.016

-0.008

-0.008

0

[Eigenvector of largest Eigenvalue]

0.5302

0.6208

0.3166

0.4829

[criteria weights]

0.2718 (k7_puptea_re1)

0.3183 (k7_pupsch_re1)

0.1623 (k7_kidtea_re1)

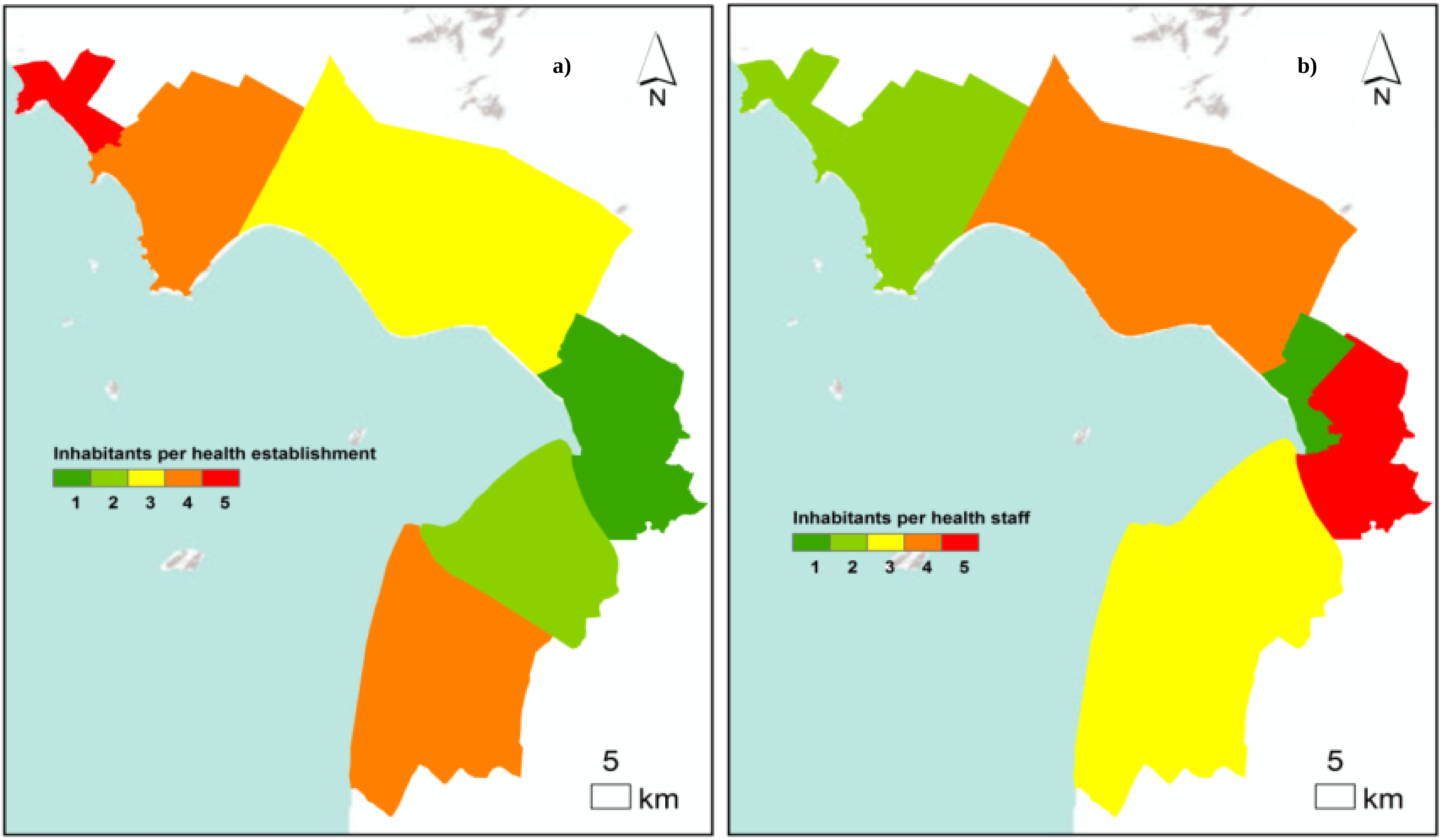
0.2476 (k7_kidsch_re1)

[consistency ratio CR]

0.0059

(Revision of preference values is recommended if CR > 0.1)

Appendix 19a.2 Mapping of health services capability for the study area.



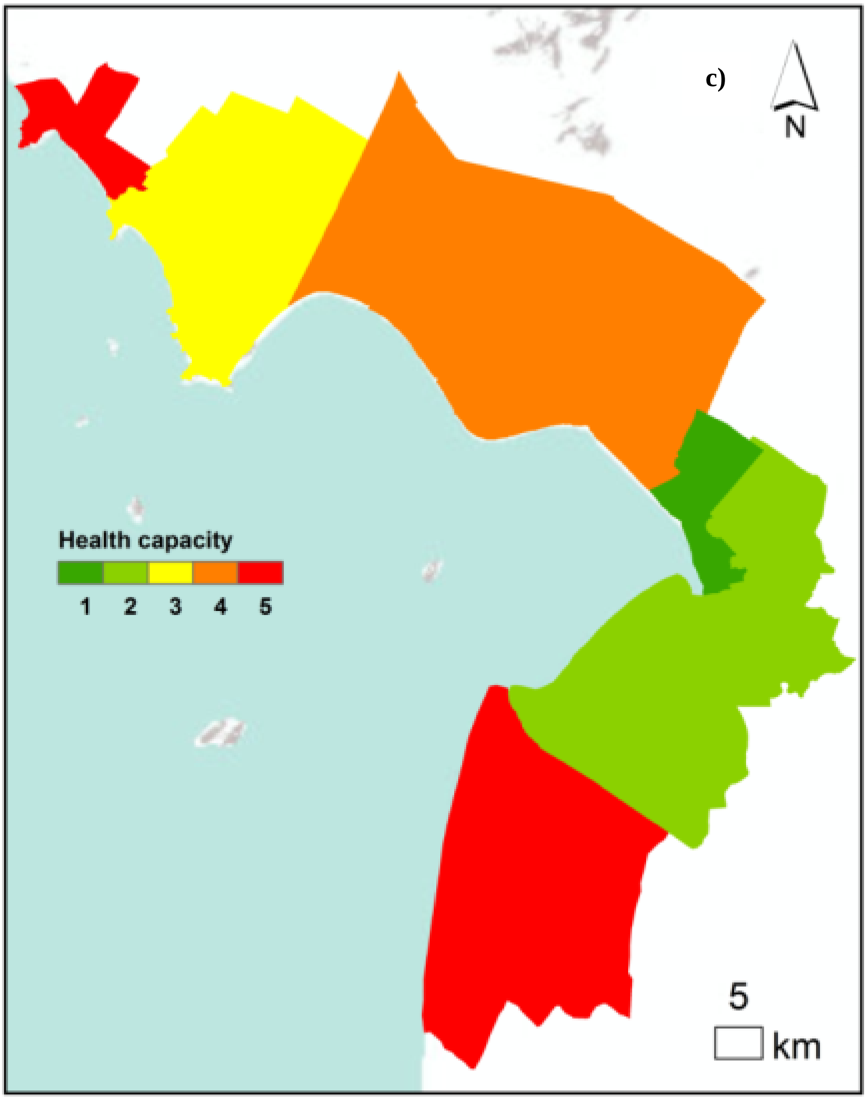


Figure a + b → Figure c by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
k7_heasta_re1 k7_heasta_re1
k7_heaest_re1 k7_heaest_re1

[Preference Matrix]

	k7_heasta_re1	k7_heaest_re1
k7_heasta_re1	1	0.5556
k7_heaest_re1	1.8	1

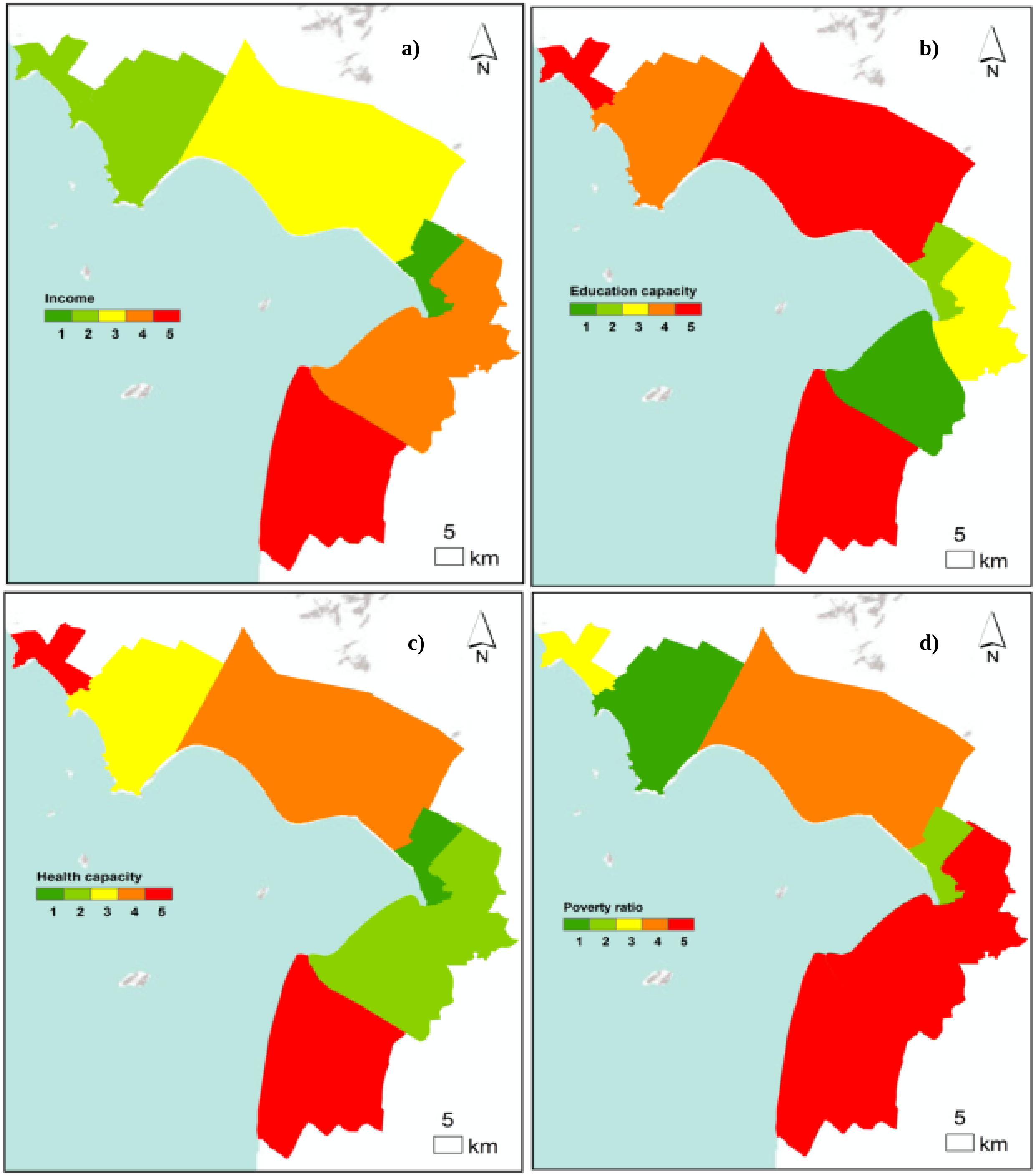
[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.4857
0.8741

[criteria weights]
0.3572 (k7_heasta_re1)
0.6428 (k7_heaest_re1)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 19a.3 Mapping of socioeconomic sub-component for the study area.



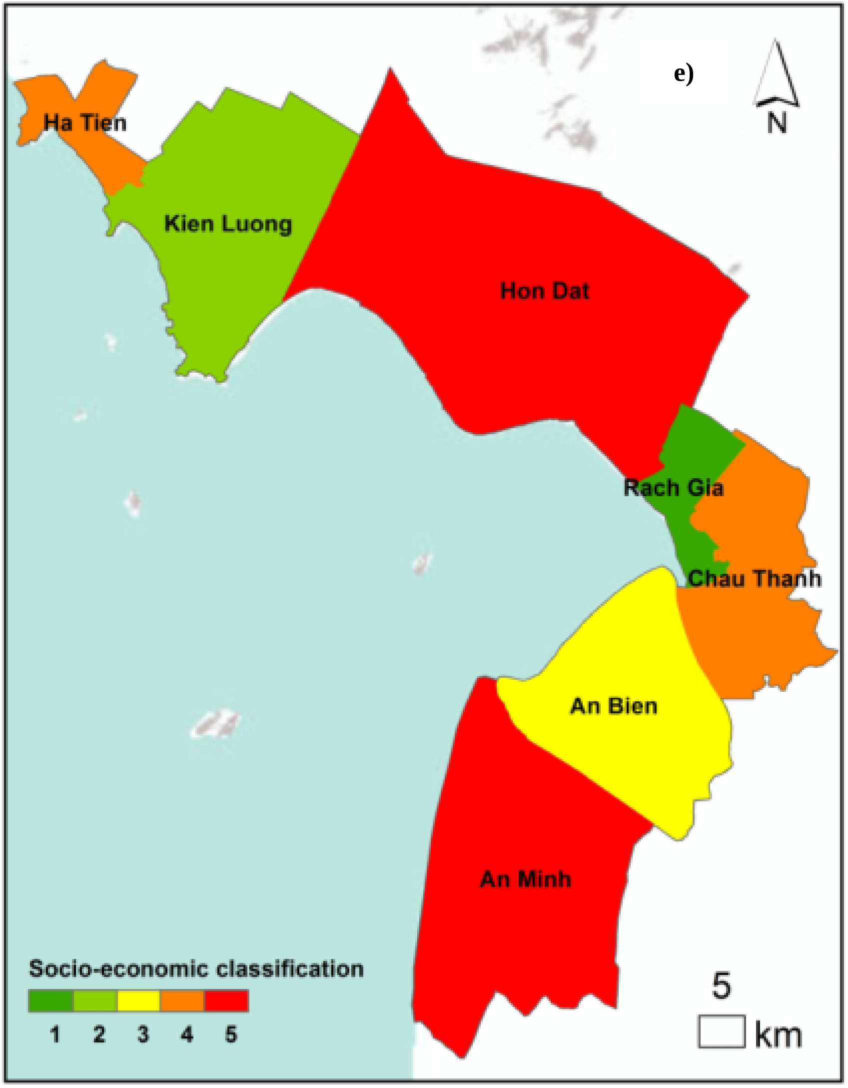


Figure a + b + c + d → Figure e by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]

k7_inc_re1	k7_inc_re1
k7_povert_re1	k7_povert_re1
k7_ahp4edu_re	k7_ahp4edu_re
k7_ahp2hea_re	k7_ahp2hea_re

[Preference Matrix]

	k7_inc_re1	k7_povert_re1	k7_ahp4edu_re	k7_ahp2hea_re
k7_inc_re1	1	2	1	1.125
k7_povert_re1	0.5	1	0.56	0.63
k7_ahp4edu_re	1	1.7857	1	1.1299
k7_ahp2hea_re	0.8889	1.5873	0.885	1

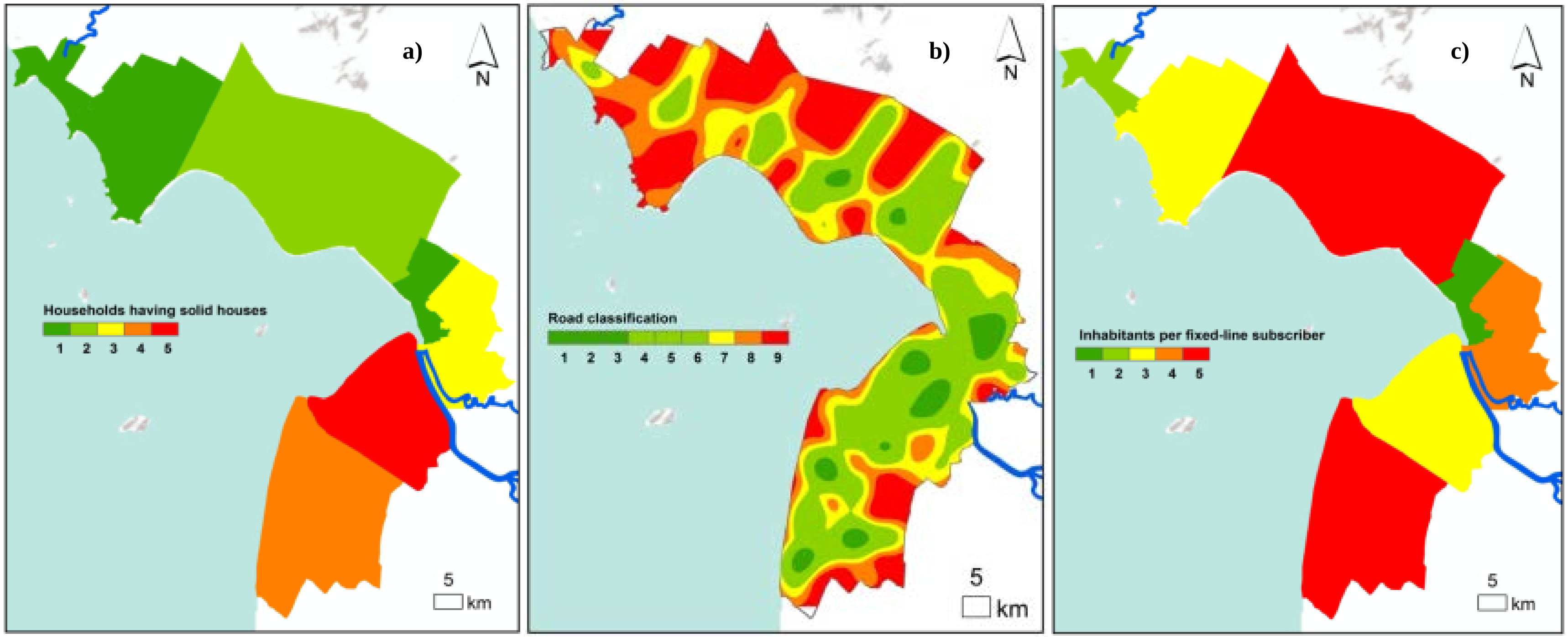
[*****AHP results*****]
[Eigenvalues]
4.0016
-0.0008
-0.0008
0

[Eigenvector of largest Eigenvalue]
0.5802
0.307
0.5644
0.5006

[criteria weights]
0.2972 (k7_inc_re1)
0.1573 (k7_povert_re1)
0.2891 (k7_ahp4edu_re)
0.2564 (k7_ahp2hea_re)

[consistency ratio CR]
0.0006
(Revision of preference values is recommended if CR > 0.1)

Appendix 19b Mapping of infrastructure sub-component for the study area.



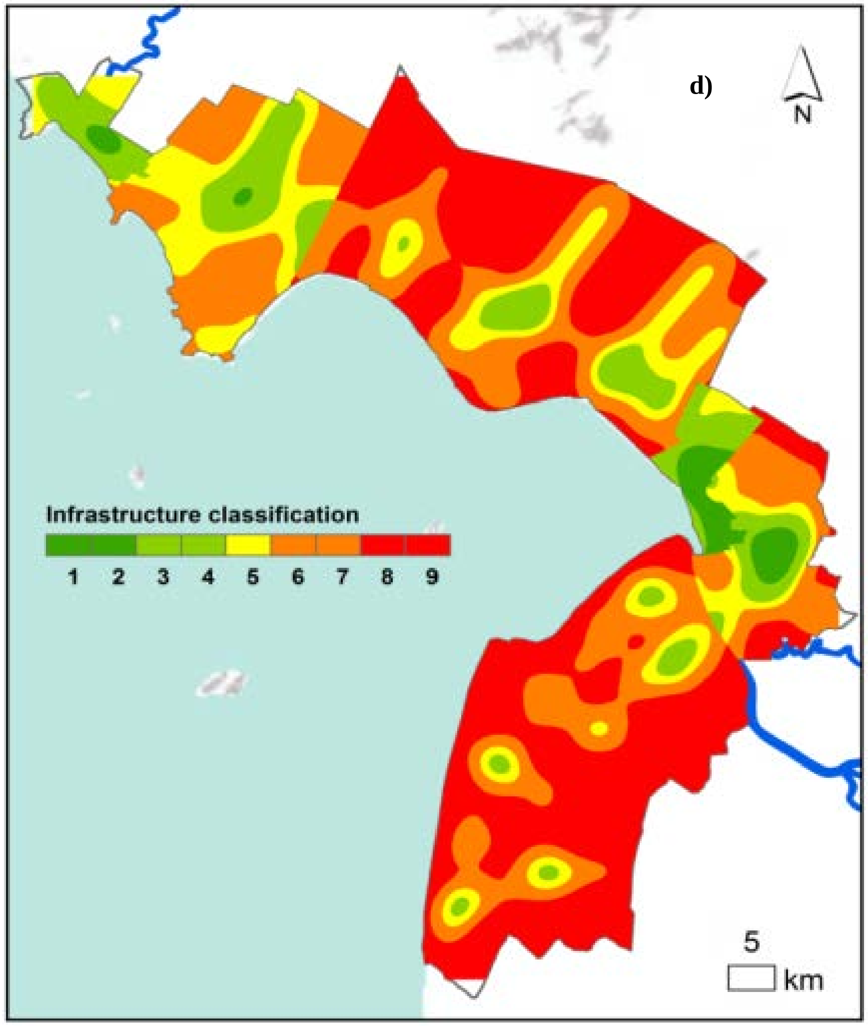


Figure a + b + c → Figure d by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]

k7_phone_re	k7_phone_re
k7_rd5000re1	k7_rd5000re1
k7_solidho_re	k7_solidho_re

[Preference Matrix]

	k7_phone_re	k 7_rd5000re1	k7_solidho_re
k7_phone_re	1	0.6667	0.56
k7_rd5000re1	1.5	1	0.78
k7_solidho_re	1.7857	1.2821	1

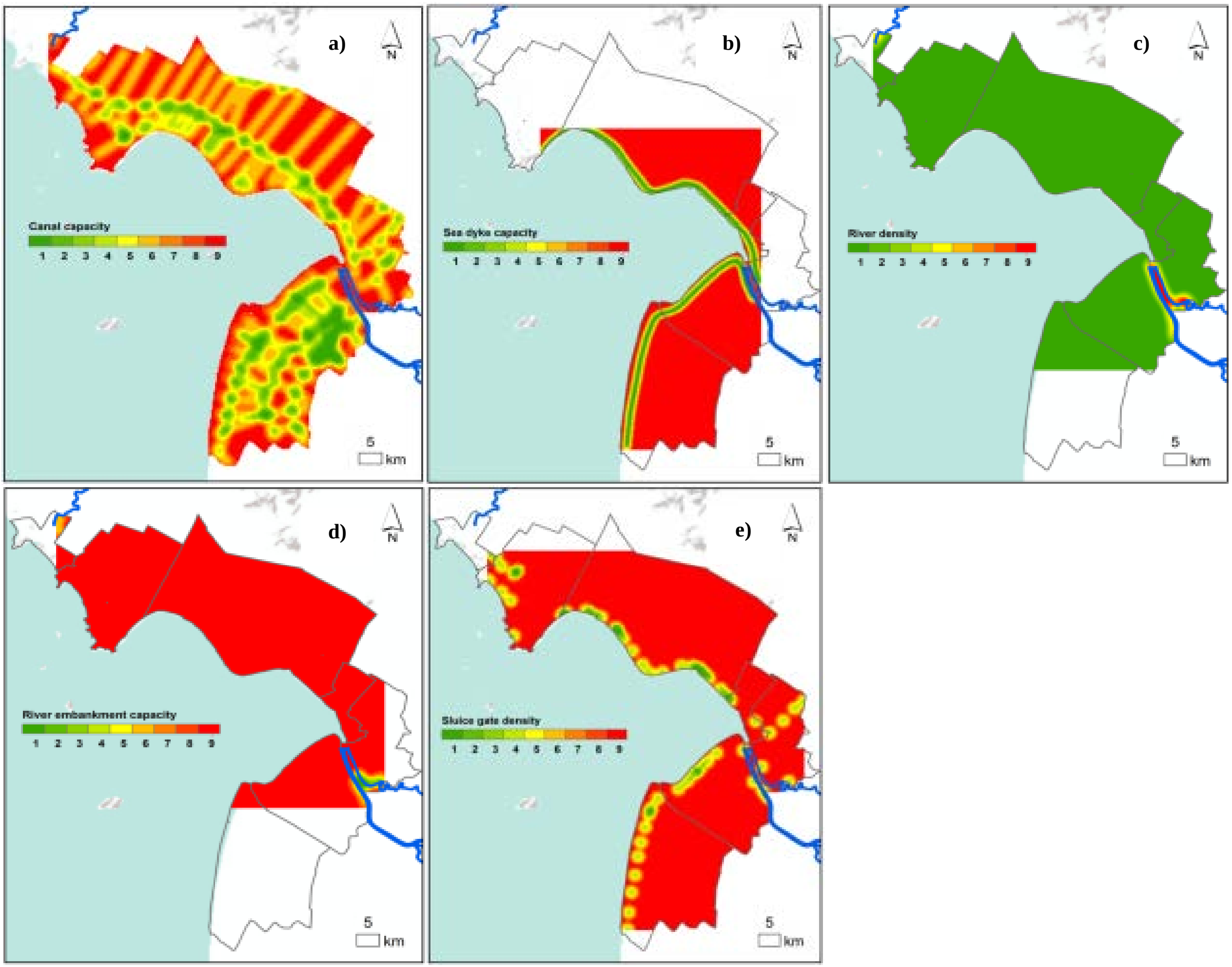
[*****AHP results*****]
[Eigenvalues]
3.0006
-0.0003
-0.0003

[Eigenvector of largest Eigenvalue]
0.3925
0.5743
0.7184

[criteria weights]
0.2329 (k7_phone_re)
0.3408 (k7_rd5000re1)
0.4263 (k7_solidho_re)

[consistency ratio CR]
0.0006
(Revision of preference values is recommended if CR > 0.1)

Appendix 19c.1 Mapping of irrigation and drainage capability for the study area.



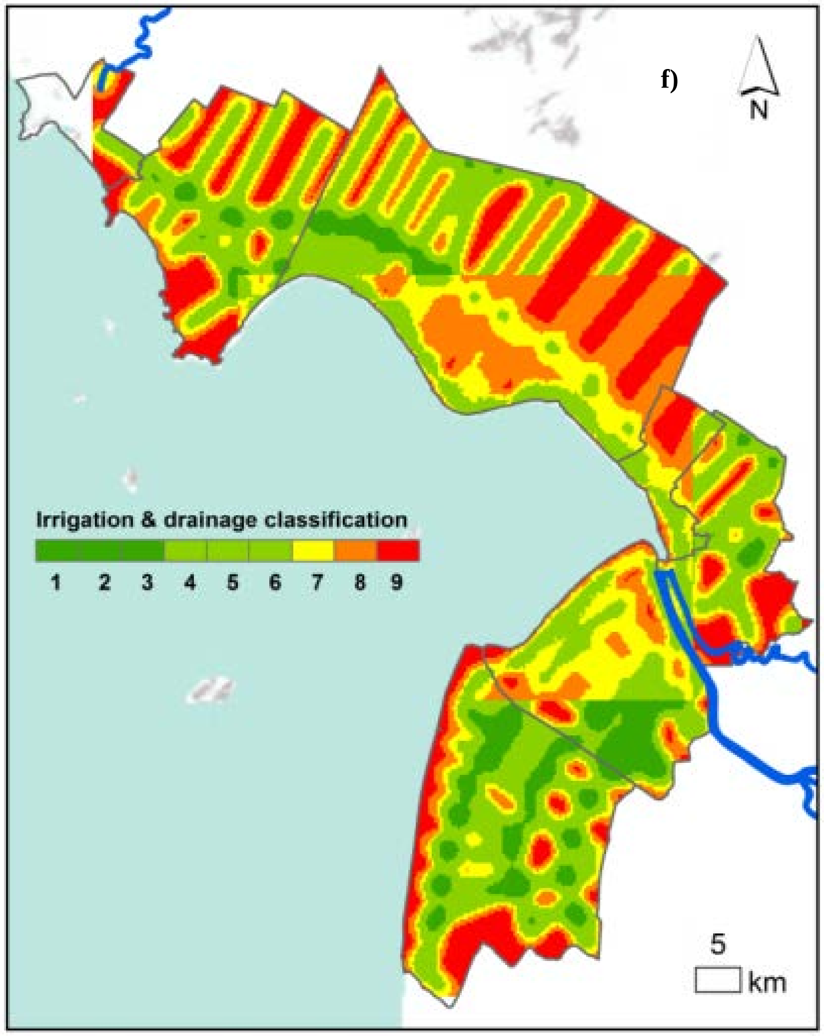


Figure a + b + c + d + e → Figure f by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]

k7_canal_int	k7_canal_int
k7_rivers_int	k7_rivers_int
k7_sluice_int	k7_sluice_int
k7_riveem_int	k7_riveem_int
k7_seady_int	k7_seady_int

[Preference Matrix]

	k7_canal_int	k7_rivers_int	k7_sluice_int	k7_riveem_int	k7_seady_int
k7_canal_int	1	2	1.4999	2	1.2857
k7_rivers_int	0.5	1	1.2857	1.5	1
k7_sluice_int	0.6667	0.7778	1	0.4444	0.3333
k7_riveem_int	0.5	0.6667	2.25	1	0.7778
k7_seady_int	0.7778	1	3.0003	1.2857	1

[*****AHP results*****]

[Eigenvalues]

5.1817
-0.0408
-0.0408
-0.0977
-0.0024

[Eigenvector of largest Eigenvalue]

0.6163
0.4048
0.2531
0.3686
0.5063

[criteria weights]

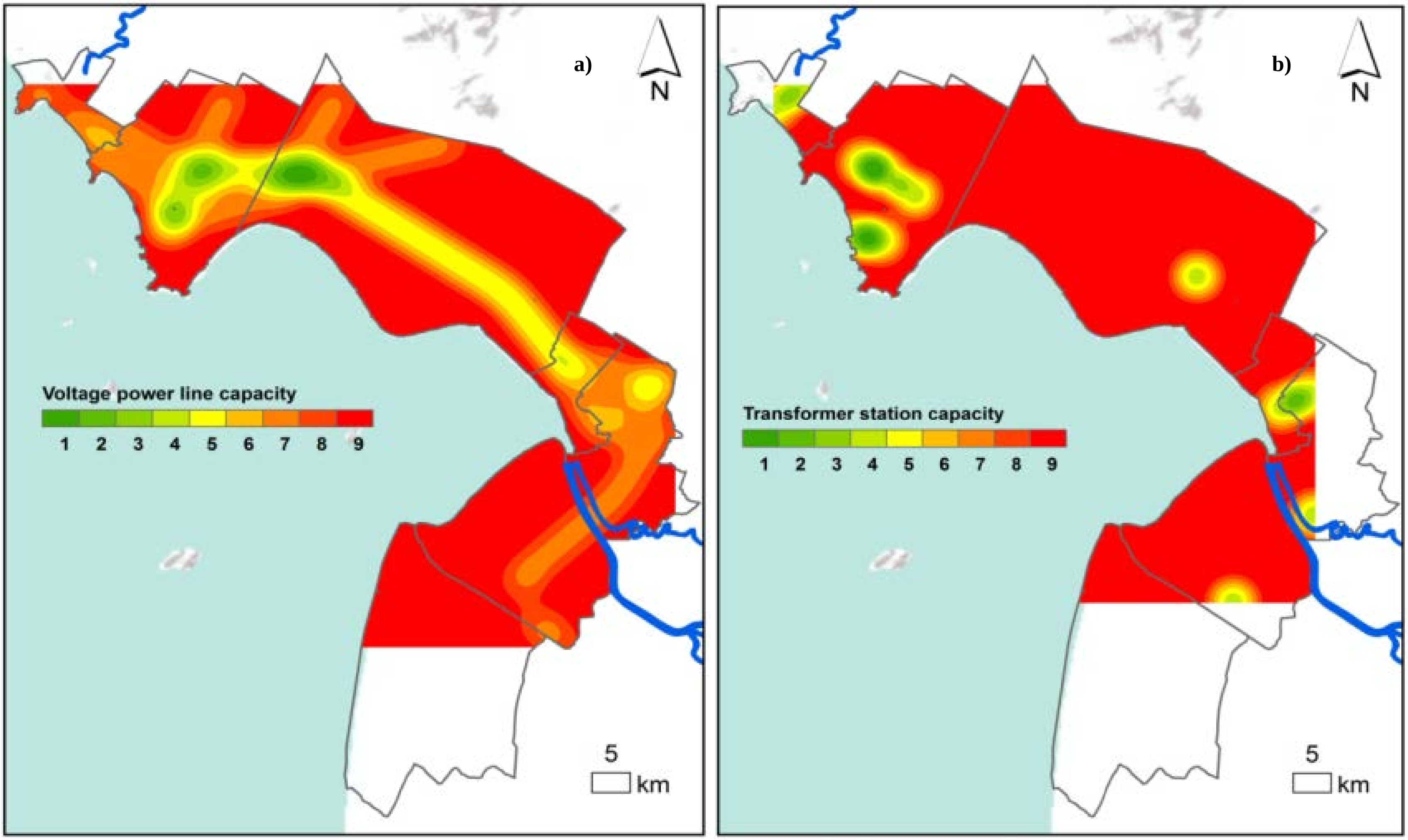
0.2868 (k7_canal_int)
0.1884 (k7_rivers_int)
0.1178 (k7_sluice_int)
0.1715 (k7_riveem_int)
0.2356 (k7_seady_int)

[consistency ratio CR]

0.0406

(Revision of preference values is recommended if CR > 0.1)

Appendix 19c.2 Mapping of electricity capability for the study area.



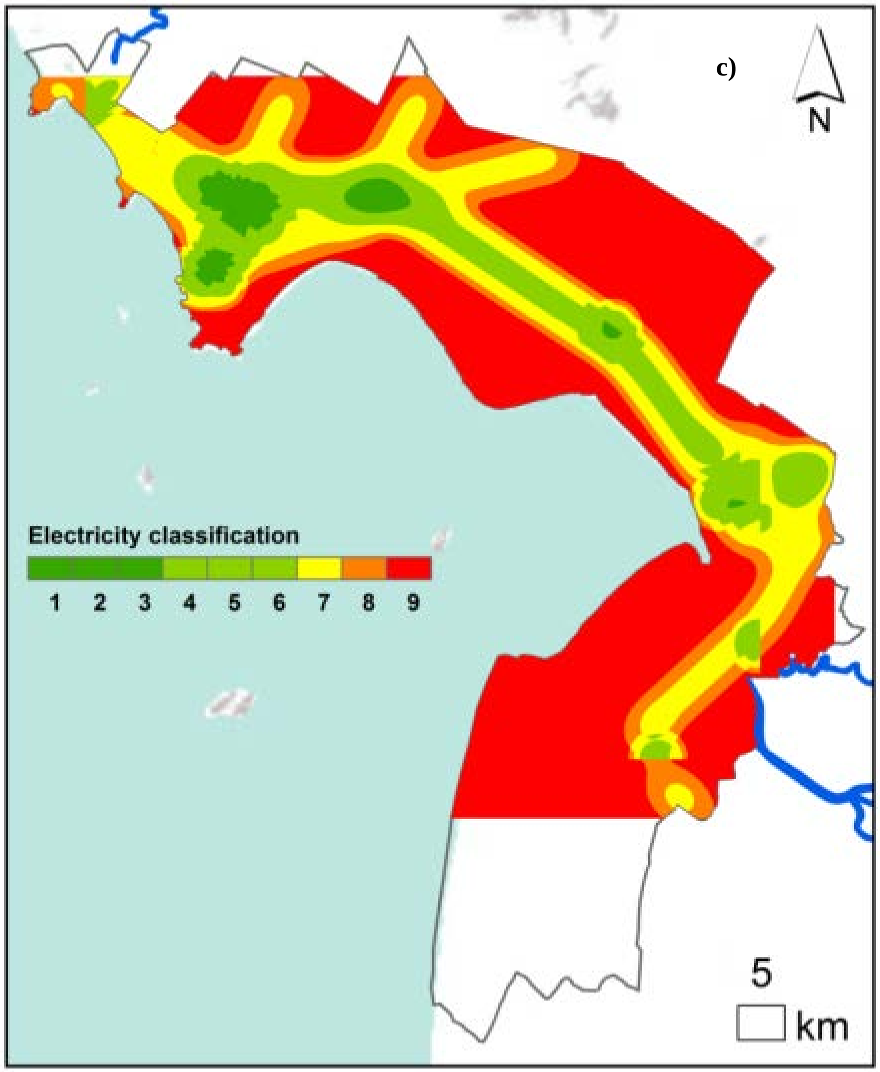


Figure a + b → Figure c by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
k7_elenet_re k7_elenet_re
k7_sta_rek7_sta_re

[Preference Matrix]

	k7_elenet_re	k7_sta_re
k7_elenet_re	1	1.4999
k7_sta_re	0.6667	1

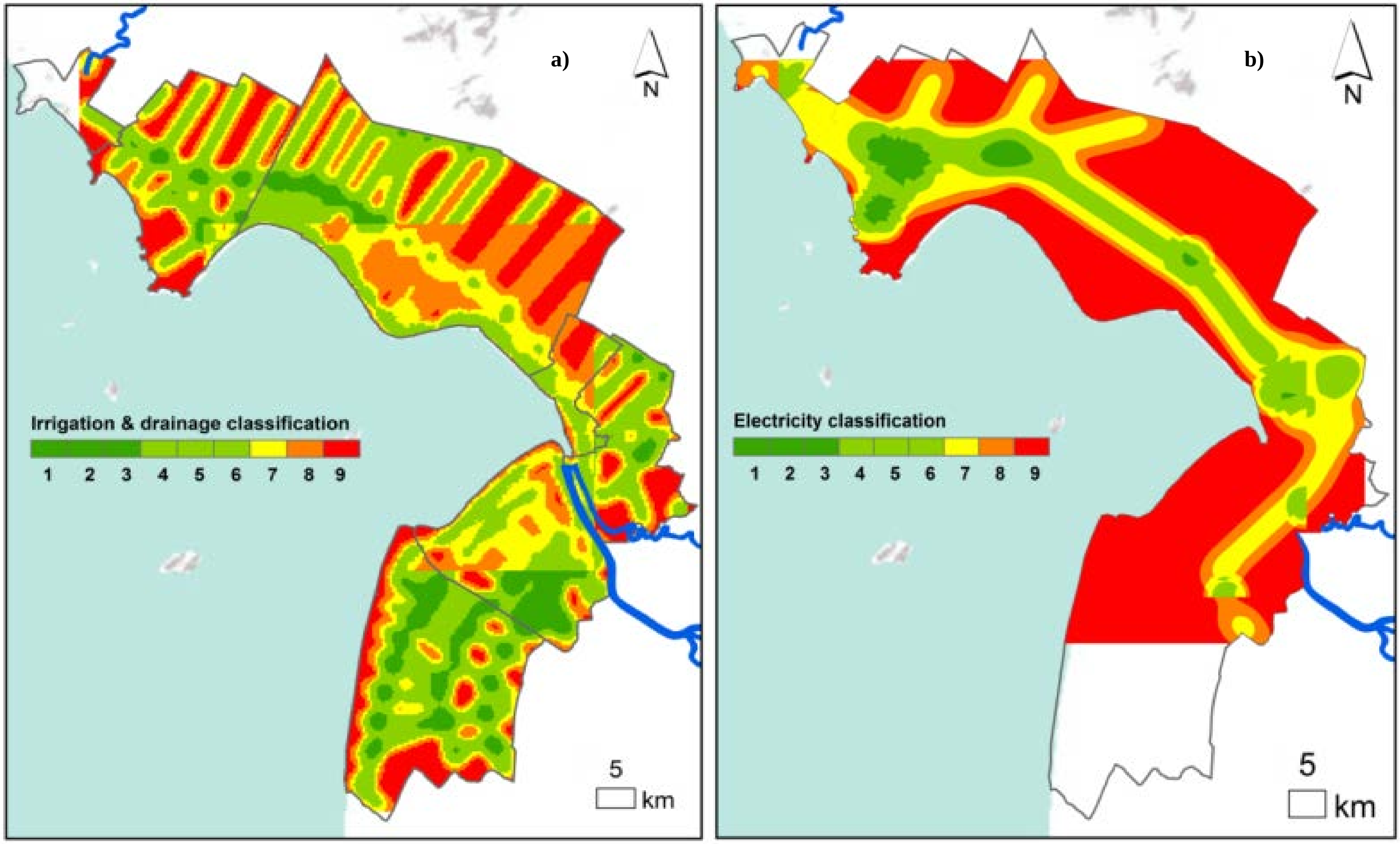
[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.832
0.5547

[criteria weights]
0.6 (k7_elenet_re)
0.4 (k7_sta_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 19c.3 Mapping of technological sub-component for the study area.



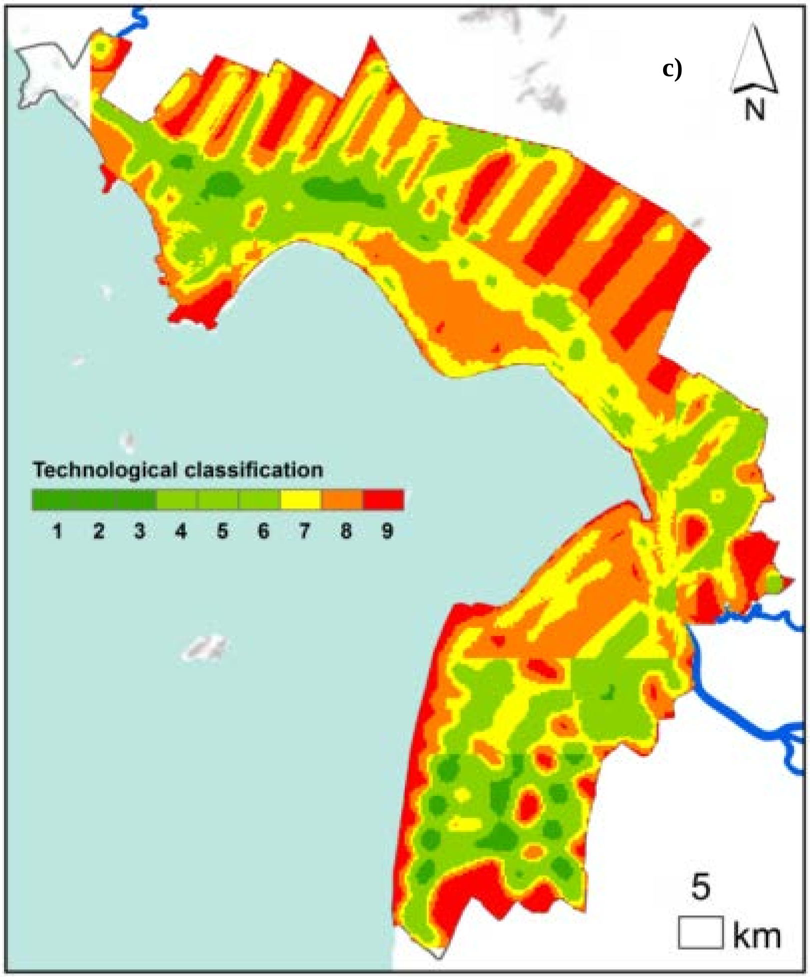


Figure a + b → Figure c by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
k7_6irr_re k7_6irr_re
k7_3elec_re k7_3elec_re

[Preference Matrix]

	k7_6irr_re	k7_3elec_re
k7_6irr_re	1	1.2857
k7_3elec_re	0.7778	1

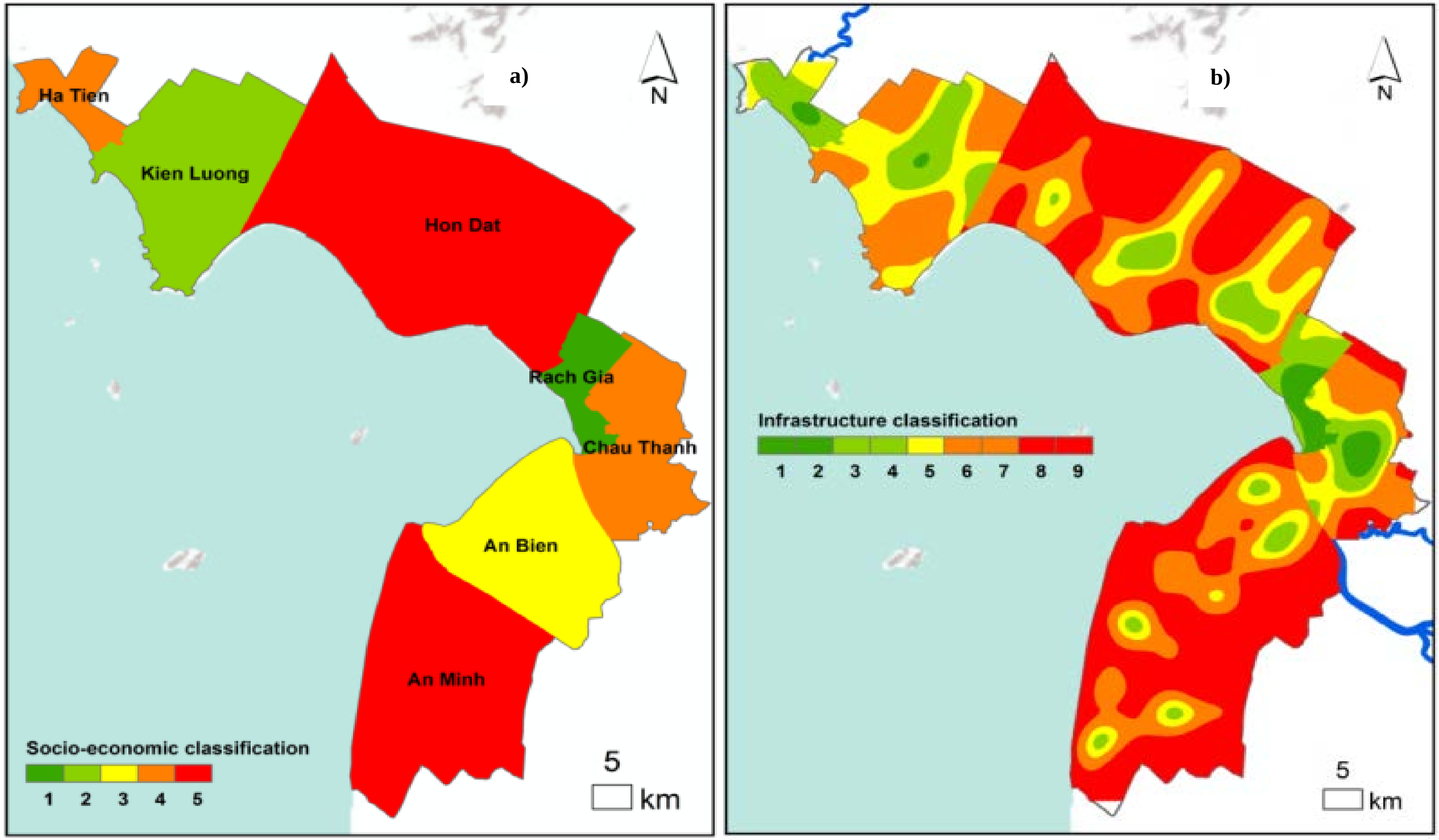
[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.7893
0.6139

[criteria weights]
0.5625 (k7_6irr_re)
0.4375 (k7_3elec_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 19d Mapping of the adaptive capacity component for the study area.



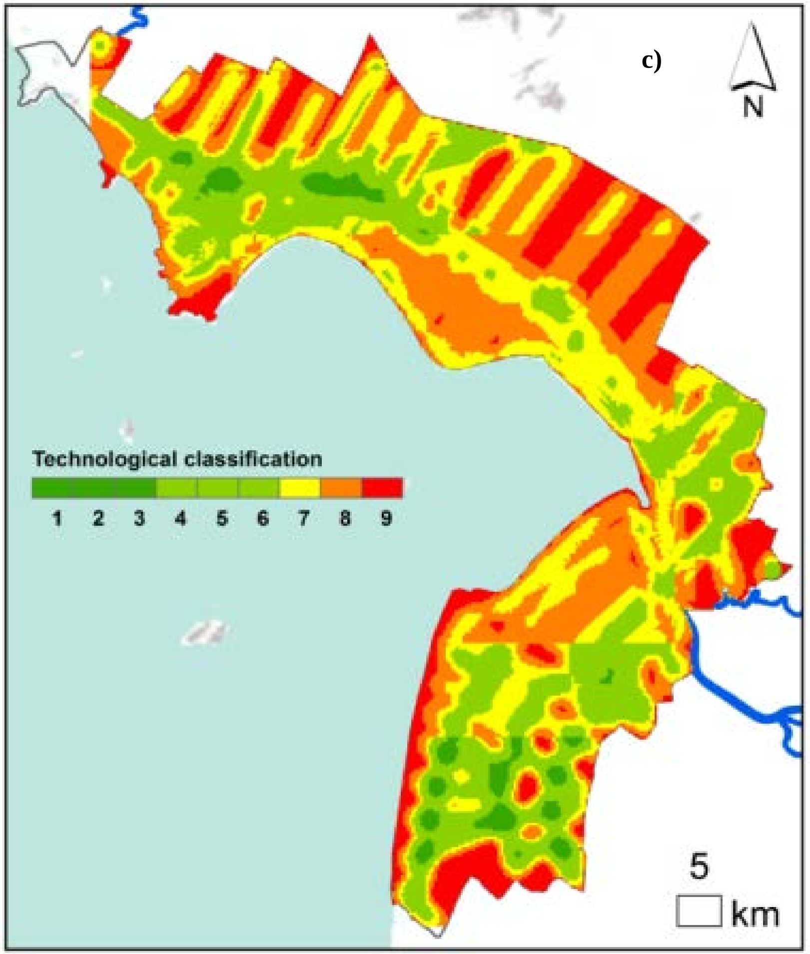


Figure a + b + c→ Figure d by AHP

The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]
k7_3infahp_re k7_3infahp_re
k7_tech_re1 k7_tech_re1
k7_socahp_re1 k7_socahp_re1

[Preference Matrix]

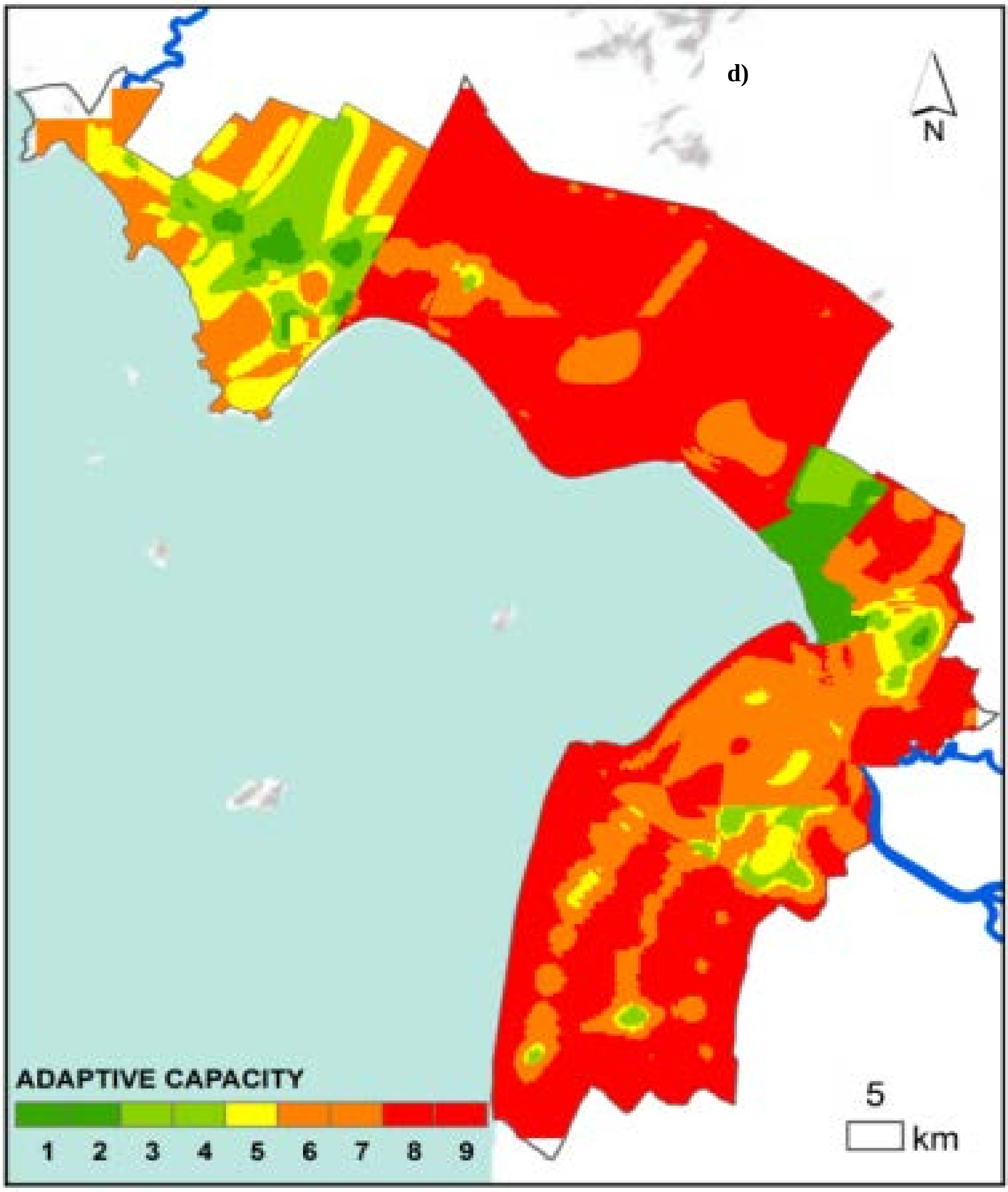
	k7_3infahp_re	k7_tech_re1	k7_socahp_re1
k7_3infahp_re	1	1	0.5555
k7_tech_re1	1	1	0.6
k7_socahp_re1	1.8002	1.6667	1

[*****AHP results*****]
[Eigenvalues]
3.0007
-0.0003
-0.0003

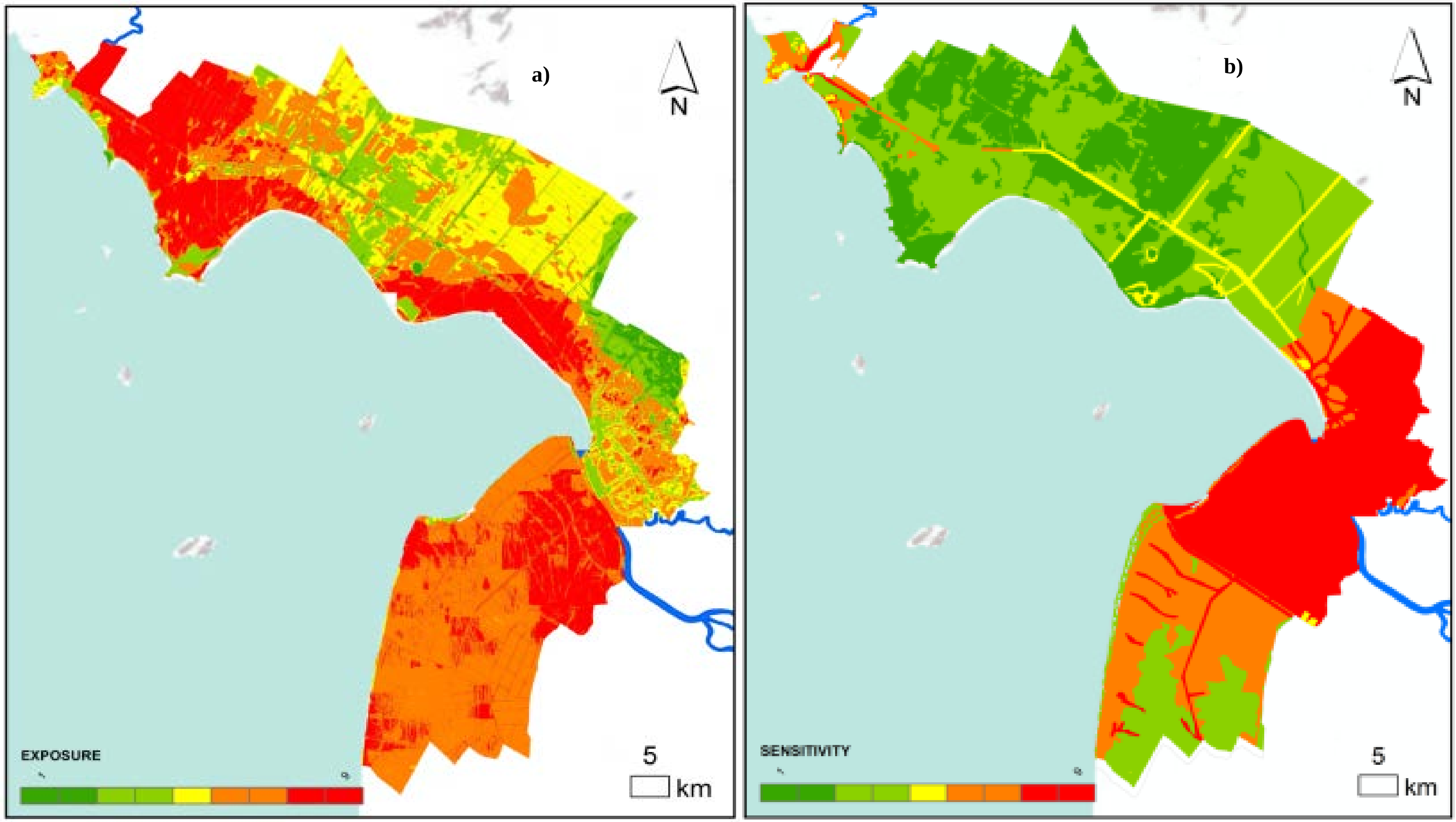
[Eigenvector of largest Eigenvalue]
0.4415
0.4529
0.7746

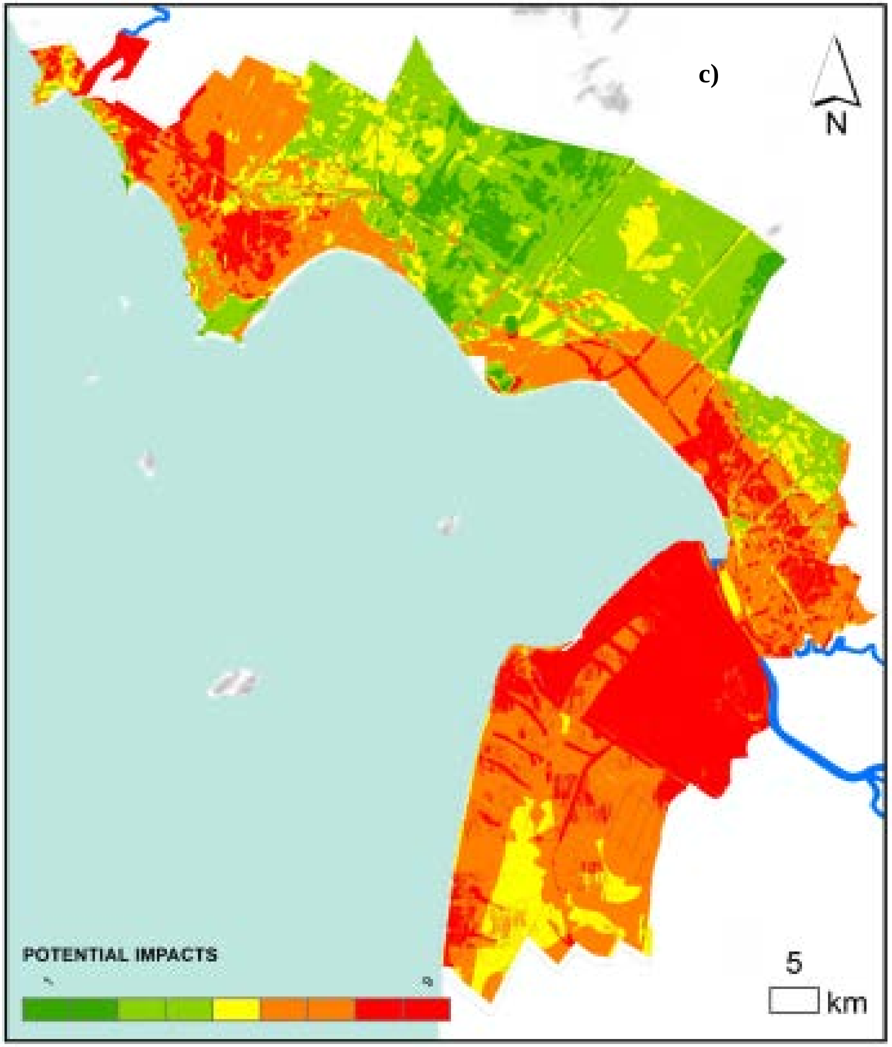
[criteria weights]
0.2645 (k7_3infahp_re)
0.2714 (k7_tech7_re1)
0.4641 (k7_socahp_re1)

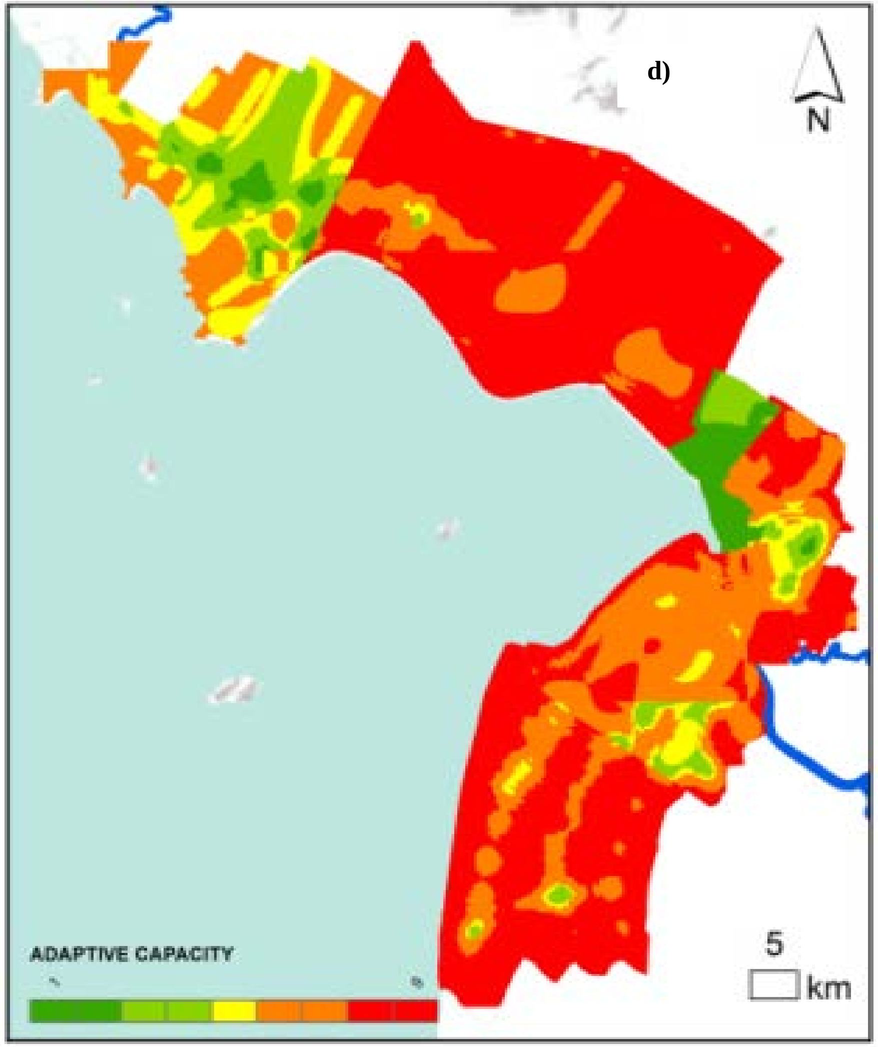
[consistency ratio CR]
0.0006
(Revision of preference values is recommended if CR > 0.1)


d)
N
ADAPTIVE CAPACITY
1 2 3 4 5 6 7 8 9
5
km

Appendix 20 Mapping of the final vulnerability for the study area.




c)
N
5
km
POTENTIAL IMPACTS


d)
N
5
km
ADAPTIVE CAPACITY

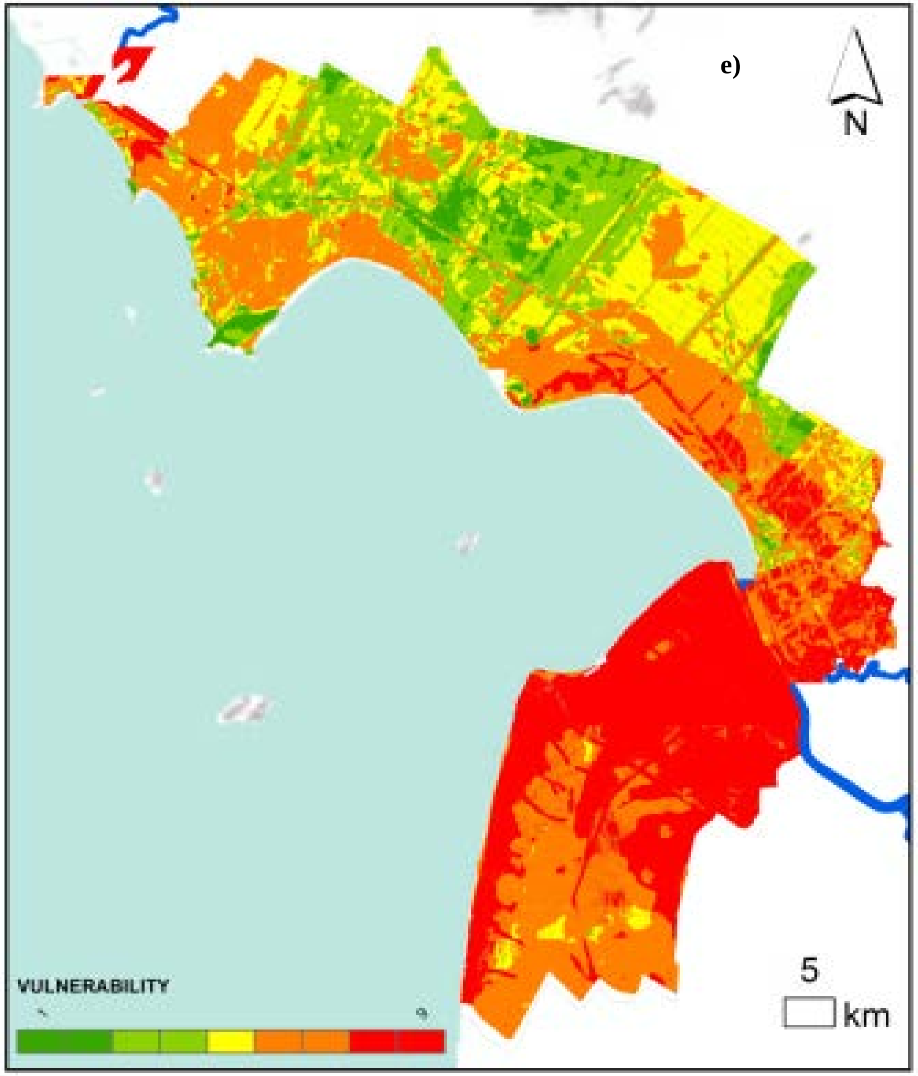


Figure a + b → Figure c by AHP

[Criteria & LayerSource (clsfd.)]
k7_ex61tes_re k7_ex61tes_re
k7_sen3ahp_re k7_sen3ahp_re

[Preference Matrix]

	k7_ex61tes_re	k7_sen3ahp_re
k7_ex61tes_re	1	1.8
k7_sen3ahp_re	0.5556	1

[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.8741
0.4857

[criteria weights]
0.6428 (k7_ex61tes_re)
0.3572 (k7_sen3ahp_re)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Figure a + b + d→ Figure e by AHP
The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]

k7_e_mos_re	k7_e_mos_re
k7_sen_ahp_re	k7_sen_ahp_re
k7_a_ahp_re1	k7_a_ahp_re1

[Preference Matrix]

	k7_e_mos_re	k7_sen_ahp_re	k7_a_ahp_re1
k7_e_mos_re	1	1.25	2
k7_sen_ahp_re	0.8	1	1.5
k7_a_ahp_re1	0.5	0.6667	1

[*****AHP results*****]
[Eigenvalues]
3.0005
-0.0002
-0.0002

[Eigenvector of largest Eigenvalue]
0.7305
0.5719
0.3732

[criteria weights]
0.4359 (k7_e_mos_re)
0.3413 (k7_sen_ahp_re)
0.2227 (k7_a_ahp_re1)

[consistency ratio CR]
0.0005
(Revision of preference values is recommended if CR > 0.1)

Figure c + d→ Figure e by AHP
The report files outlined as below can be automatically created where all the information of the AHP procedure are stored

[Criteria & LayerSource (clsfd.)]

k7_potsoci_re	k7_potsoci_re
k7_a_alg1_re3	k7_a_alg1_re3

[Preference Matrix]

	k7_potsoci_re	k7_a_alg1_re3
k7_potsoci_re	1	1.8
k7_a_alg1_re3	0.5556	1

[*****AHP results*****]
[Eigenvalues]
2
0

[Eigenvector of largest Eigenvalue]
0.8741
0.4857

[criteria weights]
0.6428 (k7_potsoci_re)
0.3572 (k7_a_alg1_re3)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 21 A summary of relative weights of variables of adaptive capacity and aggregating of vulnerability for the study area that were simultaneously, obtained from the AHP tool.

No.	Component	Sub-component	Variable/Sub-variable	Weight	CR	Variable	Sub-component	Final	References
1	Exposure			***0.4359***					Appendix 20
2	Sensitivity			***0.3413***					Appendix 20
3	Adaptive capacity			***0.2227***					Appendix 20
3.1		Socioeconomic		*0.4641*			***0.1034***	***0.1034***	Appendix 19d
3.1.1			Income	0.2972		*0.2972*	*0.1379*	*0.0307*	Appendix 19a.3
3.1.2			Poverty ratio	0.1573		*0.1573*	*0.0730*	*0.0163*	Appendix 19a.3
3.1.3			Health services	0.2564			*0.1190*	*0.0265*	Appendix 19a.3
			Inhabitants/a establishment	0.6428		*0.1648*	*0.0765*	*0.0170*	Appendix 19a.2
			Inhabitants/a staff	0.3572		*0.0916*	*0.0425*	*0.0095*	Appendix 19a.2
					0				Appendix 19a.2
3.1.4			Education system	0.2891			*0.1342*	*0.0299*	Appendix 19a.3
			Kids/a school	0.2476		*0.0716*	*0.0332*	*0.0074*	Appendix 19a.1
			Kids/a teacher	0.1623		*0.0469*	*0.0218*	*0.0048*	Appendix 19a.1
			Pupils/a school	0.3183		*0.0920*	*0.0427*	*0.0095*	Appendix 19a.1
			Pupils/a teacher	0.2718		*0.0786*	*0.0365*	*0.0081*	Appendix 19a.1
					0.0059				Appendix 19a.1
					0.0006				Appendix 19a.3
3.2		Infrastructure		*0.2645*			***0.0589***	***0.0589***	Appendix 19d
3.2.1			Road density	0.3408			*0.0901*	*0.0201*	Appendix 19b
3.2.2			% household having solid house	0.4263			*0.1128*	*0.0251*	Appendix 19b
3.2.3			Inhabitants/ a fixed-line telephone subscriber	0.2329			*0.0616*	*0.0137*	Appendix 19b
					0.0006				Appendix 19b
3.3		Technological		*0.2714*			***0.0604***	***0.0604***	Appendix 19d
3.3.1			Irrigation & drainage capability	0.5625			*0.1527*	*0.0340*	Appendix 19c.3
			Canal density	0.2868		*0.1613*	*0.0438*	*0.0098*	Appendix 19c.1
			River density	0.1884		*0.1060*	*0.0288*	*0.0064*	Appendix 19c.1
			Sluice gate density	0.1178		*0.0663*	*0.0180*	*0.0040*	Appendix 19c.1
			River embankment density	0.1715		*0.0965*	*0.0262*	*0.0058*	Appendix 19c.1
			Sea dyke density	0.2356		*0.1325*	*0.0360*	*0.0080*	Appendix 19c.1
					0.0406				Appendix 19c.1
3.3.2			Electricity network density	0.4375			*0.1187*	*0.0264*	Appendix 19c.3
			Power line density	0.6		*0.2625*	*0.0712*	*0.0159*	Appendix 19c.2
			Transformer density	0.4		*0.1750*	*0.0475*	*0.0106*	Appendix 19c.2
					0				Appendix 19c.2
					0				Appendix 19c.3
					0.0006				Appendix 19d
4	Vulnerability			1					Appendix 20
					0.0005				Appendix 20

Note: The CR < 0.1 (acceptable by Saaty (1980)) and the CR< 0.05 and 0.08 for 3 by 3 matrices and 4 by 4 matrices (acceptable by Saaty (1994)), respectively.

Appendix 22 Three variables within district level: a) irrigation and drainage capacity, b) electricity capacity, and c) road capacity were aggregated in order to represent the adaptive capacity.

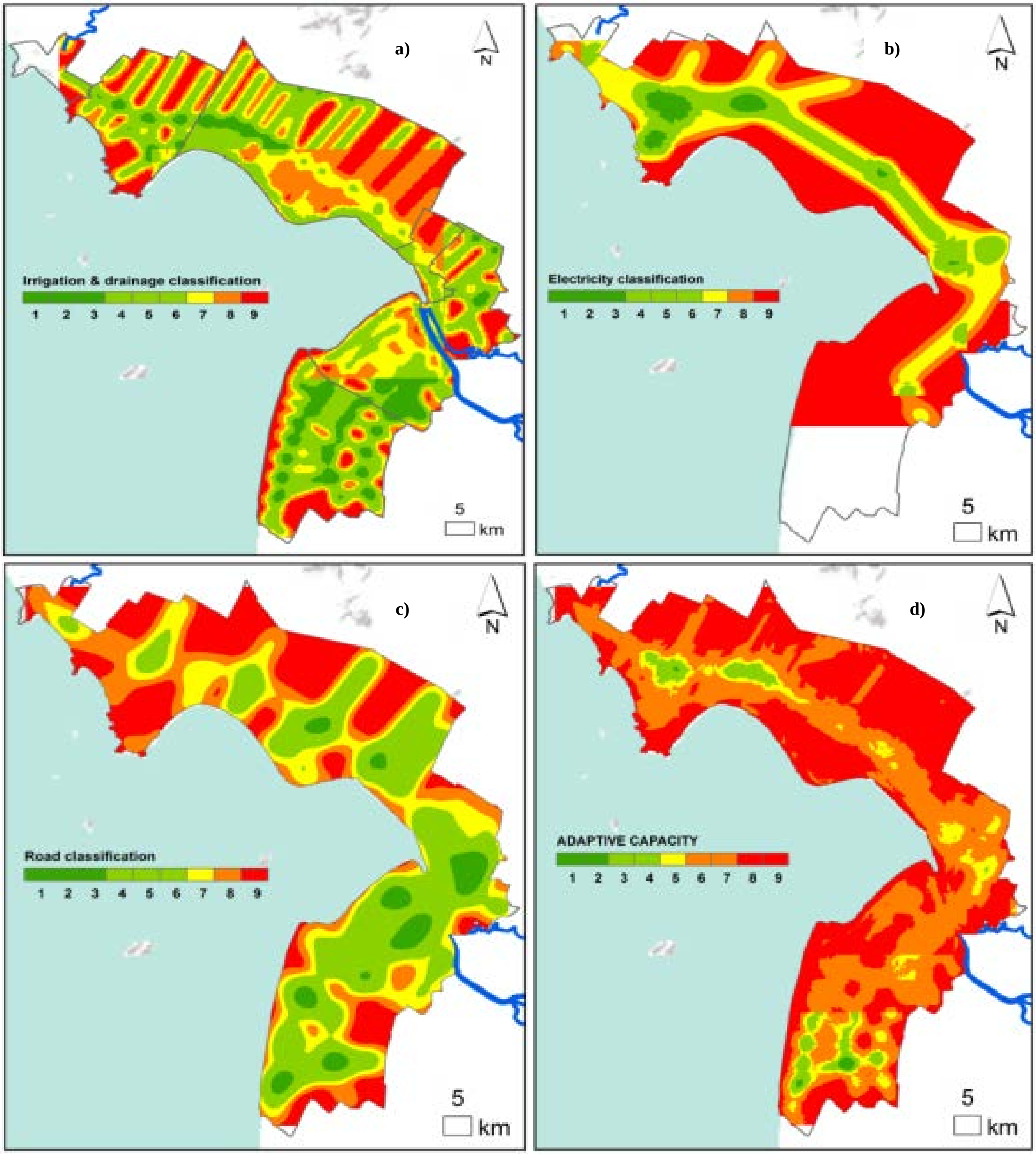


Figure a + b + c → a map by AHP (input raster).

[Criteria & LayerSource (clsfd.)]

k7_6irr_re	k7_6irr_re
k7_3elec_re	k7_3elec_re
k7_rd5000re1	k7_rd5000re1

[Preference Matrix]

	k7_6irr_re	k7_3elec_re	k7_rd5000re1
k7_6irr_re	1	1.2775	1.2
k7_3elec_re	0.7828	1	1
k7_rd5000re1	0.8333	1	1

[*****AHP results*****]
[Eigenvalues]
3.0004
-0.0002
-0.0002

[Eigenvector of largest Eigenvalue]
0.6587
0.5265
0.5376

[criteria weights]
0.3824 (k7_6irr_re)
0.3056 (k7_3elec_re)
0.312 (k7_rd5000re1)

[consistency ratio CR]
0.0004
(Revision of preference values is recommended if CR > 0.1)

Figure a + c → a map by AHP (target raster).
Mosaic was used to generate a map in Figure d

[Criteria & LayerSource (clsfd.)]

k7_6irr_re	k7_6irr_re
k7_ rd5000re1	k7_ rd5000re1

[Preference Matrix]

	k7_6irr_re	k7_ rd5000re1
k7_6irr_re	1	1.8
k7_ rd5000re1	0.5556	1

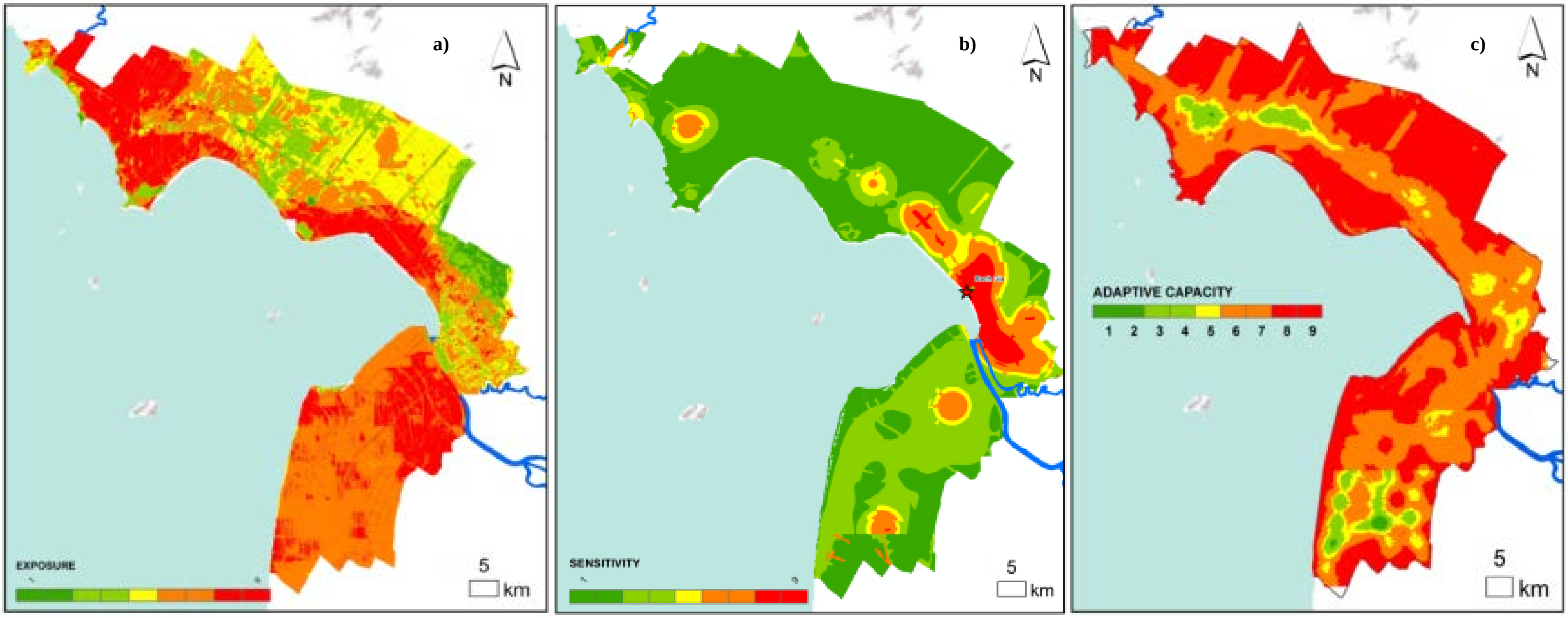
[*****AHP results*****]
[Eigenvalues]
2
0

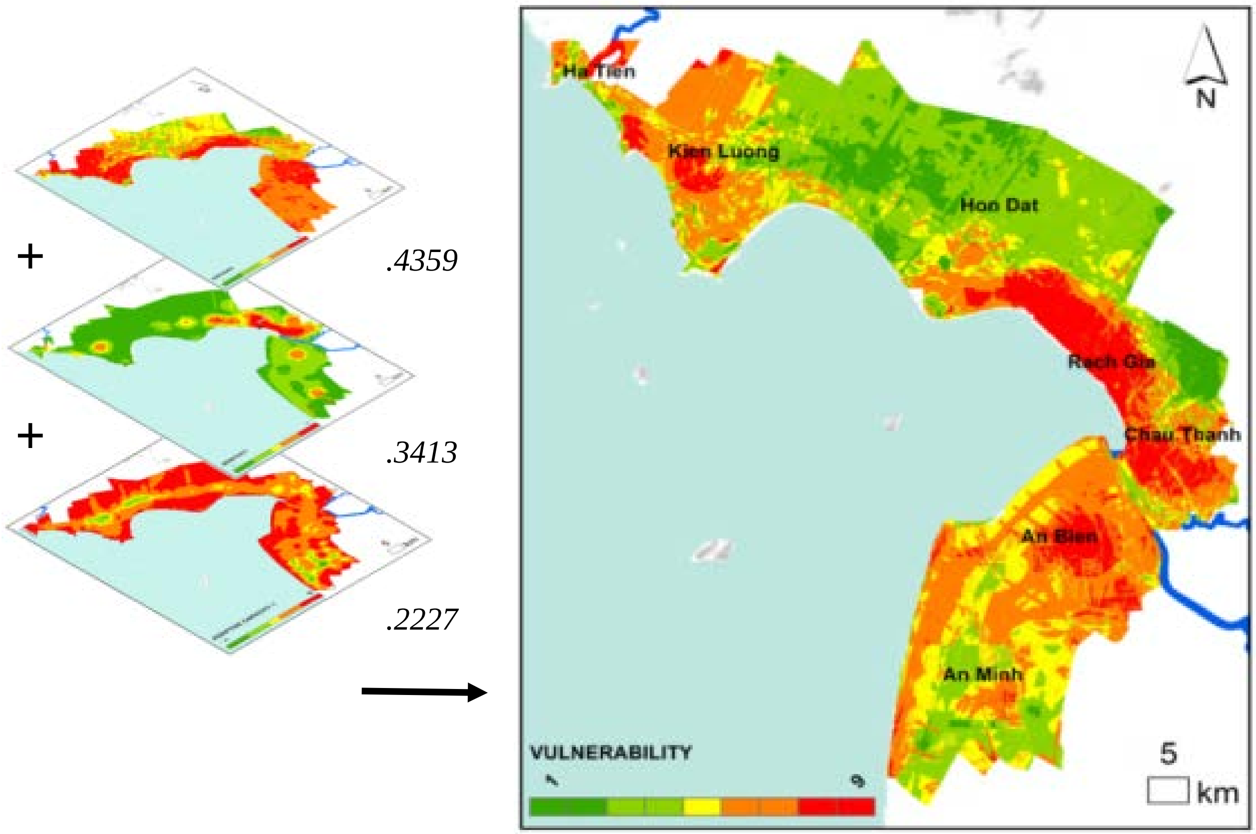
[Eigenvector of largest Eigenvalue]
0.8741
0.4857

[criteria weights]
0.6428 (k7_6irr_re)
0.3572 (k7_ rd5000re1)

[consistency ratio CR]
0
(Revision of preference values is recommended if CR > 0.1)

Appendix 23 Three components obtained within district level: a) exposure, b) sensitivity, and c) adaptive capacity were aggregated in order to represent evaluating outcome of coastal vulnerability assessment.

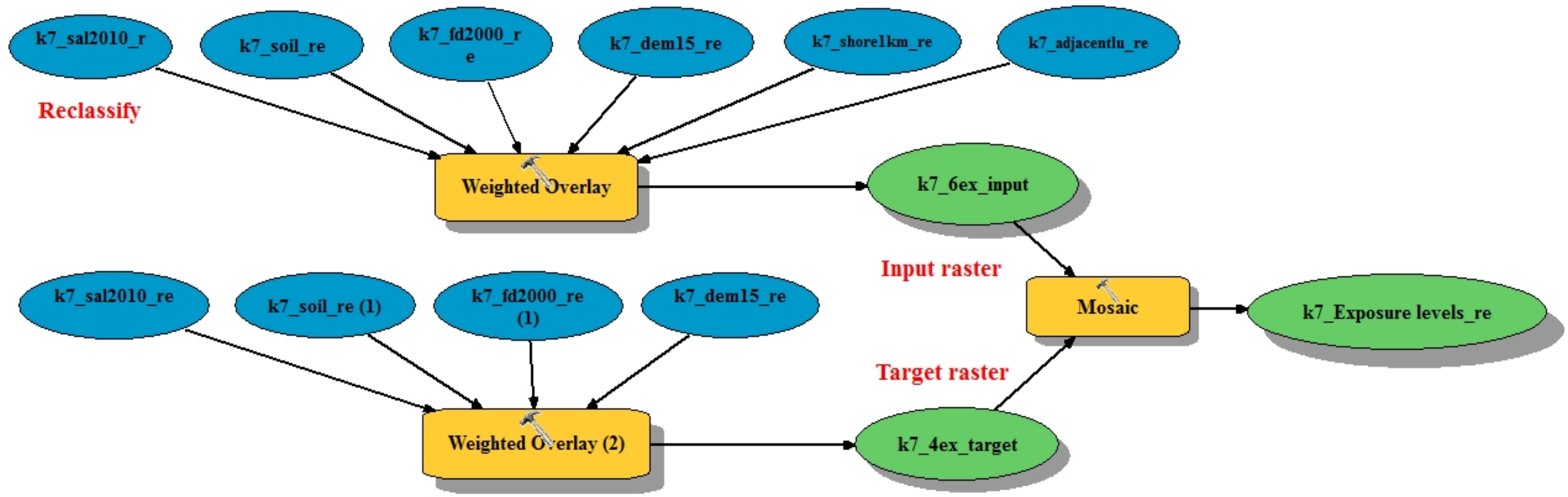




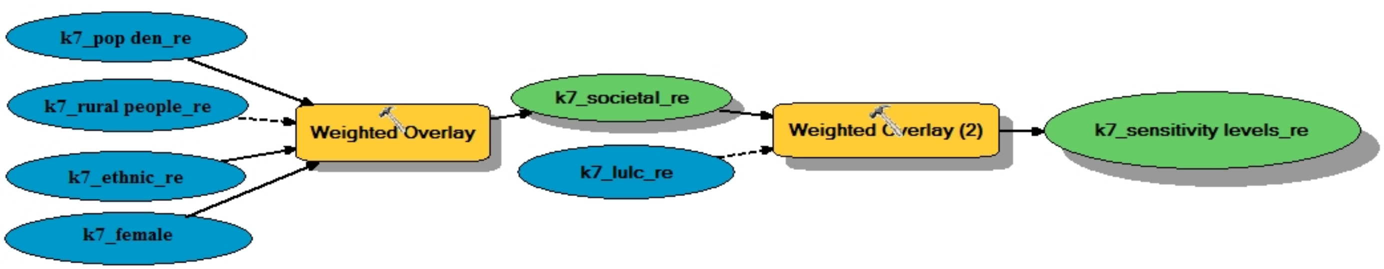
Note: see in detail for representing exposure a) in Appendix 11d, sensitivity b) in Appendix 17c, and adaptive capacity c) in Appendix 22.

Appendix 24 The weighted overlay tool used in ArcGIS ModelBuilders.

Appendix 24a.1 The weighted overlay tool used in ArcGIS ModelBuilders to generate the exposure component.

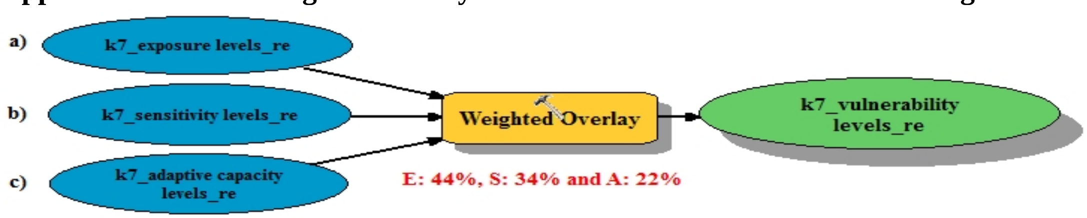


Appendix 24a.2 The weighted overlay tool used in ArcGIS ModelBuilders to generate the sensitivity component.

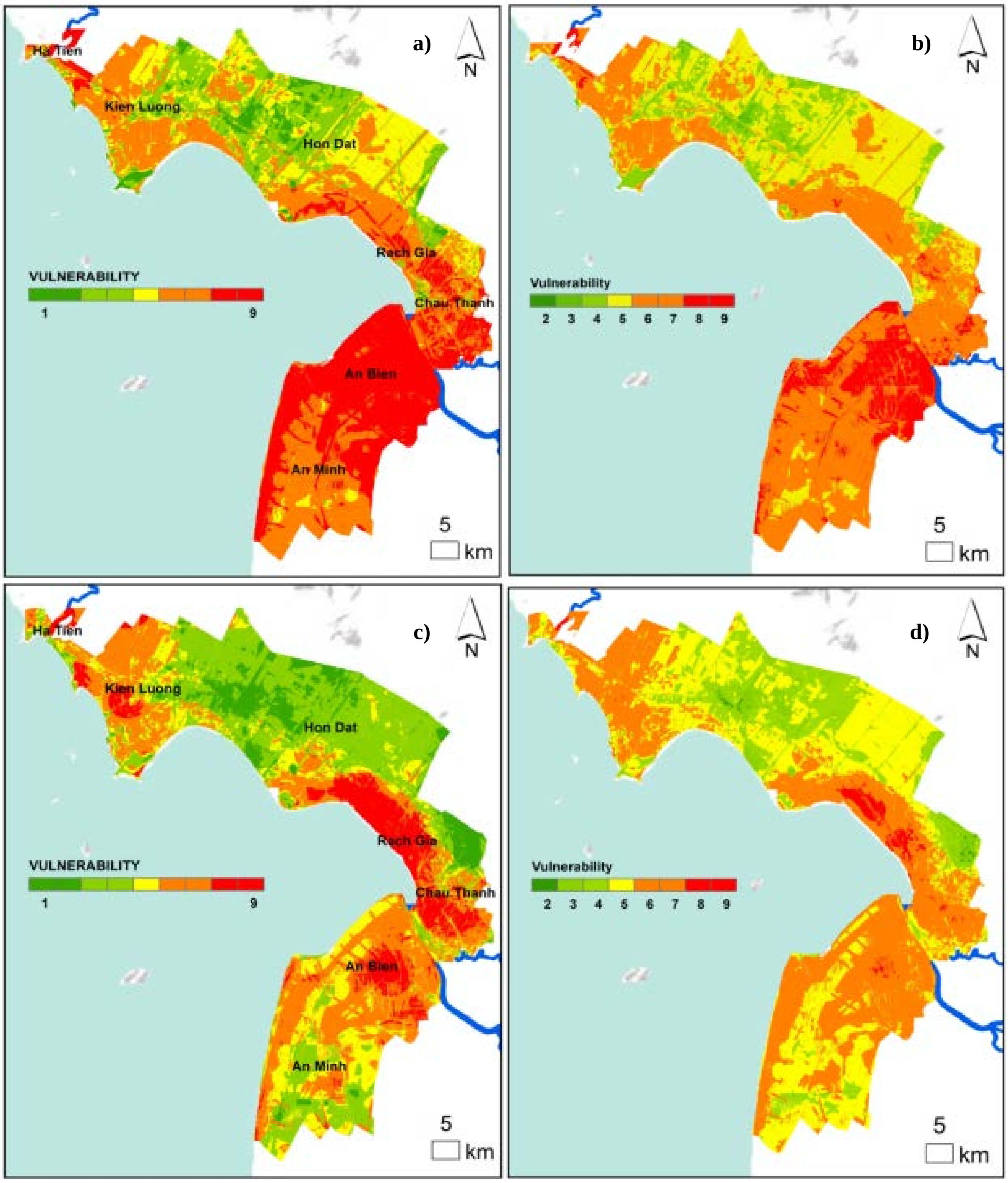


Appendix 24a.3 The weighted overlay tool used in ArcGIS ModelBuilders to generate the adaptive capacity component.

Appendix 24a.4 The weighted overlay tool used in ArcGIS ModelBuilders to generate the final vulnerability.



Appendix 24b Mapping of the vulnerability outcomes: the final vulnerability at an entire district a) obtained from AHP and b) obtained from the weighted overlay tool; the vulnerability within district level c) obtained from AHP and d) obtained from the weighted overlay tool.



Note: When the weighted overlay in ModelBuilder was used (% influence), the relative weight of the layer exposure was 44%, those in sensitivity was 34%, and those in adaptive capacity was 22%, based on **Equation 6.6 in chapter 6: $\mathbf{Layer_V}$ = 0.4359** * $layer_E$ + **0.3413** * $layer_S$ + **0.2227** * $layer_A$ (in which, V: vulnerability, E: exposure, S: sensitivity, and A: adaptive capacity).