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Population accessibility to radiotherapy services in New South Wales Region of Australia: a methodological contribution

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Population Accessibility to Radiotherapy Services in New South Wales Region of Australia: a methodological contribution

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Abstract. This paper proposes an integrated modelling process to assess the population accessibility to radiotherapy treatment services in future based on future cancer incidence and road network-based accessibility. Previous research efforts assessed travel distance/time barriers affecting access to cancer treatment services, as well as epidemiological studies that showed that cancer incidence rates vary with population demography. It is established that travel distances to treatment centres and demographic profiles of the accessible regions greatly influence the demand for cancer radiotherapy (RT) services. However, an integrated service planning approach that combines spatially-explicit cancer incidence projections, and the RT services accessibility based on patient road network have never been attempted. This research work presents this novel methodology for the accessibility assessment of RT services and demonstrates its viability by modelling New South Wales (NSW) cancer incidence rates for different age-sex groups based on observed cancer incidence trends; estimating the road network-based access to current NSW treatment centres; and, projecting the demand for RT services in New South Wales, Australia from year 2011 to 2026.

1. Introduction

Cancer control is a health priority in almost every national jurisdiction. Cancer is estimated to be the leading cause of burden of disease in Australia in 2010, accounting for 19% of the total burden [1]. This becomes increasingly important as life expectancy continues to grow; the proportion of elderly people in the population will steadily increase over the next decades [2]. Therefore, it is expected that the number of cancer cases will continue to grow, as the 'baby boomers' ageing population is entering the high incidence period.

Beyond demographic influences, other factors like socio-economic status and ethnicity have also an effect on cancer incidence [2]. Furthermore, geographical variations also occur among the rate of treatment and survival from cancer [3-4]. As the number and diversity of cancer cases increase, the pressure on specialised treatment services will increase as well, calling for better planning and allocation of healthcare resources, particularly at the regional level.

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Radiotherapy (RT) is an essential cancer therapy whether aimed at cure or palliation. The Collaboration for Cancer Outcomes Research and Evaluation (CCORE) literature-based findings were used by the Radiation Oncology Reform Implementation Committee (RORIC) to estimate that 52.3% of all diagnosed cancer cases in Australia would benefit from radiotherapy at some point after diagnosis. The Australian state health department for New South Wales (NSW) uses this estimate for planning their RT services [5-7].

Similar to other jurisdictions, NSW studies of access to RT services have established that utilization rates are well below this optimal number [8-11] clearly demonstrating the existence of barriers to accessibility to existing RT services. Currently, only 38% of cancer sufferers receive radiotherapy at some point after the initial detection [2,12-13] indicating that ~14% of cancer sufferers, who would benefit from RT services, miss the opportunity for improved cancer control and appropriate evidence-based management [2,12,14].

Various studies have examined the effect of geographical accessibility, based on travel times/distances as proxy to travel effort, on uptake of RT based cancer treatment. For example, Madelaine et al. [15] reported lower treatment rates for rural lung cancer patients in France. Punglia et al. [16] found that increasing distance to the nearest radiotherapy centre was associated with a decreasing likelihood of receiving post-mastectomy radiation therapy. Greenberg et al., [17] asserted that lung cancer patients living at greater straight line distance from a specialist cancer centre, in rural USA, were significantly more likely to undergo surgery but were less likely to receive radiotherapy or chemotherapy than closer patients. Athas et al. [11] also found that breast cancer patients living further than 75 miles from a radiotherapy services centre were significantly less likely to receive radiotherapy than those living closer. It is possible that the deterring effect of transportation may be even more pronounced in patients who are faced with weeks of daily outpatient treatment, as is common for radiation therapy.

The planning of efficient and accessible RT services for cancer care at regional level requires appropriate estimates of current and future cancer demand based on the spatial distribution and evolution of various socio-demographic groups, spatial accessibility based on transport network and probabilities of re-treatment. In this study, we will develop a modelling tool which can be systematically used for planning of radiotherapy services.

2. Methodology for planning of radiotherapy services

The proposed methodology for modelling and predicting the future cancer incidences and their accessibility to existing RT centres in the state involves datasets such as Australian Institute of Health and Welfare (AIHW) cancer incidence data, Australian Bureau of Statistics (ABS) population projection dataset, residential areas dataset, road network dataset, and data about the existing radiotherapy (RT) centres.

2.1. Datasets used in the proposed methodology

2.1.1. AIHW cancer incidence dataset

The AIHW cancer incidence dataset [18] provides the information about age group and sex specific cancer rates for all and specific cancer types in Australia. The major source of this data comes from the Australian Cancer Database (ACD) which contains records of all the primary, malignant cancers (except basal cell and squamous cell carcinomas of the skin) diagnosed in Australia since 1982. The age-specific rates (ASR) for cancer in males and females, in past years, are used to model and predict the cancer incidences in the state.

2.1.2. ABS population projection dataset

The population projection data prepared by the ABS to permit the Australian Government Department of Social Services to plan and evaluate aged care. These projections are based on the past trends (over a decade) of fertility, mortality, and migration trends, using the cohort-component method, where the base population is projected into the future year annually by estimating the effect of births, deaths and migration within each age-sex group according to the specified fertility, mortality and migration assumptions. The population projections cover the period from 2012 to 2026, using the 2011 ABS census year as a base. More information about this dataset is presented elsewhere [19].

2.1.3. Residential areas dataset

A digital spatial dataset of the residential areas in NSW (Figure 2) is extracted from the catchment-scale land use maps collated by the Australian Collaborative Land Use and Management Program (ACLUMP), which is established to promote the development of nationally consistent land use and land management practices information for Australia.

2.1.4. Road network dataset

The road network of NSW was downloaded from the most up-to-date OpenStreetMap (OSM) database, using Quantum GIS software [21]. OpenStreetMap is a crowd-sourced initiative to collect and map roads, trails, and points of interest, with an ultimate aim of building a geographic database that contains every single feature on the planet [22]. OSM data was selected for this study as it is a readily available and open data source with sufficient positional accuracy [23].

2.1.5. Existing radiotherapy (RT) centres

The data about the existing RT treatment facilities is accessed from Department of Health, Australia. DoH [24] provides publically available information about radiation therapy services including accommodation and travel schemes, facility locations and treatment options. The facility locations for RT centres were used for estimating the RT treatment accessible regions for future cancer incidences.

2.2. Methods

2.2.1. Age specific rate (ASR) for cancer incidence modelling

Ordinary least squares linear regression is used to model the past trend of the cancer incidence. The linear regression models have been developed for each age-sex group. Age specific rates (ASR) from AIHW dataset, for cancer incidences for 10 years (2000-2009), have been used to estimate the coefficients of the linear regression model. Time in years is used as a variable to determine the ASR in each age-sex group.

The confidence level is set to be 95% for the two sided hypothesis test. If the ASR model for an age-sex model is found significant, then the rate is estimated based on the regression model. Otherwise, mean of ASR (for years 2000 – 2009) for a particular age-sex group is used for prediction.

2.2.2. Predicting the cancer cases

Once the regression models for the cancer incidence is obtained for each age-sex group, they are then used together with the ABS population projections dataset to estimate the future cancer cases in the study area. The ABS population dataset is aggregated into a contingency table having attributes such as *age group*, *sex*, *geographical area*, and *number of people at risk*. This data table is then used together with the predicted ASR for each year (derived from section 2.2.1) to produce *cancer cases* in different age-sex group in different local government areas (LGAs). The result of this analysis provides cancer cases distributed in various LGAs in future. Once the number of cancer cases for future years are identified, it can be used to estimate the future radiotherapy demand/workload.

2.2.3. Travel distance modelling and the estimation of accessible residential area

Following the literature that supports a strong relationship between travel distance and uptake rates (as discussed in Section 1) we calculated constant driving distance polygons using the popular open source software 'pgRouting' [25], taking treatment centres as points of origin.

Routing functions provided by pgRouting were implemented as an extension to the open source PostgreSQL/PostGIS geospatial database [26], and the OSM road network of NSW was imported into PostgreSQL/PostGIS as a pgRouting-enabled (i.e. routable) network dataset. A custom function that leverages the default pgRouting function 'pgr_drivingDistance' was used to loop through all treatment centres, thereby calculating constant driving distance polygons for all centres and for several distances. The function 'pgr_drivingDistance' utilises Dijkstra shortest path solution to calculate constant polygons [25]. When a polygon calculated for a large driving distance encompasses a polygon for a smaller driving distance, the area of the smaller polygon is then erased from the larger polygon to construct a ring for a range of driving distances (e.g. from 50km to 100km).

Considering the fact that dwellings are not uniformly distributed in space, the digital dataset of the residential areas of NSW is used to estimate the fraction of the population that live in a particular LGA within a given distance ring.

2.2.4. Radiotherapy based treatment demand estimation

The predicted cancer cases and ratios of LGA within each distance bands were used together with the radiotherapy rates to estimate the future demand for RT services. The RT rates were chosen based on the distance bands provided in Gabriel et al. [27]. Furthermore, Delaney et al. [28] have summarised the overall optimal radiotherapy utilization rate for all registered cancers in Australia. They summarised the recommended optimal radiotherapy utilisation rates for individual cancers such as skin, breast, lung, gastrointestinal, genitourinary and others. Evidence for radiotherapy based treatments such as systematic review of relevant randomised studies, randomised/controlled trials, and case series, were used in modelling decision trees for determining optimal radiotherapy rates. For more information about these rates and methodology see [28]. The optimal RT rates varied from 0% in case of liver cancer patients and 92% for patients with central nervous system tumors. The overall estimate of optimal radiotherapy utilisation rate was estimated to be 52.3% of all the notifiable cancer cases in Australia. Furthermore, an additional 23% of the cancer patients who have already received RT will require retreatment according to the SSDB report [29]. This means that an apparent 64.33% (52.3% + 0.23×52.3%) of the total cancer patients would need radiotherapy treatments in future. We have used this estimated rate of 64.33% for determining the optimal RT demand for the future year.

All the methods in this section are coded in R, which is an open source software environment for statistical computing and graphics using open source R libraries such as *maptools*, *ggplot2*, *plyr*, *rgeos, rgdal, sp, RColorBrewer* for this methodology development and data analysis.

3. Results and Discussion

This study estimates a spatially explicit demand and accessibility for radiotherapy services in the NSW state of Australia using the methodology described above. The choice of the NSW was justified by the accurate data currently available for NSW and a well-defined geographical area that is known to mirror average demographic distributions in Australia.

Ordinary least squares linear regression for each age-sex group were conducted on the past cancer incidence data from AIHW. In females, the incidence rates for age groups '*55-59 yrs'*, *'65-69 yrs*', and '*80-84 yrs*' were found significant at 95% confidence interval. In case of males, the incidence rates for age groups '*45-49 yrs'*, *'50-54 yrs'*, *'55-59 yrs'*, *'60-64 yrs'*, *'65-69 yrs'*, and '*70-74 yrs*' were found significant at 95% confidence interval. Figure 4 illustrates the results from linear regression analysis (all age groups combined) of cancer incidences projected in future and its comparison with the past incidence rates. In Figure 1, the overall rates for cancer incidence in females are not increasing compared to the incidences in males. The dotted lines in Figure 1 represent the results of the model and the solid lines represent the actual rates observed. The results of the ASR prediction model for future years were then applied to the ABS population projections.

The NSW population data provided by the ABS was used in this study. It is estimated that the population will grow significantly in future. However, the growth in population in different age groups and sex varies across NSW. Figure 2 illustrates the growth of population in different age-sex group in year 2011 and 2026. In year 2026, number of individuals in age groups with a higher cancer incidence (i.e., above 50 years) will be larger than 2011 for both females and males. There will be more aged people living in year 2026 in NSW, and because of cancer incidence in the aged population sub-groups, more cancer cases.

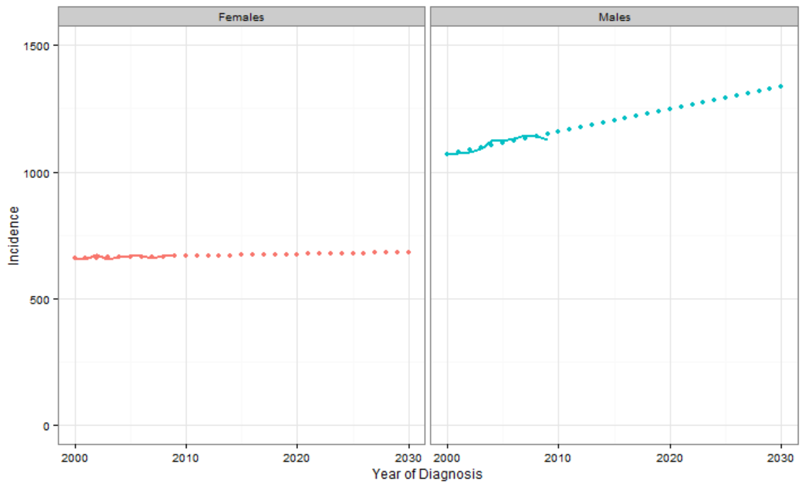


Figure 1. Predicted (points) and observed (solid line) incidence rates (per 100,000) for all cancers in males and females in Australia

Figures 3a and 3b illustrate the cancer incidences (cancer cases per 100,000 individuals) for year 2011 (Figure 3a) and future year 2026 (Figure 3b). The cancer incidences in all the local government area (LGA) of NSW (total of 154) are based on the age-sex specific rates obtained based on ordinary least square linear regression modelling (p<0.05, see Figure 1) and future population estimates data (see Figure 2). In year 2011, the average cancer incidence at LGA level is approximately 617 per 100,000 individuals. However, it increases to 812 (approx.) per 100,000 individuals for future year 2026. Based on the spatial distribution of cancer incidences in year 2011 and 2026, which suggests more cancer cases in the coastal, mid-eastern and southern LGAs of NSW, planning of radiotherapy services for these areas is important.

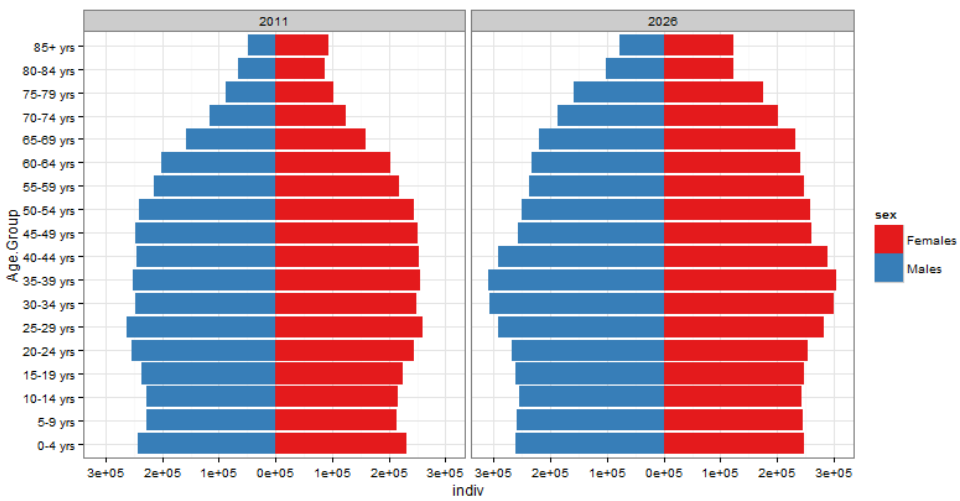
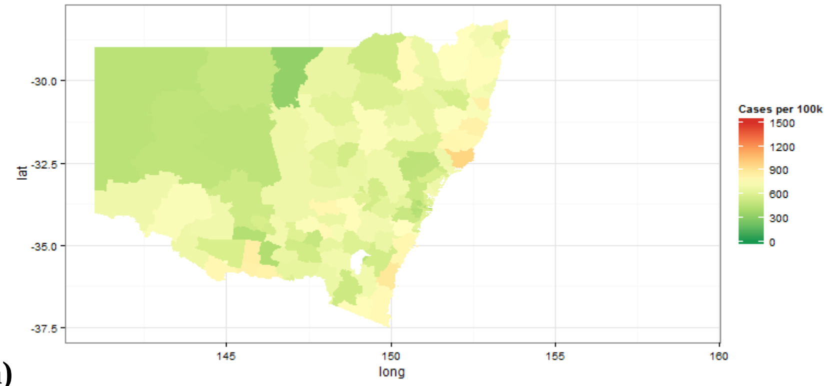
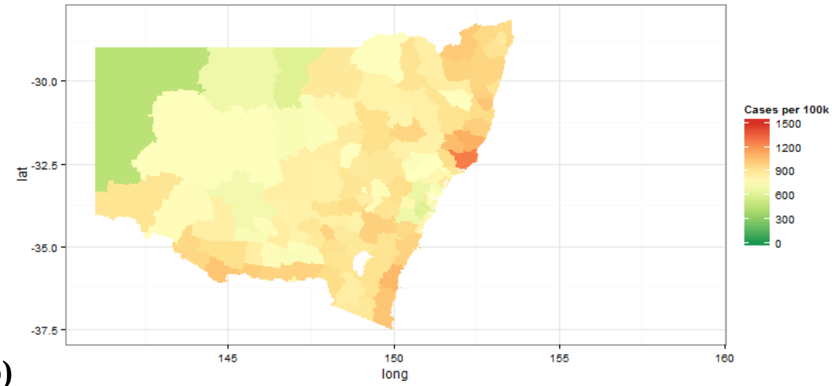


Figure 2. Age structure of NSW population in years 2011 and 2026



(a)



(b)

Figure 3. Overall cancer incidences in year 2011 (a) and 2026 (b) in NSW state of Australia

Figure 4 depicts driving distance polygons or the accessible regions considering all radiotherapy centres as trip origins. We have included existing radiotherapy centres in the NSW and also the nearby centres from the two bordering states, Victoria and Queensland. This is done to account for patient leakage in to those centres from NSW. As described in Section 2.2.3, for each LGA the fraction of population living in each distance band is estimated. Table 1 shows these calculated fractions for two LGAs as an example.

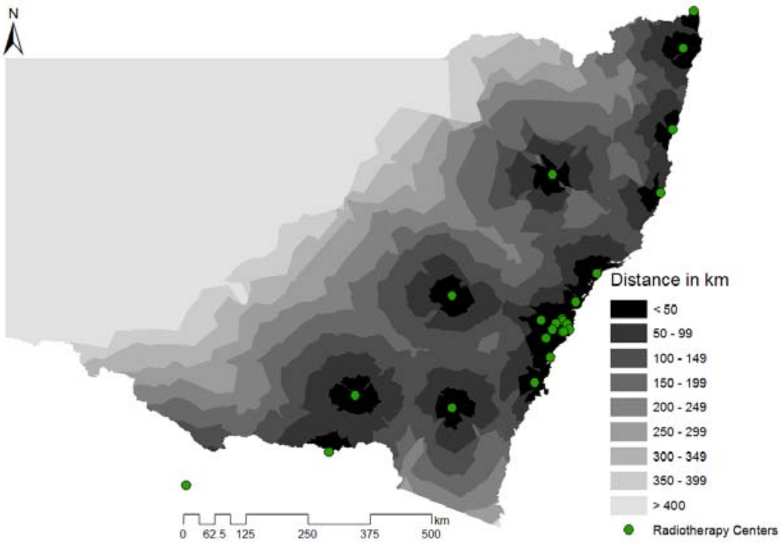


Figure 4. Constant driving distance polygons from radiotherapy centres

Table 1. Estimated fractions of residential population living in constant driving distance bands from radiotherapy centres

LGA	Distance band	Fraction of population
Hawkesbury	< 50	0.88
Hawkesbury	50 - 99	0.11
Hawkesbury	100 - 149	0.01
Wingecarribee	< 50	0.15
Wingecarribee	50 - 99	0.85

The ratios for each LGA in the NSW (illustrated in Table 1) were used together with the cancer cases for respective LGA (illustrated in Figure 3) to estimate the total number of cancer patients residing in each distance band. The cancer cases residing in each distance band can be used for planning and locating new radiotherapy centres.

Table 2 illustrates the demand for the RT services based on the above mentioned modelling methods. RT demand at the current service level is based on the RT rates by road distance estimated in Gabriel et al. (2012). However, the optimal RT demand is estimated by using cancer incidence number and optimal RT utilisation rates (64.33%).

Table 2: RT demand from year 2011 to 2026

Year	RT Demand at current service level	Optimal RT demand based on evidence
2011	10898	21665
2016	12602	25056
2021	14472	28755
2026	16452	32651

4. Conclusion

The treatment of cancer, which touches a large proportion of the community, represents a significant health and economic burden in Australia. Nearly one in two men and one in three women have a lifetime risk of being diagnosed with cancer in NSW. Radiotherapy (RT) based cancer treatments are often integral to achieving permanent or long-term remission. There will be large demand for RT services for cancer patients in NSW in next ten years. However, decision on new LINAC units usually take a long time to be made, resulting in local congestion of services or unreasonable travel time for patients, with some individuals opting out of RT treatment. Thus, there is pressing need to estimate patient's accessibility to respective treatment centres in future. This can also help to rationally justify the placement of new radiotherapy centres to meet the future RT demand. This study makes a unique contribution to the policy debate on accessibility to RT treatment centres through the establishment of an integrated modelling approach. This study marks an attempt at informing the government about maximising accessibility to RT centres to meet future cancer patient demand.

The demonstrated generic methodology includes cancer incidence predictive modelling to estimate the cancer cases residing within different travel distance bands from the RT centres, and is easily applied to the NSW circumstance. The methods described in this research study can be applied in other jurisdictions with availability of the necessary data.

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