Trace metal contamination of soils and sediments in the Port Kembla area, New South Wales, Australia

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NOTE

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Chapter 1

Introduction to this Study

1.1 Sediment and soil contamination

One of the inevitable consequences of urban, rural and industrial development is pollution of adjacent soils and lagoonal systems. There are many different types and sources for pollutants. Rural and agricultural activities are main sources for phosphorus and nitrogen while trace metals often come from urban and industrial practices, like base-metal refining and metallurgical processing (Chenhall et al., 2001). Although some natural phenomena such as flood cycles can increase sediment influx, anthropogenic activities like initial deforestation and clearing of the catchment causes increased rates of erosion and transportation of sediments and higher sedimentation rates (Chenhall et al., 1995). Both natural (lithogenic) and anthropogenic sources, which may be of point or non-point (diffuse) origin, account for the accumulation of trace metals in estuarine and lagoonal sediments. In this way, factors like lithology and surface processes operating in the catchment control natural or background concentrations of trace metals in both soils and estuarine deposits (Chenhall et al., 2004).

In recent decades, soil investigations have also ranged from problems relating to nutrient deficiency to research on soil metal chemistry and its environmental impacts affiliated with extreme heavy metal inputs from different anthropogenic sources (Pacheko et al., 2009, in prep). It is well known that areas surrounding many industrial complexes are particularly liable to contain significant levels of toxic metals, which are derived from the discharge of poorly treated liquid effluents to land or come from atmospheric fallout of metal emissions from smelters (Krishna and Govil, 2004; Martley et al., 2004). Considering a world-wide scale, the potential for increasing the quantity of anthropogenic toxic metals (e.g., Pb, As, Hg) into the food chain is one of the unfavourable and harmful environmental impacts of trace metal contamination of sediments and the water column in any terrestrial, riverine, lagoonal and marine settings. Entrance of toxic metals into the food chain may cause serious human diseases such as brain damage, mental deficiency and different types of cancer (Chenhall et al., 2001).
Estuarine and coastal lagoonal sediments are known as a sink and subsequent source for anthropogenic pollutants, including trace metals (Arakel, 1995; Kenish, 1997). Humans often use these lagoonal systems as a place for intentional or inadvertent waste disposal, neglecting the fact that the discharged contaminants will also be diluted and scattered into adjacent open marine settings (Chenhall et al., 2004). Also due to the potential health risks trace elements pose to humans, great concern has been expressed about the impact of elements associated with industrial activities, especially smelting, upon residential and agricultural soils that act as growth media of plants (Fernandez et al., 2001). In this regard, it has been argued that total metal content in soils is not an appropriate measure to assess their bioavailability, and not a very useful tool to detect potential risks from soil and sediment contamination (Meers et al., 2007).

The bioavailability of a chemical in the soil has been determined as the fraction of the total contaminant in the interstitial pore water and soil particles which is available to the receptor organism. Bioavailability of metals in soils can be investigated using chemical extraction tests which include single extraction and sequential fractionation (Bolan et al., 2008). Different single extraction methods have been widely used to assess bioavailability and toxicity of pollutants, especially trace metals in soils. Although these methods do not always demonstrate plant uptake exactly, they are suitable for the estimation of phytoavailability. The extractants used are classified into the following groups: acids (HCl, HNO₃, aqua regia), chelating agents (EDTA, DTPA), buffered salt solutions (NH₄OAc) and unbuffered salt solutions (CaCl₂, MgCl₂, NaNO₃ and NH₄NO₃) (Takeda et al., 2006). Among these extractants, dilute HCl and EDTA are commonly used as indicators of trace-metal bioavailability in soil and sediments (Batley, 1987; Ying et al., 1992; Birch et al., 2000). Dilute HCl removes loosely bonded and adsorbed metal participated salts without any significant attack on the detrital lattice and has been used to simulate the effects of gastric juices in the gut of a detritus feeder (Bradshaw et al., 1974; Agemian and Chau, 1977; Sutherland et al., 2001). EDTA also releases adsorbed, precipitated and complexed metals, which are usually considered as being potentially bioavailable in soils and sediments. Although the problem of post-extraction readsorption has been a concern for some extractants, EDTA is the one reagent which retains the extracted metals in solution (Ying et al., 1992).
1.2 Study area

1.2.1 Location and Strategy:
The study area is based around the Port Kembla industrial complex located in the Illawarra region about 75 km south of Sydney, 5 km south of Wollongong on the NSW coast (Figure 1.1). The basic strategy of this study is to assess the degree of trace metal pollution in residential and estuarine areas adjacent to the industrial complex.

1.2.2 Settlement history of the catchment:
The Illawarra catchment was first settled in 1817 and since then about 47% and 23% of the catchment has been converted to agricultural and urban purposes, respectively (Chenhall et al., 2001). Smelting started in the area in 1896 at a site near Kanahooka Point, but since 1910 the northern hinterland of the lagoon has become the location of the diversified Port Kembla industrial complex comprising an integrated steelworks, a copper refining and smelting plant (decommissioned in August 2003), coal and grain handling facilities and chemical fertilizer works (Chenhall et al., 2001). The coal fired Tallawarra Power Station, which was located on the western foreshore of the lagoon and operated from 1954 to 1989, was demolished in the second half of the 1990s. It has been replaced by a modern gas-fired power station.

Lake Illawarra is considered to be important because it supports commercial fish and prawn production, while it is also a major tourist attraction and provides recreational fishing and boating. In previous studies (Roy and Peat, 1975; Ellis and Kanamori, 1977; Chenhall et al., 1994; Chiaradia et al., 1997; and Payne et al., 1997), environmental issues like water and sediment pollution by trace metals and nutrients, and also high sedimentation rates, have been identified as serious problems in the lagoon. Atmospheric deposition of emissions from the copper smelter and the integrated steelworks facility adjacent to the catchment have been recognized as a major source of trace metals to the lake (Gillis and Birch, 2006).
Figure 1.1: Location of the study area.
1.2.3 Soil samples from Port Kembla:
Trace metal pollution in soils caused by atmospheric fallout of metal emissions from industrial activities, especially smelters, is well known. Aside from investigations around the Port Pirie smelter (Cartwright et al., 1976), there is limited published information on contamination of soil from emissions associated with Australian smelters. Although most studies of smelter emissions and soils have investigated the soils in detail, only limited research has been done to relate the variations in metal concentrations in soils to the steelworks, copper smelter, fertilizer plant, historical power stations and Kanahooka base metal smelter. The copper smelter has been considered as the major source of metal contamination to the surrounding area (State Pollution Control Commission of New South Wales, SPCC, 1986).
Past efforts on metal contamination in the area were mainly on sediments from Lake Illawarra (Roy and Peat, 1974; Ellis and Kanamorie, 1977; Chenhall et al., 1994, 2001 and 2004; Gillis and Birch, 2006). In the current study, trace metal impacts on soils will be investigated using samples from the southern suburbs of Wollongong and Port Kembla in the Illawarra region. Port Kembla is bounded to the east by the Pacific Ocean, to the west by the Illawarra Escarpment, to the north by the city of Wollongong, and to the south by Lake Illawarra (Figure 1.1).

1.2.4 Sediment samples from Lake Illawarra:
Lake Illawarra is an almost land-locked, shallow, saline coastal lagoon located on the New South Wales coast, 75 km south of Sydney (Figure 1.1). The lagoon is approximately 35 km² in area with an average depth 1.9 m and a mean salinity of about 32%. Table 1.1 denotes general features of the lake, obtained from previous studies (e.g., Payne, 1994).
During low stands of sea-level, erosion of the Late Permian Broughton Formation and earlier Quaternary deposits of the Shoalhaven Group formed the depression now occupied by the lagoon (Roy and Peat, 1974; Yassini and Jones, 1987; Payne, 1994). The lagoon had its maximum extent about 7500 years ago after the last rise in sea level because of the growth of a coastal sand barrier across the eastern part of a shallow embayment and subsequent flooding of the enclosed river plain during the peak of the Holocene marine transgression (Chenhall et al., 1995, 2001; Sloss et al., 2004). The lagoon is normally
connected to the ocean by a single, shallow (< 2 m), narrow (20 m) sinuous tidal channel 2.4 km in length (Chenhall et al., 2001). On several occasions in the past 50 years, complete closure of the lagoon occurred because of heavy shoaling at its mouth (Chenhall et al., 1994; Payne, 1994). The lagoon, in common with many other estuarine lagoons along the eastern coast of the NSW, is characterized by a micro-tidal environment with diurnal fluctuations in the order of 2-3% of the tidal range measured in the adjacent open ocean (Eliot et al., 1976). The perennial rivers Mullet Creek, Duck Creek and Macquarie Rivulet are sourced in the steep Illawarra escarpment 9-14 km west of the lagoon. Several smaller, local creeks also deposit sediment into this shallow lagoon. Deltas are associated with all these creeks, the largest and most noticeable of which is the active birds-foot delta of Macquarie Rivulet in the southwest corner of the lagoon (Chenhall et al., 1995, 2001). Wind-induced waves and currents are directed towards the southwest in summer and east in winter and act as additional factors to transport sediments within the lagoon (Payne et al., 1997).

Lake Illawarra features:

Table 1.1: General features of Lake Illawarra (Payne, 1994).
1.3 Climate of the region:

The southern coast of Australia shows a moderate climate generally warm to hot temperatures during summer and cool temperatures during winter. The southern coast of Australia has been classified as a high energy coast with a generally deep-water wave climate. The wave regime is dominantly southerly and southeasterly, with a mean wave height of 1.5 m and a mean period of 10 s. Due to low pressure systems off the southern coast of the NSW and in the Tasman Sea, severe weather conditions occur periodically along the coast. The prevalence of the southeasterly wind and wave regime has resulted in a 1200 km long-shore transport system moving sediment northward to Fraser Island in Queensland. The major ocean current is the East Australia Current, and its eddies, which influences southward water and sediment movement on the outer parts of the southeastern shelf of Australia significantly. Furthermore, the tidal range along the NSW coast is microtidal, with an average spring tide between 1.1 and 1.3 m (Haredy, 2003).

Table 1.2: Seasonal wind directions and percentage of time that winds originate from the two quadrants in the Illawarra regional area (from Smith, 2001).

<table>
<thead>
<tr>
<th>Season</th>
<th>Quadrant of origin</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N/NE/E</td>
<td>S/SW/W</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>44%</td>
<td>41%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>51%</td>
<td>32%</td>
<td>83%</td>
<td></td>
</tr>
<tr>
<td>Autumn</td>
<td>40%</td>
<td>46%</td>
<td>86%</td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>24%</td>
<td>62%</td>
<td>86%</td>
<td></td>
</tr>
</tbody>
</table>

Note: Total = Percentage of time/season that wind originates from the 2 quadrants.

As illustrated in Table 1.2, 85% of total winds in the Illawarra area originate from the NE and SW predominant wind directional quadrants (Smith, 2001).

Figures 1.2 and 1.3 illustrate the wind directions and intensity for the months of December and June respectively.
Figure 1.2: Illustrates wind direction and intensity for December (summer) based on observations taken between 10/2006 - 12/2008 daily from 7am to 7pm local time.

Source: www.windfinder.com

Figure 1.3: Illustrates wind direction and intensity for June (winter) based on observations taken between 10/2006 - 12/2008 daily from 7am to 7pm local time.

Source: www.windfinder.com
1.4 Geology of the area:
The geology of northern Lake Illawarra is distinguished by Quaternary alluvium along the foreshore of the lake, specifically in the northwest where Hooka and Mullet Creeks have incised into earlier alluvial floodplain material. Also the low-lying topography around Berkeley and Warrawong are characterized by Quaternary alluvium. The intermediate to mid slopes of the northern catchment area are characterized by litho-felspathic quartz lithic and minor quartzose sandstone of the upper Broughton Formation that is a part of the Shoalhaven Group. The upper parts of the northern catchment are dominated by dark grey mafic latite, which ranges from aphanitic and vesicular to porphyritic in texture, and forms part of the Late Permian Dapto Latite Member, in the Shoalhaven Group. In the upper parts of the northwestern catchment there are some small outcrops of interbedded andesitic sandstone, coal, carbonaceous mudrock and mudrock associated with the Pheasants Nest Formation and Unanderra Coal Member, with small outcrops of fine-grained latite (Berkeley Latite Member) stratigraphically above. These upper units are part of the Illawarra Coal Measures formed during the Late Permian (Smith, 2001). The background geology has a direct influence on the type of soil and the natural content of trace metals present within the soil.

1.5 Aims of this Project:
The Port Kembla area has been significantly impacted by the operations of heavy industries over the past 100 years. Previous studies have assessed aspects of the changes to environmental concentrations of trace elements, but a full assessment has not been completed. This project will add to our knowledge by:

1) establishing trace metal concentration profiles for the lagoon sediments and soils from the area;
2) estimating the concentration of trace metals that can be attributed to anthropogenic inputs;
3) establishing relationships between sediment and soil grain size and trace metal concentrations; and
4) assessing for bioavailability of trace metals using HCl and EDTA extractants.