CHAPTER 6

GENERAL DISCUSSION AND CONCLUSION
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The importance of undertaking toxic heavy metal studies has been underlined by Nriagu (1988), who observed that developing countries (including India) have become major producers of non-ferrous metals, with many industries tending to be dirtier, and employing less stringent environmental control measures as compared with the developed countries. He also argued that populations in developing countries are likely to be more susceptible to environmental metal pollutants as a result of: i) the high population density and poor hygienic conditions in the crowded cities, ii) the preponderance of the groups considered to be most at risk, notably children and pregnant women, iii) poor nutritional and health status, and iv) consumption of high proportion of foods grown locally in metal contaminated areas. It is also observed that other endemic health problems may also influence the course and severity of metal toxicity in the developing countries.

The aim of the present study was to investigate the distribution and chemical fractionation of heavy metals in liquid and solid waste from selected industrial sites in the NCT of Delhi. In addition, since phosphorus poses potential environmental problems and because of its ability to form complexes with metals, studies were carried out to estimate the forms present in the solid waste and bed residues.

In general, there was a wide variation of pH in the wastewater from strongly acidic (pH 2.25) to moderately basic (pH 9.39). The majority of the wastewater samples however, had pH near the neutral range. Jhilmil had more samples in the acidic range compared with the other industrial sites. Low pH was in many cases associated with higher levels of heavy metals. This was to be expected, since low pH often leads to higher dissolution and hence higher mobility and bioavailability of metals. Overall, Jhilmil had higher concentrations of Ni, Cu, Zn, Pb, Mn, Cd, Co and Fe in wastewater compared with the other industrial areas in the study. This was suggestive of the presence of both ferrous and non-ferrous based industries, including Ni, Cu and Zn plating and battery manufacturing activities. There was no significant seasonal variation of heavy metals in wastewater within the individual industrial areas.
The mean annual fluxes of heavy metals showed that Mayapuri discharges the highest proportions of Cr, while Jhilimil generates more Ni, Cu, Zn, Mn and Fe, with Naraina having a somewhat higher levels of Cd in the wastewater. In addition, it was observed that there was anomalously high Ni fluxes in the wastewater of the major canals draining the industrial sites and the Yamuna river water. In view of the comparatively lower levels of Ni in the wastewater and suspended matter within the industrial sites, it was speculated that additional Ni discharge from other industrial sites might be responsible for the high fluxes.

In the same way, it has been well recognized that suspended sediments incorporate metals, attaining 3 to 5 orders of magnitude (Bryan and Langston 1992) compared with the overlaying water column. With such high concentrations, the bioavailability of even a small fraction of the total sediment metal assumes considerable importance, especially in some filter-feeding and burrowing organisms. Also, several metals, including Hg and Pb may be transformed in sediments to organometallic compounds having increased bioavailability and toxicity. The results of the present study indicate that the mean concentration of heavy metals in suspended matter was high compared with the levels in the bed residues. This was to be expected, since suspended matter has a much larger surface area and are therefore more reactive compared with the bed residues.

While the suspended matter from Jhilimil had higher mean concentrations of Cu and Zn, Mayapuri had higher levels of Cr, Mn and Fe and Patparganj had Cd and Ni. This to a large extent reflects on the industrial activities taking place in these areas. Also, there was no significant seasonal variation of heavy metal levels in all the industrial areas. However, Jhilimil exhibited higher metal levels during monsoon and winter compared with the summer. This was not duplicated in the other industrial areas.

The environmental effects and toxicity of heavy metals and metalloids to plants and animals is well documented. The mean concentration range of most of the metals in the solidwaste was between 10mg Kg$^{-1}$ and 10000 mg Kg$^{-1}$, with a few going beyond this mark. There are often no standards that are universally applicable to all situations in all countries, however, the high levels of metals observed in the waste from these industrial areas suggest that there
is a real potential threat to the environment. This was compounded by the sometimes low pH levels observed in some of the waste, which may lead to the dissolution of the metals, thus enhancing their mobility and bioavailability. Haphazard disposal of the solidwaste on roadsides and in some cases, low lying areas and unscientifically engineered landfill sites may result in the leaching of these metals, thus threatening both plant and animal life.

The spatial distribution of heavy metals in the solidwaste showed that Jhilmil had higher mean levels of Cu and Hg, while Naraina had Cd and Zn, and Mayapuri had Pb, Ni, Cr, Fe and Co compared with the other sites. There was however, no significant seasonal variation of heavy metals in all the industrial areas under this study. This was to be expected since the industrial processes within the industrial units are often carried out independent of the seasonal changes. Thus, while the type of waste generated from different industrial units reflect on their individual activities, the nature and quality of the waste may remain basically the same throughout all seasons.

The heavy metals in the solidwaste and bed residues from selected sites in the NCT of Delhi were sequentially extracted in order to estimate the forms in which they were present. The study demonstrated that these metals were mostly associated with the residual phase, which possibly consisted of detrital silicates and perhaps resistant synthetic materials from the industrial processes. It was also noted that in general, the residual fraction in the solidwaste was comparatively higher than in the bed residues.

There was however, evidence of substantial anthropogenic fluxes indicated by the relatively high mean levels and proportions of the potentially mobile forms associated with the water-soluble, exchangeable, carbonate-bound and Fe-Mn oxide fractions. The solidwaste from Jhilmil and Mayapuri had a significant proportion of Cu (6.9 and 4.0%) in the carbonate-bound fraction respectively. On the other hand, there was a substantial amount of exchangeable (2.1%), carbonate (5.1%) and Fe-Mn oxides (5.4%) of Zn in solidwaste from Mayapuri. High levels in these fractions pose a serious threat to plants and animal life in the aquatic and other systems.
In order to estimate the impact of phosphorus, it was necessary to obtain information about the magnitude of flux and its geochemical reactivity within different chemical composition. Thus, five pools of phosphorus were isolated. The mean levels of phosphorus were high and ranged from 2286 to 2958 mg Kg\(^{-1}\) in solidwaste while, 2157 to 4292 mg Kg\(^{-1}\) was in the bed residues. It was also noted that the authigenic carbonate fluoroapatite fraction (Acet-P) was the most dominant fraction both in the solidwaste (39.8-57.8%) and in the bed residues (32.6-46.6%). This fraction consists of the active phosphorus pool that often acts both as a source and sink of phosphate. It has also been reported (Subramanian 1999) to be dominant in the Yamuna river sediments which receives large quantities of urban and industrial effluents from the NCT of Delhi.

As well, the mean exchangeable phosphorus (Exch-P) ranged from 53 to 201 mg Kg\(^{-1}\) in solidwaste and 157 to 606 mg Kg\(^{-1}\) in bed residues. These levels were significantly high and may be indicative of high anthropogenic input from urban, industrial and agricultural sources. Balchand and Nair (1994) also reported similarly high phosphorus levels in recently deposited sediments of a tropical estuary. Fractions associated with Fe and organics in both solidwaste and bed residues were comparatively lower than all other phosphorus phases. The general pattern of distribution was: Acet-P > Det-P > Exch-P > Org-P > Fe-P.

In conclusion, the results presented in this thesis exhibited low pH, high metal levels in wastewater, suspended matter, bed residues and solidwaste. This was indicative of high anthropogenic input of heavy metals from ferrous and non-ferrous metal based industries among others. It was also reflection of the inefficient technologies and processes employed in these industrial sites, giving rise to high waste generation.

Similarly, sequential extraction showed that there were significantly high levels of heavy metals in the potentially mobile and bioavailable non-residual phases that would seriously threaten the aquatic environment and the livelihood of millions of people down stream. It was also observed that there were elevated annual heavy metal fluxes in the wastewater and suspended matter from the selected industrial sites and a few major canals draining the industrial belt of the NCT of Delhi. Indeed, high Ni levels in wastewater and suspended
matter, and the anomalously high annual fluxes from these canals suggest that there may be other sources of discharge apart from those used in the present study. It should also be noted that the study covered 4 sites out of over 28 industrial areas. Thus, in order to build a database, on the heavy metal discharge from the industrial belt of the NCT of Delhi, it would be necessary to critically carry out a systematic study of the remaining sites. This will be useful in the overall assessment of the quantities and the potential threat posed by toxic heavy metals discharged on to the terrestrial and aquatic systems in and around the NCT of Delhi.