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Lead pollution of Dhanmondi Lake in Dhaka

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ABSTRACT: Dhanmondi Lake, which is located in densely populated central Dhaka, has been found to be heavily contaminated with lead. The average lead concentration in the lake water was found to vary from 151 to 210 μg/L during the dry period, and from 30 to 120 μg/L during the wet period. Increased rainfall and surface runoff appears to be responsible for reduced lead concentrations during the wet period. The lead concentration in the bottom sediment was found to vary from 10.7 to 44.7 mg/kg (dry weight), with sediment samples collected from locations in close proximity to major inlet points showing higher levels of contamination. The lead concentration in Dhanmondi Lake exceeds the values set for drinking, fishing, livestock, industrial and irrigation use in the environmental quality standards set out for Bangladesh. The determination of lead concentration in various parts of a fish of the Nilotica species revealed maximum bio-accumulation in the fins (4.90 mg/kg wet weight) and gills (4.78 mg/kg). Contaminated fish from the lake are becoming a local public health concern. Speciation calculations revealed that the major soluble lead species in Dhanmondi Lake are $PbCO_3$(aq), Pb^{2+} and $PbOH^+$, with $PbCO_3$(aq) being the most dominant, while $PbHCO_3{}^+$, $PbCl^+$ and $PbSO_4$(aq) are minor species. Although the concentration of free ionic Pb^{2+}, apparently the more toxic form, was found to be relatively low, any drop in pH would result in an increase in this species. With rapid industrialisation and an increasing number of motorised vehicles using leaded gasoline, lead pollution is likely to get worse unless appropriate remedial and regulatory measures are taken.

INTRODUCTION

The heavy metal contamination of lakes and reservoirs is a common problem, especially when they are geographically confined and receive input from various anthropogenic sources. Lead is a highly toxic heavy metal and is thought to be a probable carcinogen. It has also been recognised as being a cause of brain and kidney damage and may possibly be a cause of mental retardation in children [1]. The concentration of soluble lead in uncontaminated freshwater is generally less than 3 μg/L [2] However, much higher levels often occur near highways and cities due to the combustion of gasoline. For example, residues in rivers in southern France and Lake Naini Tal in India were 3.5–53 and 20–89 μg/L, respectively [3,4]. Lead concentrations in rain water generally vary from 1 to 50 μg/L [5,6]; however, in densely populated industrial areas, it may exceed 1000 μg/L [7]. Rognerud & Field [8] reported a very great accumulation of lead in the sediments of a number of lakes in Norway. Here the major sources of lead were rainfall and surface runoff containing atmospheric lead emitted from smelting industries and automobiles in that region. Although investigations into the heavy metal contamination of lakes in Dhaka City is yet to be conducted, in a recent study by the Bangladesh Atomic Energy Commission, it was reported that atmospheric lead pollution in certain areas of Dhaka City are one of the worst in the world, with lead concentrations as high as 463 ng/m^3.

Dhanmondi Lake, with 92.23 acres of total water area and 17.80 acres of lakeside green land (see Fig. 1) is located in densely populated central Dhaka with heavy concentrations of motor vehicles. As many as 80 surface and subsurface drains discharge into the lake. A number of storm sewer outlets discharge into the lake, bringing in pollutants from a variety of sources e.g. washouts from streets, market places, gas stations, auto-workshops, community centres, clinics, hospitals and households. Occasionally, tannery wastes from the nearby Hazaribag area flow back into the lake with storm sewer overflow during high flood period. A detailed investigation of the quality of the effluents discharging into the lake has not yet been performed. These discharges, comprising largely of biodegradable organic wastes and a wide range of other pollutants, are also likely to contain heavy metals such as lead. This is particularly true in view of the heavy atmospheric lead pollution that exists in central Dhaka.

Atmospheric lead deposited through rainfall and surface runoff may accumulate in lakes over several decades. The fate of trace metals in natural aquatic systems is often controlled by adsorption on to fixed and mobile adsorbents. Hydrous metal oxides (e.g. iron and manganese oxides) are the principal inorganic adsorbents, while organic adsorbents include particulate humic matters. The sedimentation of heavy metals, including lead, is often initiated by adsorption on particulate matter. This process may lead to a huge accumulation of lead in the bed sediment, unless it has some means of naturally purifying itself. In Norway, the lead concentration in lake sediments increased from 60–100 μg/gm to 400–600 μg/gm over a 30-year period [8]. A nonflowing lake such as the Dhanmondi Lake, once it is contaminated with a nondegradable pollutant such as lead has little chance of purifying itself naturally and with a continuous input the level of pollution will only increase over time.

Dhanmondi Lake is widely used by the population for various purposes. Certain parts of the lake are regularly used by low-income people for bathing and for washing clothes. Dhanmondi Lake has been a popular fishing spot in Dhaka. There is also a public fishing programme on the lake which works on a rental basis and has proven to be very popular. A large number of people of the city regularly consume fish from this lake. Therefore, the bio-accumulation of lead in fish is also a major concern. Thus there is an urgent need to investigate the possible lead contamination of Dhanmondi Lake. Recently, the Dhaka City Corporation has set up a scheme to renovate the lake site and convert it into a recreation centre. In this regard, an investigation into the water quality of the lake is also very important.

The overall objective of this study was to investigate the level of lead pollution in Dhanmondi Lake. Specific objectives were: (i) to assess concentration of lead (as well as a number of other water quality parameters) in the water column as well as the sediments of Dhanmondi Lake; (ii) to assess the bio-accumulation of lead in fish collected from this lake; and (iii) to determine the chemical speciation of lead in water column of the Lake. Lead concentrations in the water column and sediment were determined at several locations in order to determine the spatial variation of lead concentration. Seasonal variations in lead concentrations in the lake were also determined through an analysis of samples collected during different periods of the year. One potentially important route of exposure corresponds to the human consumption of contaminated fish. In order to determine bio-accumulation, various parts of a Nilotica fish from the lake were analysed for lead. Since the toxicity of a heavy metal such as lead often depends on its chemical form, chemical speciation of lead in the water column was determined in this study.

METHODS AND MATERIALS

In this study, water and sediment samples from Dhanmondi Lake (see Fig. 1) were collected from seven sampling locations (see Fig. 2) in order to determine spatial variation of lead contamination. In selecting these locations, the following criteria were used as guidelines: (i) sampling locations should cover the entire lake; (ii) locations at close proximity to the major drainage discharge points of the lake should be covered. Locations 1, 2, 3 and 7 (see Fig. 2) are such points; (iii) locations representative of the average conditions in the lake, e.g. loca-

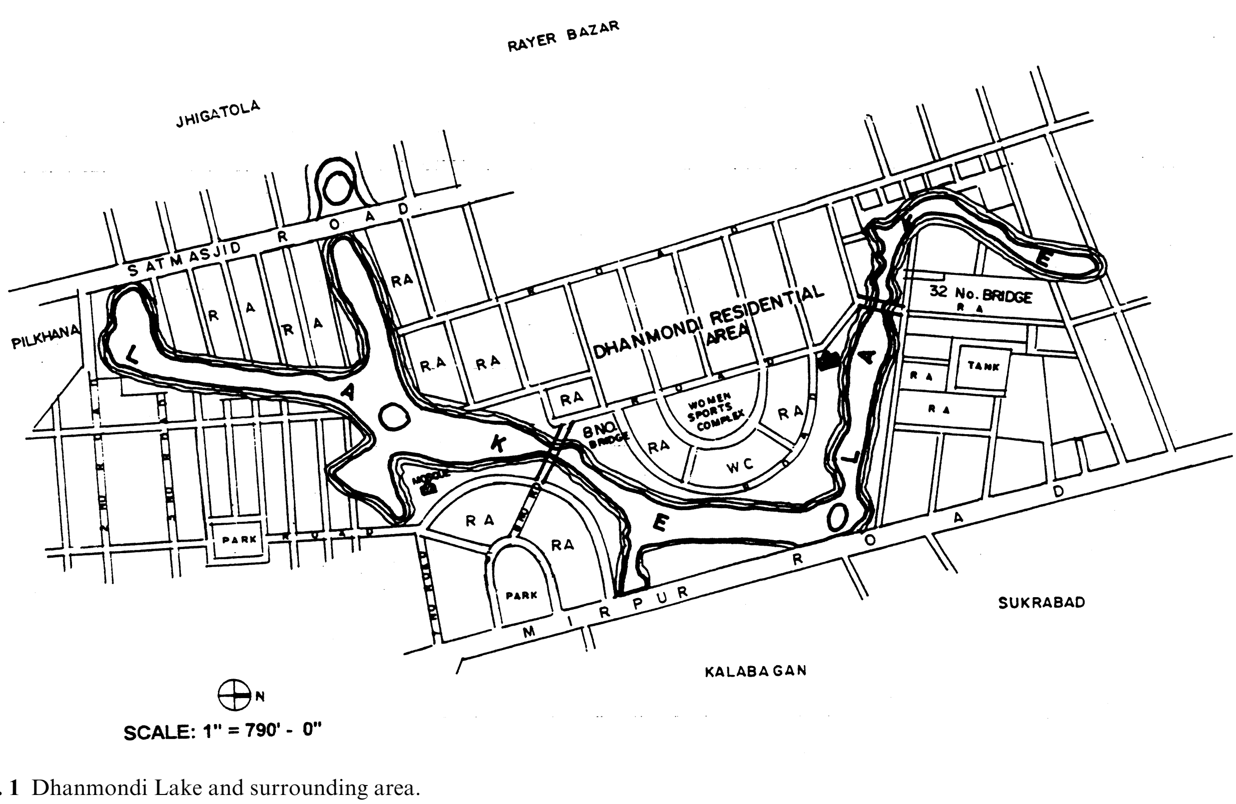

Fig. 1 Dhanmondi Lake and surrounding area.

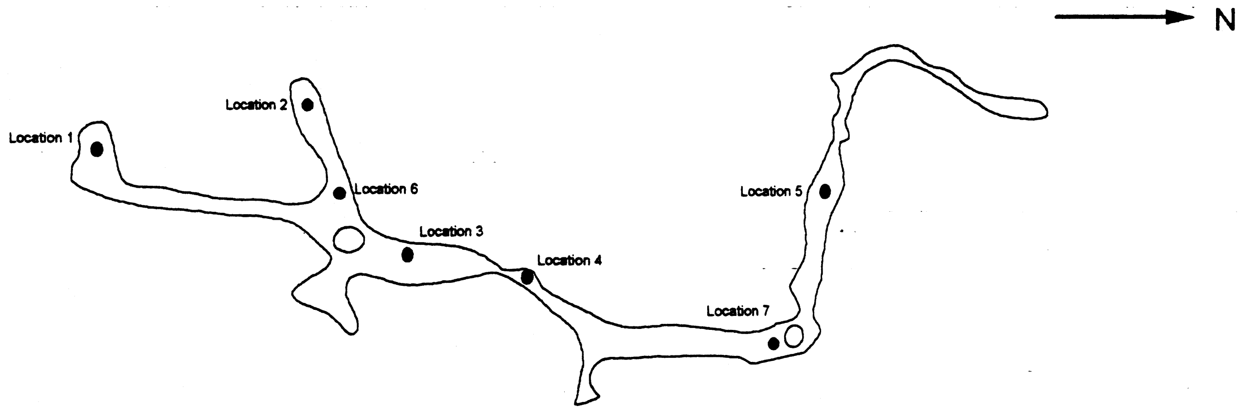

Fig. 2 Sampling locations in Dhanmondi Lake.

tions at some distance away from the major discharge points where complete mixing is expected, should be covered. Locations 4, 5 and 6 are such points.

The sampling programme was divided into three different periods. The 'dry period' covered the end of spring and beginning of summer (February–April), the 'wet period' covered the monsoon (June–July) and the 'interim period' covered the end of summer (April–May). Two sampling operations were performed during the dry period, two during the interim period and three during the wet period. During each sampling operation, about 2 L of water samples were collected in polyethylene containers, approximately from the mid-depth, at each sampling location. The mid-depth was determined by a metal chain with a heavy weight attached to its lower end. Since Dhanmondi Lake is relatively shallow and almost stagnant, this method of measurement is expected to give a good estimate of the depth of the water column at the sampling locations. In the absence of a sophisticated depth sampler, assistance was taken from a diver associated with the Amateur Anglers' Association. A bamboo pole was lowered at each sampling location and the diver went into the water along the pole holding a capped sampling container. After reaching the mid-depth, which was marked on the bamboo pole, the diver opened the cap and collected the water sample. Water samples (of approximately 1 L) for testing the concentration of metal ions, including lead, were collected in a separate polyethylene container. A portion of these water samples were filtered using a 0.45 μm filter in a filter holder attached to a syringe. Both the filtered and unfiltered portions were acidified with concentrated nitric acid (at a rate of 5 mL per litre) for the analysis of metal ions. At each location, sediment samples from the top layer of the sediment (about 4 cm thick) were collected using a locally made hollow (9 cm inside diameter) tube sampler. In this study, the pH and temperature of the water samples were determined in the field.

In order to determine the chemical composition of the lake water, the water samples were analysed for chloride, sulphate, alkalinity, hardness, ammonium, nitrate, phosphate, and total and suspended solids. Chloride, sulphate, alkalinity and total and dissolved solids were determined by volumetric methods following standard methods [9]. Hardness was determined by EDTA titrimetric method; while ammonium, nitrate and phosphate concentrations were determined with a spectrophotometer (Hach, DR/EL4). Ammonium was determined using Nessler method, nitrate by the cadmium reduction method, and phosphate by the molybdenum blue method. Unfiltered water samples were analysed for five metal ions: lead, sodium, potassium, calcium and magnesium; while filtered water samples and sediment samples were tested for only lead. An analysis of the metal ions in water and sediment samples was performed by an Atomic Absorption Spectrophotometer (Shimadzu, AA680). The concentration of lead adsorbed on to the suspended sediment was determined by subtracting the concentration in the filtered sample from that in the unfiltered sample. Unfiltered water and sediment samples were digested before analysis for an extraction of metal ions. For the digestion of water samples, 5 mL nitric acid (1:3) and 10 mL hydrochloric acid (1:3) were added to a 100 mL water sample. The sample was then boiled for 5–10 min and the volume was reduced to about half. When the boiled sample had cooled to room temperature, its volume was adjusted to 100 mL with distilled water and it was then filtered. The filtrate was then analysed for metal ions. For the digestion of sediment samples, 10 mL nitric acid and 30 mL hydrochloric acid were mixed with about 10 mg of the oven-dried sediment sample. About 100 mL of deionised water was then added to the sample and the mixture was boiled for 15–20 min. The sample was then allowed to cool for about 30 min, and adjusted to 500 mL by deionised water, thoroughly stirred and then filtered. The filtrate was then tested for sediment-bound lead. For a determination of the lead concentration in fish tissues and bones, portions of fish tissues and bones were digested following the procedure that was employed for the sediment samples.

The average inorganic chemical composition of the lake water determined through laboratory analysis was used as an input in the chemical equilibrium model MINEQL$^+$ [10]. In speciation calculations, the adsorption of lead on to a suspended sediment in the water column was modelled using a simplified approach. It was assumed, in the absence of detailed characterisation of the adsorbents, that hydrous oxides are the principal adsorbents in the lake. The sorption of lead and other ions was modelled by a surface complexation model, the Generalised Two Layer Model [11], using Hydrous Ferric Oxide (HFO) as adsorbent. The advantage of using this approach is that the adsorption model has already been included in MINEQL$^+$ and the adsorption reactions and equilibrium constants of a wide range of ionic chemical species on to HFO (reported in Dzombak & Morel [12]) have been included in the database of MINEQL$^+$. In the speciation calculations, the concentration of adsorbent (HFO) was varied until the simulated concentration of aqueous (or adsorbed) lead matched the experimentally determined value.

All the chemicals used in this study were of reagent grade. Chemicals that were used for a determination of ammonium, nitrate and phosphate using a spectrophotometer (Hach, DR/EL4) were proprietary items and were procured from Hach Co., USA.

RESULTS AND DISCUSSION

Analysis of experimental results

Table 1 shows the average aqueous lead concentrations in Dhanmondi Lake (as determined from the filtered water samples) at all seven sampling locations for the three sampling periods. The average lead concentration varies from 151 to 210 μg/L during the dry period, from 30 to 170 μg/L during the interim period and from 40 to 120 μg/L during the wet period. These values are significantly higher than those that have been reported for rivers in southern France and Lake Naini Tal in India [3,4]. Table 1 shows that average lead concentrations from the seven sampling locations do not vary significantly during the dry period, while variation is greater for the interim and wet periods. This is probably due to the fluctuating nature of the rainfall and the consequent surface runoff during the interim and wet periods. It is clear from Table 1 that the lead concentration in Dhanmondi Lake is significantly higher during the dry period compared to the interim and wet periods. In fact, aqueous lead concentrations during the wet period at all seven sampling locations are approximately half of those during the dry period. A reduction of lead concentration during the wet period most likely results from dilution caused by rainwater and increased surface runoff. The average concentration of lead adsorbed on suspended sediment was found to vary from a negligible level to a maximum of about 100 μg/L. For most sampling locations, these values were low compared to the corresponding total aqueous lead concentrations. As is the case with total aqueous lead, the concentration of lead in suspended sediments was found to be higher in the dry period compared to the interim and wet periods. Suspended sediments consisting of hydrous metal oxides and colloidal organic sorbents usually sorb metal ions, and such sorption also depends on pH, with a higher pH favouring metal ion sorption. However, no correlation was observed between lead concentration in suspended sediment and the corresponding concentration of suspended sediment in the lake. Since the pH of lake water at the seven sampling locations does not vary significantly, a lack of any correlation probably indicates variations in the sorption characteristics of suspended sediments in the lake.

Table 2 shows the average lead concentration in the sediment from the bottom at the seven sampling locations during three different sampling periods. It should be noted that during the dry period, sediment samples could not be collected from the sampling locations, other than locations 1 and 2, due to mechanical difficulty with the sampler. Table 2 shows that, unlike in the water column, there are significant variations in lead concentrations in the bottom sediment between the seven sampling locations. Lead concentrations in the bottom sediment at sampling locations 1 and 2 were found to be significantly higher (varying from 26.6 to 44.7 mg/kg) than those at other locations (varying from 10.7 to 23.3 mg/kg). This is probably due to the close proximity of locations 1 and 2 to two major inlet points. It is interesting to note that, compared to the interim sampling period, the average lead concentrations in the bottom sediment have actually increased during the wet period; while for aqueous lead the trend was reverse. This probably indicates that most of the lead input into the lake comes during the wet period (along with higher surface runoff and other waste inputs) in particulate form and quickly finds its way to the bottom sediment. Since the lake water is slightly alkaline (average pH about 7.7), the sorption of lead on to

Table 1 Average aqueous lead concentration in Dhanmondi Lake at the seven sampling locations during different sampling periods

Sampling period	Lead concentration (μg/L)						
	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7
Dry period	178	177	171	154	151	167	210
Interim period	170	65	104	113	30	59	51
Wet period	120	54	77	66	51	40	54

Table 2 Average lead concentration in the bottom sediment of Dhanmondi Lake at the seven sampling locations during different sampling periods

Sampling period	Lead concentration (mg/kg dry weight of sediment)						
	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7
Dry period	44.7	32.1	*	*	*	*	*
Interim period	26.6	29.6	13.0	23.3	13.9	14.4	10.7
Wet period	37.1	42.9	23.0	19.6	31.4	17.7	16.8

*Sediment samples could not be collected.

suspended solids and the subsequent sedimentation to the bottom probably play a major role in increasing sediment lead concentration, particularly during the wet period, when suspended solids concentrations are higher.

The bio-accumulation of lead in various parts of a Nilotica fish, a common fish of the Dhanmondi Lake, is presented in Fig. 3. It shows the concentration of lead in gills, muscles, skin, stomach, fins and head muscles of a Nilotica fish. The concentration of lead was found to be a maximum in the fins and gills (4.90 and 4.78 mg/kg wet weight, respectively); while that in the muscle, the part consumed as food, was found to be 0.62 mg/kg. Moore & Ramamoorthy [13] reported that in Wintergreen Lake (USA), the average lead concentration was 7.9 mg/kg wet weight in invertebrates, 0.2–0.5 mg/kg in primary carnivorous and 0.3–0.4 mg/kg in secondary carnivorous. Omnivorous and carnivorous fish in the Illinois River (USA) had average residues of 0.7 and 0.6 mg/kg, respectively, in the muscle tissue, whereas levels in invertebrates ranged up to 39 mg/kg. In Mackay *et al.* [14], the reported average distribution of lead in the muscles of various fish species was found to range from 0.06 mg/kg for Spotted Wolfish to 1.36 mg/kg for Atlantic fish

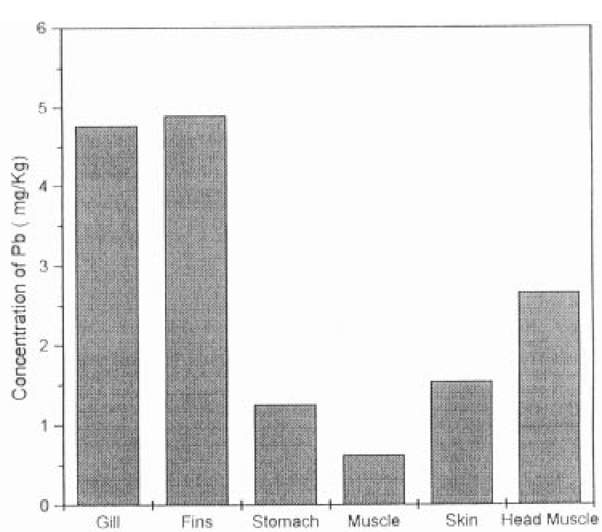

Fig. 3 Concentration of lead in different parts of a Nilotica fish from Dhanmondi Lake.

species. Comparison of these results with those for Nilotica fish, presented in Fig. 3, suggest that lead concentration in various fish tissues of Dhanmondi Lake is relatively high.

According to the proposed Environmental Quality Standards (EQS) for Bangladesh [15], the maximum level of lead is set at 50 μg/L for drinking water, fishing water, and livestock water; 10 μg/L for industrial water, and 100 μg/L for irrigation water. Under most circumstances, lead concentration in the Dhanmondi Lake exceeded these limiting values by a wide margin. The introduction of lead into the food chain through its bio-accumulation in fish tissue is particularly alarming. With the rapid industrialisation and increasing volume of motorised traffic in central Dhaka, the lead pollution of Dhanmondi Lake is bound to get worse in the coming days, unless appropriate measures are taken for remediation.

Speciation of lead in Dhanmondi Lake

A knowledge of the chemical forms of trace metals such as lead is essential for estimating its toxicity as well as its bio-availability and reactivity. For most heavy metals, the rule of thumb is that free ionic forms are much more toxic than the complexed forms. In aquatic systems, metal ions form solution complexes with a wide range of inorganic and organic ligands, and at the same time they have a tendency to sorb on aquatic particles such as hydrous metal oxides and particulate organic matter.

For chemical speciation calculations, the average chemical composition of the lake water was determined through a laboratory analysis of unfiltered samples from the seven sampling locations. The water samples were analysed for pH, alkalinity, chloride, sulphate, nitrate, phosphate, sodium, potassium, calcium, magnesium and ammonium. The pH of the lake water was found to be slightly alkaline throughout the sampling period and varied from 7.6 to 7.8 during the dry period and 7.6–8.0 during the wet period. From test results it appears that dilution by rainfall and increased surface runoff play a significant role in reducing alkalinity, chloride, calcium and magnesium concentrations during the wet period. Sodium and potassium concentrations did not vary significantly over the sampling period. The alkalinity of lake water was found to vary from 138 to 160 mg/L (as $CaCO_3$) during the dry period and from 72 to 124 mg/L during the wet period. Chloride concentration ranged from 110 to 180 mg/L during the dry period to 35–58 mg/L during the wet period. Slightly elevated levels of chloride were found in the southern part of the lake (particularly at locations 3 and 6). A discharge of sewage through inlet points in this part of the lake may be responsible for this. A slightly increasing trend of sulphate content in the wet season compared to that during the dry season was observed. Sulphate concentration during the dry season ranged from 16 to 106 mg/l, while that during the wet period ranged from 13 to 145 mg/L. Sodium concentration remained more or less uniform during the sampling period and ranged from 4.94 to 5.21 mg/L between the seven sampling locations. The potassium concentration was found to vary from 8.5 to 58 mg/L during the dry period and 12–45 mg/L during the wet period. Calcium and magnesium concentrations of the lake water during the dry period ranged from 34 to 76 and 17–38 mg/L, respectively; while during the wet period it ranged from 24 to 48 and from 14 to 23 mg/L, respectively. Ammonium, nitrate and phosphate concentrations were determined for a limited number of samples. The ammonium concentration was found to vary from 0.040 to 0.658 mg/L, phosphate from 0.400 to 0.820 mg/L, and nitrate from 1.8 to 2.2 mg/L. It should be noted that the organic constituents of lake water were not determined in this study.

Equilibrium chemical speciation in the water column of the Dhanmondi Lake was evaluated using the equilibrium model MINEQL$^+$ [10]. The simplified assumptions used in the equilibrium calculations are as follows: (i) dissolved and particulate organic matter have little influence on the speciation of lead; (ii) lake water is in equilibrium with atmospheric CO_2; (iii) trace metals other than lead have little influence on speciation; (iv) adsorption of lead can be described by the Generalised Two Layer Model [11], using Hydrous Ferric Oxide (HFO) as an adsorbent. It should be noted that dissolved and particulate organic matters (e.g. humic and fulvic acids) can influence solution complexation as well as the adsorption of metal ions in aquatic systems [16,17]. However, in the absence of data on the organic matter composition of lake water, such an influence was neglected. All equilibrium analyses were performed at 25 °C, which is expected to be the temperature at the mid-depth of the lake water. For each sampling location, the speciation in the water column was determined for both dry and wet periods.

Tables 3 and 4 show the speciation of lead at all sampling locations during dry and wet periods, respectively. These tables show that in all cases, the major soluble lead species are $PbCO_3$(aq), Pb^{2+} and $PbOH^+$, with $PbCO_3$(aq) being the most dominant, while $PbHCO_3{}^+$, $PbCl^+$ and $PbSO_4$(aq) are minor species. The concentration of the major species

Table 3 Concentration of aqueous lead species (determined using MINEQL$^+$ [10]) at the seven sampling locations during the dry period

	Lead concentration (μg/L)						
Lead species	Location 1 pH = 7.6	Location 2 pH = 7.8	Location 3 pH = 7.7	Location 4 pH = 7.7	Location 5 pH = 7.7	Location 6 pH = 7.75	Location 7 pH = 7.75
$PbCO_3$	128.4	148.0	133.9	120.5	118.0	129.9	163.0
Pb^{2+}	25.7	11.8	16.8	5.2	14.8	16.5	20.7
$PbOH^+$	16.5	12.0	13.7	12.2	12.1	13.3	16.7
$PbHCO_3{}^+$	3.0	2.1	2.4	2.2	2.1	2.4	3.2
$PbCl^+$	2.4	1.2	1.7	1.4	1.2	2.0	1.9
$PbSO_4$	1.8	1.0	1.8	2.3	2.6	1.7	2.5

Table 4 Concentration of aqueous lead species (determined using MINEQL$^+$ [10]) at the seven sampling locations during the wet period

	Lead concentration (μg/L)						
Lead species	Location 1 pH = 7.6	Location 2 pH = 7.7	Location 3 pH = 7.7	Location 4 pH = 7.6	Location 5 pH = 7.8	Location 6 pH = 7.8	Location 7 pH = 8.0
$PbCO_3$	78.0	45.0	60.8	41.6	39.8	32.0	34.2
Pb^{2+}	24.2	3.5	7.4	13.0	5.0	3.4	10.5
$PbOH^+$	12.7	3.6	6.1	6.8	4.1	3.1	5.6
$PbHCO_3{}^+$	2.1	0.6	1.0	1.2	0.7	0.6	1.0
$PbCl^+$	0.9	0.1	0.3	0.5	0.2	0.2	0.4
$PbSO_4$	2.0	0.5	1.3	2.5	1.1	0.5	2.4

$PbCO_3$(aq), Pb^{2+} and $PbOH^+$ at all seven sampling locations during the dry period varied from 118 to 163, 11.8 to 25.7 and 12 to 16.7 μg/L, respectively; while during wet period these concentrations varied from 32 to 78, 3.5 to 24.2 and 3.1 to 12.7 μg/l, respectively. A close inspection of Tables 3 and 4, along with the average chemical composition data of lake water suggest that the pH was the principal factor in determining relative proportions of the various lead species. An increase in pH favoured the complexation of lead with carbonate, while a decrease in pH resulted in higher percentage of ionic lead (Pb^{2+}). For example, at pH 7.6 (location 1, dry season), percentages of $PbCO_3$(aq), Pb^{2+} and $PbOH^+$ in aqueous lead were found to be $\approx$ 72%, 14% and 9%, respectively; while at pH 7.8 (location 2, dry period), these percentages were $\approx$ 84%, 7% and 7%, respectively. As a general rule, free ionic forms of heavy metals (e.g. Pb^{2+}) are much more toxic than the complexed forms. The equilibrium speciation presented in Tables 3 and 4 suggests that, although total aqueous lead concentrations in Dhanmondi Lake are high, the concentration of the free ionic form Pb^{2+} is relatively low (varying from 11.8 to 25.7 μg/L during the dry period and 3.5 to 24.2 μg/L during the wet period). However, speciation appears to be a strong function of pH and a decrease in the pH of the lake water (e.g. due to the discharge of acidic wastes or acid rain) would result in a rapid increase in the proportion of the free ionic form Pb^{2+}.

SUGGESTED REMEDIAL MEASURES

Lead pollution of the lake is becoming a potential threat to public health, either through direct contact or through its introduction into the food chain via contaminated fish. Therefore immediate remedial and regulatory measures are needed to quell the public health concern and to restore the lake to its natural state before it gets any worse. In fact, the Dhaka City Corporation (DCC) has recently taken up a project for renovation of Dhanmondi Lake. Major steps in a remedial plan would include: (i) sealing/diversion of storm sewer lines, sewerage lines, and surface and subsurface drains discharging into the lake; (ii) removal of contaminated sediments from the bottom of the lake; (iii) appropriate regulatory measures for protection against future contamination; and (iv) proper management of the lake with regular monitoring of its quality.

There are about 80 surface and subsurface drains discharging into the lake, including two major storm sewers. The storm sewer lines need to be sealed in order to prevent the discharge of wastes with storm sewer overflow during high flood periods. Illegal sewerage lines discharging into the lake need to be connected to the central sewer line that is now available in that area. All surface and subsurface drains discharging into the lake should be diverted.

Removing contaminated sediment from the bottom of the lake would be a major task in the renovation process. The depth of contaminated sediment appears to vary significantly across the lake. The limited available information suggest that at some locations close to the inlet points, this depth may exceed eight feet (2.5 m). The depths of contaminated sediments at other locations, especially those away from the inlet points, are expected to be less. Therefore, actual data on sediment quality is needed for proper planning of the removal of contaminated sediment. If this is not done properly, the heavily contaminated sediment would act as a continuous source of lead, with lead adsorbed on to the bottom sediment slowly diffusing back into the lake water.

Strict regulatory measures are essential for guarding against the future contamination of Dhanmondi Lake. The lake is currently being used for a variety of purposes including uncontrolled bathing, the washing of clothes and cars, as well as fishing. It is also used as a convenient waste dumping point for houses, community centres and medical clinics located in the surrounding areas. Such illegal dumping of wastes and the uncontrolled use of the lake must be stopped through proper regulatory measures and their appropriate enforcement. Leaded gasoline is still in use in Bangladesh and its gradual discontinuation is a prerequisite for safeguarding lakes against lead contamination.

Proper management is essential for the preservation of the lake. Currently there is no organised body for the management of Dhanmondi Lake. The land of the lake belongs to the Public Works Department (PWD) while the Department of Fisheries is entrusted with the responsibility of producing and conserving fish. The Amateur Anglers Association has secured the annual fishing rights from the Department of Fisheries. The Dhaka City Corporation is responsible for the overall maintenance of the lake, as the guardian of the City. Subsequently, the Dhaka Water Supply and Sewerage Authority (DWASA) became involved because its storm sewer lines ran into the lake, while a good number of private sewer lines also discharged sewage into the lake. Finally the Department of Environment (DOE) stepped in when the question of pollution was raised. However, due a to lack of coordination between the departments/agencies, none could discharge their responsibility properly. An appropriate management body with representatives from all stakeholders concerned should be developed for proper management of the lake.

CONCLUSION

Water and sediment samples collected from Dhanmondi Lake have been found to be heavily contaminated with lead. Average aqueous lead concentrations varied from 151 to 210 μg/L during dry season and from 30 to 120 μg/L during the wet period, while the average lead concentration in the bottom sediment varied from 10.7 to 44.7 mg/kg dry weight. Total aqueous lead concentration throughout the lake did not vary significantly during any particular season. Aqueous lead concentrations decreased significantly from the dry to the wet season, by almost by a factor of two, primarily due to the dilution effect resulting from increased rainfall and surface runoff. The concentration of lead in the bottom sediment varied significantly among sampling locations, with locations close to inlet points showing higher levels of lead. The seasonal variation of lead levels in the bottom sediment were found to be minimum. The average lead concentration in Dhanmondi Lake water exceeds the limiting values set for drinking, fishing, livestock, industrial and irrigation use in the environmental quality standards for Bangladesh. A significant accumulation of lead was found in various parts of a Nilotica fish collected from the lake. The concentration of lead was found to be greatest in the fins and gills (4.90 and 4.78 mg/kg wet weight, respectively); while in the muscles, the part which is consumed as food, it was 0.62 mg/kg. This result is alarming, because Dhanmondi Lake is a popular fishing spot, and fish from the lake are widely consumed by people. Speciation calculations revealed that major aqueous lead species in the lake are $PbCO_3$(aq), Pb^{2+} and $PbOH^+$; while $PbHCO_3^+$, $PbCl^+$ and $PbSO_4$(aq) are minor species. Concentration of the free ionic form of lead (Pb^{2+}), apparently the most toxic form, was found to be relatively low. Speciation was found to be a major function of pH, and Pb^{2+} concentration was found to increase with decreasing pH. With the wide use of leaded gasoline, automobile exhausts in addition to a number of other anthropogenic sources appear to be the major contributors to the lead contamination of Dhanmondi Lake. Immediate remedial and regulatory measures are needed to protect and preserve Dhanmondi Lake. Currently the management of the lake is entrusted to a number of departments/agencies, and the proper maintenance of the lake suffers due to a lack of coordination between them. A coordinated effort on the part of all stakeholders is needed for the proper management of the lake.

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