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Probability of Aluminum Toxicity from Bhandup Complex Water Treatment Plant, Mumbai: Case Study

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Abstract: Bhandup Complex water treatment plant located in Mumbai, India, supplies water to most of Mumbai. The plant receives raw water from Vehar Lake. Alum has been used as a coagulant in the treatment process for the past 27 years. The backwashed water from the plant is released into Vehar Lake, which carries a significant amount of suspended matter. Therefore, a layer of sludge was deposited on the meeting point of backwashed water and Vehar Lake. The status of aluminum (Al) concentration in sludge deposits, banks, water, and sediment samples of Vehar Lake and its comparison with Al concentration of soil in the area surrounding the plant is presented in this paper. The comparison showed that the surrounding soil samples had the least Al concentration (16,394–26,081 mg/kg), whereas the highest values of 53,882–73,382 mg/kg and 62,096–76,496 mg/kg were reported in upper and lower layers of sludge, respectively. This paper also discusses the detrimental effect of Al when it is available in toxic form at acidic pH. **DOI: 10.1061/(ASCE)HZ.1944-8376.0000064.** © *2011 American Society of Civil Engineers.*

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Introduction

The Bhandup water treatment plant is situated approximately 35 km from Mumbai City (MPCB 2005). It is the largest water treatment plant operated by the Municipal Corporation of Greater Mumbai (MCGM) for the past 27 years. It supplies potable water to Mumbai entirely. The treatment process of this plant includes sedimentation as a pretreator, filtration, and disinfection. Previously, alum was added as a coagulant during the coagulation process to settle down suspended solids, and the settled sludge was removed from clarifiers at periodic intervals. Aluminum (Al) is a component of alum and it could be toxic to the environment at acidic pH (Evans et al. 1982). Recently, alum has been replaced by polyaluminum chloride (PAC) as a coagulant. The annual requirement of liquid alum was 12,000 t. In the filtration unit, water from the pretreator passes through filter beds. These filter beds are made up of two layers; an upper layer of Godra sand (90 cm) and lower layers of gravels (10 cm). Backwashing of the filter bed is carried out at an interval of 24 h to remove settled suspended solids adhered to the sand. This treatment plant generates $2{,}000 \times 10^6$ L/day of potable water and 50×10^6 L/day of wastewater during backwashing of the filter and desludging activities. During backwashing, a huge amount of suspended solids is removed from the sand filters. This backwashed water is released into Vehar Lake, leading to siltation. Over a period of time, a large amount of sludge was deposited at the point where backwashed water enters Vehar Lake (Fig. 1). Vehar Lake is a freshwater lake and the source of raw water for Mumbai. This raw water is treated at the treatment plant before it is supplied to the city as potable water. Because of the release of backwashed water into Vehar Lake, water sediment of the lake could be affected by Al toxicity in the near future. Also, Al present in sludge deposits could leach into the nearby soil and affect plant growth. A high concentration of Al entering into the water of Vehar Lake could have a direct impact on flora and fauna of the lake and an indirect effect on human beings. Recent studies have shown that Al under acidic pH could affect the growth of flora and fauna (Elizabeth et al. 2009; Campbell et al. 1983). Similarly, prolonged exposure to Al causes neurological disorders (Keith et al. 2002), Alzheimer's disease (Wong et al. 2003), and Parkinson's disease, osteomalacia, and anemia (Verissimo et al. 2006) in humans. Species of fish (Buckler et al. 1987), daphnids (Havas 1985), and immature aquatic insects (Witters et al. 1984) were tested and found net losses of sodium (Na^+) and chloride ions (Cl^-) in the presence of Al. Toxic effect of Al on plants from soil has been reported in various studies, and it is dependent on the forms or species of Al (Matus et al. 2006; Elizabeth et al. 2009; Pietraszewska 2001). Bioavailability and toxicity of Al is also dependent on the acidity or pH of the soil (Matus et al. 2006).

Hence, the objective of the study was to determine the existing level of Al concentration in water samples and water sediment deposits of Vehar Lake, in accumulated sludge at the point where the

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J. Hazard. Toxic Radioact. Waste 2011.15:305-311.

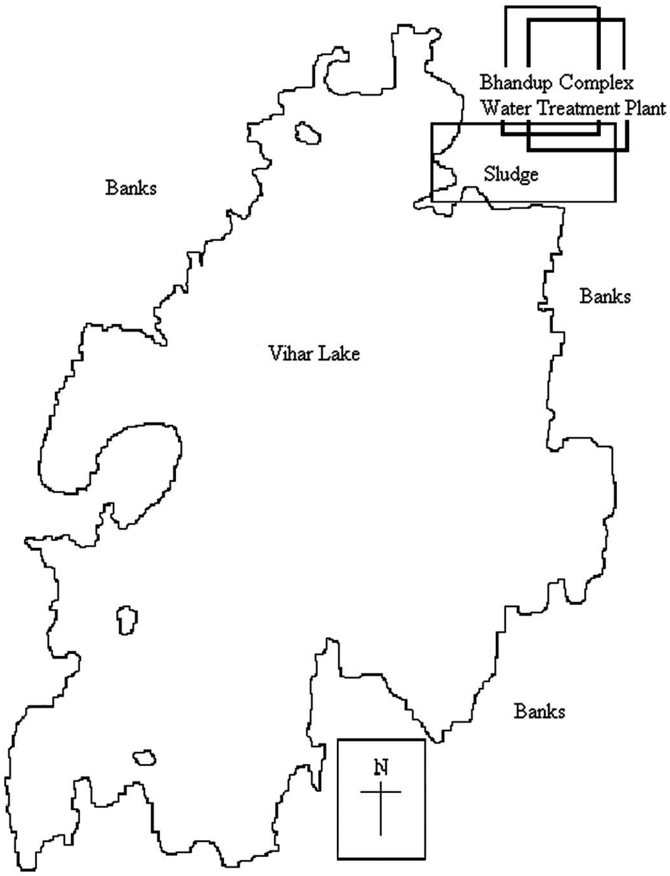

Fig. 1. Location of Vehar Lake and sludge deposited area

outlet of backwashed water meets Vehar Lake, soil samples along the banks of Vehar Lake, and the surrounding soil of Bhandup complex water treatment plant. The probable harmful impacts of Al on human health and on the environment are also presented in this paper.

Materials and Methods

Water Sampling

Water samples were collected from 12 different locations of Vehar Lake by using a mechanized boat. These water samples were drawn out with a 5 L bucket and then stored in 5 L clean jerry cans. Samples were preserved at low temperature and brought to the laboratory within 6 h for analysis. All the analysis was carried out within 24 h of sampling (Rousseau et al. 2009; Li et al. 2009). Samples collected were labeled W1–W12.

Sediment Sampling

Sediment samples were collected with a mechanical Van Veel Grab sediment sampler, stored in an airtight ziplocked bag and brought to laboratory, and then air dried. After drying, they were sieved, and fine-sieved sediments were used for analysis (Gustavsson et al. 2006; Dermatas et al. 2006). Twelve water sediment samples were collected from the same locations in Vehar Lake where water samples were collected (Rousseau et al. 2009). The locations of water sediment samples were labeled S1–S12.

Sludge Sampling

A layer of sludge has been deposited at the point where backwashed water from Bhandup complex water treatment plant meets Vehar Lake. The sludge soil samples were collected from different locations. At each location, two samples were collected from different depths, one at a depth of 30 cm from the surface and the other at 90 cm. They were collected manually by digging with a spade, and depths were measured with a measuring tape. Two-point depth sampling was carried out to determine whether Al was leached into the lower layer of soil over the period. These samples were stored in airtight ziplocked bags and brought to the laboratory for air drying and sieving. The sieved samples were taken for analysis (Gustavsson et al. 2006; Dermatas et al. 2006; Rousseau et al. 2009). Locations of the nine sludge samples were labeled SL1–SL9.

Soil Sampling along the Banks of Vehar Lake and the Surrounding Area of Bhandup Complex Water Treatment Plant

Soil samples were collected at different locations from the banks of Vehar Lake and also from the surrounding area of the Bhandup complex water treatment plant. These samples were collected at a depth of 30 cm from the surface, stored in an airtight ziplocked bag, and brought to the laboratory. They were air dried and sieved, and the sieved soil was taken for analysis (Gustavsson et al. 2006; Dermatas et al. 2006). Locations of the nine soil samples along the banks of Vehar Lake were labeled B1–B9. Similarly, locations of the nine soil samples from the surrounding area of Bhandup complex water treatment plant were labeled L1–L9.

Determination of pH

Water Samples

The water samples were preserved at low temperature and brought to room temperature before being analyzed. The pH was determined by using a pH electrode of M/S Thermo (Mumbai, India). It was calibrated with standardized pH buffer of 4.0, 7.0, and 9.2 (Mondal et al. 2007). The pH buffers were prepared by using pH tablets supplied by Merck Chemicals (Mondal et al. 2007).

Soil and Sludge Samples

The air dried soil samples were mixed with water in the ratio of 1:2. Then, they were kept on a shaker (80 rpm) for 30 min. Thereafter, the aliquot was used to determine pH by using the pH electrode of M/S Thermo. This instrument was calibrated by the same method as Mondal et al. (2007).

Determination of Total Al

Water Sample

The total Al concentration of water samples was determined by using the methodology of the American Public Health Association (APHA 2005). The samples were acid digested and then aliquot was used to determine the total Al concentration using an inductively coupled plasma spectrometer (ICPE) (Jobin Yvon JY−24 maker). This instrument was calibrated with a calibration mixture (1, 10, 100, and 1,000 ppm). It had a detection limit of 0–1,000 ppm. The calibration of the instrument was repeated at an interval of 10 samples to obtain more accurate results (Suleiman et al. 2008).

Sludge and Soil Samples

Total Al concentration (in mg/kg) of soil samples was determined by using the methodology given in Black et al. (1965). 1 g of sample was acid digested and then the total Al concentration of aliquot was determined instrumentally by the ICPE. This instrument was calibrated by the method given in Suleiman et al. (2008).

J. Hazard. Toxic Radioact. Waste 2011.15:305-311.

Table 1. Summary of Al Concentrations of Different Soil and Water Samples of Vehar Lake

	Al Concentration (mg/kg)	
Locations	Minimum	Maximum
Surrounding soil	16,094.12	29,694.94
Water sediment	11,581.36	41,982.81
Sludge deposits		
Upper layer	22,093.17	73,382.19
Lower layer	18,782.04	76,496.07
Soil at banks	20,681.12	63,681.10
Water	0.23 mg/L	1.17 mg/L

Statistical Analysis

The soil samples were collected from different locations of Bhandup complex water treatment plant, sludge deposited area (both upper and lower layer), and along the banks of Vehar Lake, whereas water samples and sediment samples were collected at different locations of Vehar Lake. One sample t-test was performed for total Al concentration. The degree of freedom (DF), mean difference, standard deviation (SD), standard error mean, and upper and lower t-test values (at 95% confidence level) were calculated with the statistical software SPSS 13.0 version for Windows (http://spss.en.softonic.com/).

Results and Discussion

The summary of Al concentrations of soil samples at different locations of Bhandup complex water treatment plant, sludge deposited area (both upper and lower layer), along the banks, and water samples from Vehar Lake (Table 1) shows that the upper layer of sludge samples has the highest Al concentration, whereas the surrounding soil has the least. The one sample t-test (upper and lower values) at $P < 0.001$, standard deviation (SD), mean error and mean difference (Table 2) were all in a statistically significant level. The level of Al concentration at different locations and its effect is discussed subsequently in this paper.

Aluminum Concentration and its Effect on Flora and Fauna of Vehar Lake

The pH of 12 water samples (7.4–7.8) and water sediment samples (7.5–7.9) from different locations of Vehar Lake was in the neutral range (Fig. 2). The total Al concentration of water samples were in the range of 0.23–1.17 mg/L (Fig. 3).

According to the U.S. EPA (1988) standard for drinking water, Al concentration must be below 0.2 mg/L. The raw water from Vehar Lake exceeded the limit of Al concentration for drinking water, but this Al is removed by subsequent treatment of raw water at Bhandup water treatment plant before supplying water to the citizens of Mumbai (MCGM hydraulic engineer, personal communication, 2007). The distribution of Al concentration in water samples shows a gradual decrease in Al concentration while moving away from the sludge deposited area (Fig. 4). W11 (1.17 mg/L) had the

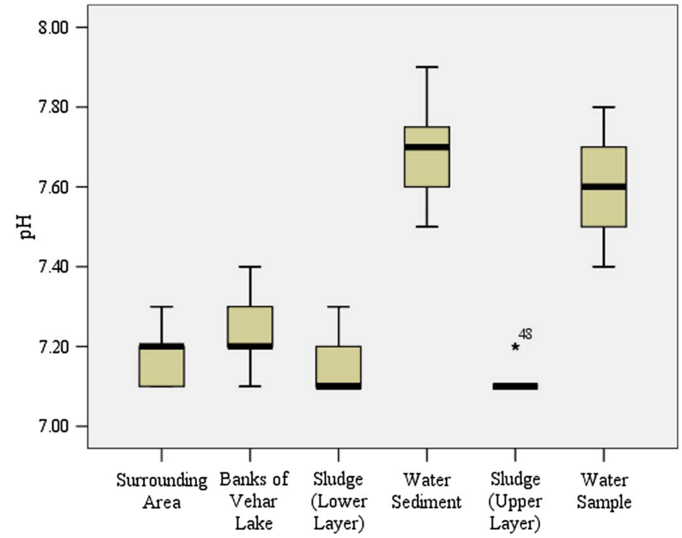

Fig. 2. pH range of water samples and water sediment samples collected at different locations of Vehar Lake and soil samples collected from the banks of Vehar Lake, surrounding area of Bhandup Complex water treatment plant, and sludge deposited area

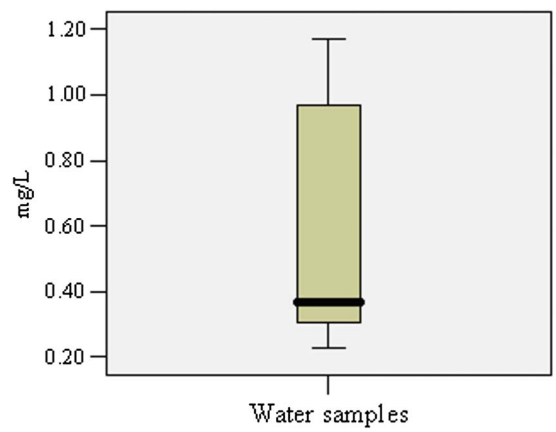

Fig. 3. Total Al concentration range of water sample (mg/L) from Vehar Lake, Mumbai

Table 2. Statistical Analysis of Total Al Concentration of Different Samples (One Way T-Test)

Sample	Degree of freedom	Mean difference	Standard deviation	Standard error mean	95% confidence level difference	
					Upper	Lower
Surrounding soil	8	22,234.71	4,434.32	1,478.13	25,643.25	18,826.16
Water sediment	10	25,278.40	2,643.21	2,643.24	31,167.81	19,388.90
Sludge deposits						
Upper layer	8	59,286.81	15,985.02	5,328.34	71,573.90	46,999.61
Lower layer	8	62,035.72	18,508.41	6,169.53	76,262.54	47,808.91
Soil at banks	8	32,778.64	14,473.91	4,824.64	43,904.12	21,652.90
Water	10	0.62	0.41	0.12	0.91	0.33

All results were obtained at P value < 0.001.

J. Hazard. Toxic Radioact. Waste 2011.15:305-311.

highest Al concentration (it was nearer to the sludge deposited area), whereas W1 (0.23 mg/L) had least concentration. This Al is in a nontoxic state because they are present in dissolved form, and pH of the samples is in neutral range. But under acidic pH, this Al could become toxic and have a direct adverse impact on phytoplankton, zooplankton, and fishes inhabiting Vehar Lake and an indirect effect on human beings (Sigel and Sigel 1988). The total Al concentration in water sediment samples at different locations of Vehar Lake was in the range of 11,581–41,982 mg/kg (Fig. 5). The distribution of total Al concentration for water sediment samples at different locations of Vehar Lake is depicted in Fig. 4. The pH of water sediment samples were also in the neutral range, which indicated that Al is in nontoxic form. Al at a concentration of 0.1 mg/L under acidic pH is toxic to fishes (Hassan 2008). Hassan (2008) also reported that gills of *Tilapia* showed fusion of lamellae and filaments, and they secreted abnormally large amount of mucous. Al ions accumulated in their gills and clog the gills by forming a slimy layer that affected their breathing (Yokel and Golub 1997). Al concentration of 1.5 mg/L was found to be fatal to trout (Driscoll et al. 1980). Al in Vehar Lake is not available in free form to cause any adverse impact, but under acidic condition (pH below 5.5), this Al could become toxic and have an adverse impact on fishes. Vourinen et al. (1999) reported the lethal concentration at which 50% of the organisms die, LC_{50}, of 250 $\mu g/L$ (pH 5.5) for newly hatched and one-month-old fishes. Al concentration in phytoplankton has increased under acidic conditions (Vitorello et al. 2005). Studies on *Asterionella ralfsii* and *Chlorella pyrenoidosa* also showed that the toxicity per unit dissolved Al is higher at pH 6 than at pH 5 or lower (Campbell et al. 1983). Hence, under acidic condition, Al from water sediment and water samples of Vehar Lake could come into an available state and cause an adverse impact on flora and fauna. The experimental results of Doshi et al. 2008 showed that when soil was amended with 10,000 mg/kg of Al, the concentration of Al in leaves and stem, respectively, was 517 + 17 and 558 + 106 mg/kg for California red kidney beans.

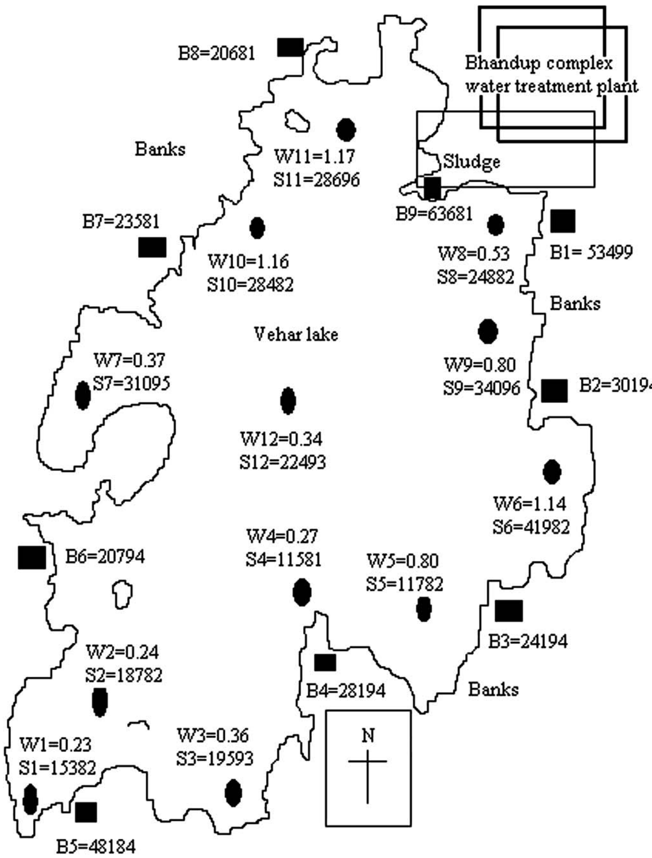

Fig. 4. Total Al concentration of water samples (mg/L), water sediment samples of Vehar Lake (mg/kg), and soil samples (mg/kg) around banks of Vehar Lake, Mumbai

Aluminum Concentration in Soil and its Effect on Plants

Nine sludge deposit samples at different locations (each of two layers; upper and lower) were collected, and the pH of the upper layer (7.1–7.2) and lower layer (7.1–7.3) were in the neutral range (Fig. 2). Total Al concentration of upper layer of sludge samples was in the range of 53,882–73,382 mg/kg except for SL5, whose concentration was 22,093 mg/kg whereas that of the lower layer was in the range of 62,096–76,496 mg/kg except for two samples whose concentrations were 46,682 mg/kg (location SL7) and 18,782 mg/kg (location SL5; Fig. 5). Comparison of total Al concentration at different locations of the sludge deposited area showed that the upper and lower layers had a similar range of Al concentration (Fig. 6). Hence, over a period of time, Al has leached into the lower layer of soil. This could be taken as an indication of leaching Al into the soil and can have adverse impact on plants.

Similarly, the pH of soil samples at different locations along the banks of Vehar Lake (7.1–7.4) and surrounding area of the Bhandup complex water treatment plant (7.1–7.3) was in the neutral range (Fig. 2). The total Al concentration of soil samples at different locations along the banks of Vehar Lake was in the range of 20,681–48,194 mg/kg (Fig. 5) except for one location whose concentration was 63,681 mg/kg. This sample was located near the sludge deposited area (Fig. 6). Hence, it had a higher concentration of Al. The total Al concentration of soil samples collected at different locations of surrounding area of Bhandup Complex water treatment plant was in the range of 16,394–26,081 mg/kg (Fig. 5). This concentration range was lowest compared with other soil samples (soil samples along the bank of Vehar Lake, sludge samples, and water sediment samples). Thus, the surrounding soil of Bhandup water treatment plant was not contaminated with Al. The distribution of total Al concentration of soil samples from the surrounding area of the plant (Fig. 7) showed that the locations

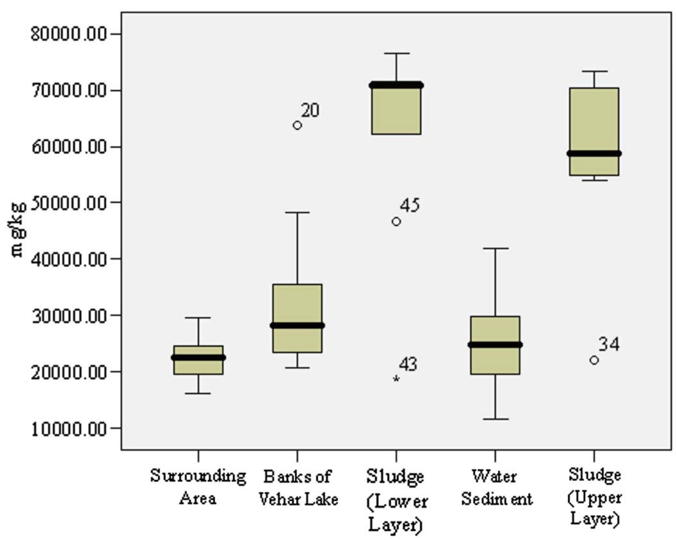

Fig. 5. Range of total Al concentrations of water sediment samples at different locations of Vehar Lake, soil samples from surrounding area of Bhandup Complex water treatment plant, banks of Vehar Lake, and sludge deposits at meeting point of backwashed water and Vehar Lake

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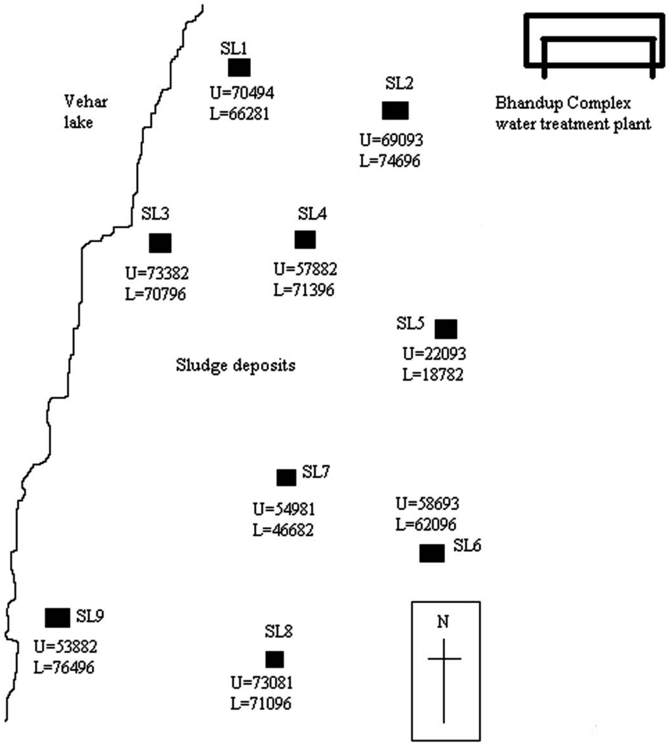

Fig. 6. Comparison of total Al concentration (mg/kg) of both layers of sludge deposits on meeting point of backwashed water from Bhandup water treatment plant and Vehar Lake, Mumbai

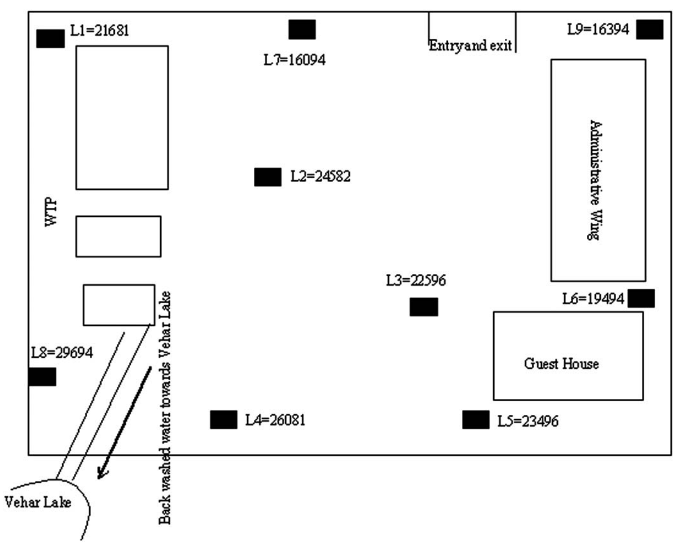

Fig. 7. Map depicting distribution of total Al concentration (mg/kg) in surrounding soil of Bhandup Complex water treatment plant, Mumbai

near the sludge deposited area had higher Al concentration (L8 and L4) than other locations. Hence, Al is leaching into the surrounding soil from the sludge deposited area. Dispersion of Al through soil is dependent on soil moisture, acidity, and organic content (Doshi et al. 2008). Harrington et al. (2003) reported that dispersion of Al in soil is also dependent on texture, pH, cation exchange capacity, surface area, total carbon, and fluoride content of the soil. Although the surrounding soil of the Bhandup plant showed a relatively low level of Al, a chance exists in the near future that this bound Al may become available and have an adverse environmental impact. Also, Al from the sludge deposit could leach into the surrounding soil and cause adverse effects on plants. Currently, the pH of the surrounding soil is in the neutral range, but if the pH falls below 5.5, then a direct impact of Al toxicity could be possible. Earth's crust contains 8% of the total Al (Black et al. 1965), and it is the third most abundant element. It is a hydrolyzing metal and relatively insoluble in neutral or slightly alkaline pH (from 6.0–8.0). Hence, at this pH, it is not toxic to plants. Under acidic condition ($pH < 5.5$), or in the presence of the complexing ligands, the solubility of Al gets enhanced. Thus, it becomes more available for biogeochemical transformations and causes an adverse impact on the growth of plants (Matus et al. 2006). In soil, availability of Al depends on the pH of soil and the types and amount of clay and organic matter. Among these, soil pH is the most important factor. When the pH of soil falls below 5.5, then Al becomes available and has a toxic effect on the environment. Acid rain could be a reason for the drop in soil pH. Bekker and Yappa (1994) reported a greater amount of release of Al in red soil at pH 5.5. The plants could be directly affected with an increase in Al concentration in the soil. Under neutral or slightly alkaline condition, Al is present as an inert form in the plant and has no effect on their growth. Kleja et al. (2005) reported that solubility of Al increases in acidic soil. This, increase in Al concentration was attributable to complexation reaction with soil organic matter. Elizabeth et al. (2009) showed that high concentration of Al inhibits root elongation. Root cells and plasma membrane (particularly of the root apex) was the target of Al toxicity (Watanabe and Osaki 2002). Beside causing shallow rooting, it also leads to drought susceptibility and poor use of subsoil nutrients in acidic soils (Lidon and Barrerio 2002). In plants, a very small amount of Al is mostly taken up by leaves through the root system. Plasma membrane and cell wall is the main target for Al toxicity in plants (Pietraszewska 2001). Al is reported to interfere with cell division in root tips and lateral roots. It increases the cell wall rigidity by cross linking pectins with an increase in the rigidity of double helix DNA, thereby affecting DNA replication and fixing phosphorous in a less available form in the soil and plant root surfaces. It also decreases root reparations, interferes with the activities of a number of enzymes, and decreases deposition of cell wall polysaccharides, production, and transport of cytokinins. The reduction in water uptake and interference with the uptake, transport, and metabolism of several essential nutrients (Pietraszewska 2001) also occurred.

Indirect Impact of Al on Human Health

Water from Vehar Lake is supplied to the city as drinking water. Thus, a high level of Al concentration could have an adverse effect on human health. The adult human contains 9 ppm of Al as dry mass. In some organs, such as the spleen, kidneys, and lungs, Al is present at a concentration of 100 ppm. WHO (2004) stated that an average adult intake of Al from food is 5 mg/day of which 10 μg/day is absorbed from drinking water. Al is both mutagenic and carcinogenic (Banasik et al. 2005). A high concentration of Al causes nerve damage, allergies, and osteomalacia (Winklhofer et al. 2000; Keith et al. 2002). Also, high concentration of Al leads to clinical disorders such as encephalopathy, low turnover bone disease, microcytic anemia, and suppression of parathyroid function (Steinhausen et al. 2004). Landkoff et al. (2006) showed that Al induces chromosomal aberrations, micronuclei, and sister-chromatid exchanges in human lymphocytes. Gonzalez-Munoz et al. (2008) reported that high Al induces neuronal apoptosis in vivo and in vitro. Keith et al. (2002) showed that Al causes neurological disorder (termed dialysis dementia), respiratory disorders, memory loss, fatigue, depression, behavioral modifications, and learning impairment, and it also increases the pulmonary level of macrophages. Dietary Al increases lipid peroxidation and Aβ

J. Hazard. Toxic Radioact. Waste 2011.15:305-311.

levels. It is also responsible for increased oxidative stress produced by transition of metals such as iron (Gonzalez-Munoz et al. 2008). Al can disrupt normal bone growth, which can lead to or exacerbate renal osteodystrophy (Pejovic et al. 2005). Studies by Rossbach et al. (2006) showed that in the Al powder industry, long-term inhalative occupational exposure to Al induced pulmonary fibrosis. Recently, it has been claimed that Alzheimer's disease (AD) is associated with Al content in the human brain (Wong et al. 2003). A high concentration of Al also causes Parkinson's disease, osteomalacia, and anemia (Verissimo et al. 2006). Though Al concentrations along the banks of Vehar Lake, water sediment, and on the soil around Bhandup plant is not in an available form but under acidic condition, this Al could become available and that could have a direct impact on the environment. This high concentration of Al could get into the water of Vehar Lake. The treatment process at Bhandup water treatment plant might not be effective in removing this high concentration of Al. This treated water is used for drinking purposes, and if a high concentration of Al is present in the drinking water, it could have the aforementioned adverse impact on human health.

Recommendations to MCGM

Proactive steps must be taken by MCGM to prevent an adverse impact of Al on the environment and human health. MCGM has taken one such step by replacing alum with PAC as a coagulant. They must also consider removing the sludge deposits and dispose of them according to the guidelines (USEPA 1996). This would prevent leaching of Al into the noncontaminated soil of the surrounding area of Bhandup complex water treatment plant. Thus, impact on plants could be minimized. This study revealed that the water sediment has a high concentration of Al. So, MCGM must consider removing these water sediments from Vehar Lake and dispose of them according guidelines (USEPA 1996). This would not only increase the water holding area of Vehar Lake but also reduce the probable direct adverse impact of Al on flora and fauna of Vehar Lake and the indirect impact on human health.

Alum could have an adverse impact on health and environment under acidic pH. So, alum could be replaced with polyaluminum chlorides (PAC), polyaluminum sulfates (PAS) and polyaluminum chlorosulfates (PACS) for coagulation process. Among the aforementioned products, PAC has become one of the most effective coagulants in water and wastewater treatment facilities. It has various applications including the removal of colloids and suspended particles, organic matter, metal ions, phosphates, toxic metals, and color (Zouboulis and Tzoupanos 2010). Thus, emphasis must be given to the use of PAC (as coagulant) as it has better efficiency in water treatment and also has a lesser environmental impact. Hence, the authors appreciate the step taken by MCGM toward the use of alum as a coagulant. De Schepper et al. (2010) reported that when PAC was used as coagulant, the EC_{50} concentration for the test organisms was found to be 90% higher than with that of alum. MCGM must also consider particular pretreatment facilities to treat the backwashed water before releasing it into Vehar Lake. This treatment could be achieved by a constructed wetland technology with appropriate media and plants. MCGM could adopt Al-tolerant plants to remove excess Al in the backwashed water. Some of the highly tolerant Al species are *Karridale*, *Trikkala*, *Woogenellup*, *Tahara*, *Empat*, *Muir*, *Seaton*, *Goulburn*, *Junee*, *Clare*, *Nungarin* species (State Government of Victoria 2005). *Melastona malabathricum* growth was enhanced in the presence of Al (Lidon and Barreiro 2002). These Al-tolerant species could be acclimatized under wetland conditions and used for treatment of backwashed water. A proper feasibility study for the same could be considered in the near future.

Conclusions

The assessment of soil samples collected from the banks of Vehar Lake, water sediment samples, and samples of sludge deposit at the meeting point of backwashed water and Vehar Lake showed a higher amount of Al concentration compared with the surrounding soil of Bhandup water treatment plant. This was mainly attributable to use of alum in the water treatment process and also release of waterworks waste into Vehar Lake. The backwashed water from Bhandup water treatment plant accumulated as sludge deposit, which had also leached into the water sediment of Vehar Lake. This deposited Al could have a direct adverse impact on flora and fauna of Vehar Lake. The water from Vehar Lake is used for drinking purposes, and hence, an indirect impact of Al on human health could be possible if appropriate measures are not taken. Thus, measures must be taken to remove the sludge deposits of Vehar Lake and safely deposit them at different locations where the detrimental effect of Al would be minimized. These water treatment sludge deposits must be treated and disposed of at different locations according to the guidelines given by USEPA (1996). Although Al was not present in toxic form as the pH of the sample was under neutral condition, if the pH falls below 5.5, this Al could become soluble and could have an adverse effect on plants and human health. Therefore, these sludge deposits must be excavated and deposited at another location where harmful impacts could be minimized. Thus, this study provided details of probable adverse effects from backwashed water (waterworks sludge) on flora, fauna, and human beings. An immediate action must be taken to prevent such adverse effects in the near future as discussed in this study.

Acknowledgments

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Notation

The following symbols are used in this paper:

B1–B9 = locations of soil samples from banks of Vehar Lake;
L1–L9 = locations of soil samples from surrounding area of Bhandup water treatment complex;
S1–S12 = locations of water sediment samples;
SL1–SL9 = locations of sludge samples; and
W1–W12 = locations of water samples.

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