ORIGINAL ARTICLE

Assessment of heavy metal pollution in lake sediments of Katedan Industrial Development Area, Hyderabad, India

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Abstract Spatial distribution and temporal trends studies were carried out at Katedan Industrial Development Area (KIDA) near Hyderabad, capital of Andhra Pradesh state, India under Indo-Norwegian Institutional Cooperation Program, to find out the extent of contamination in streams and lake sediments from the discharge of industrial effluents. Stream and lake sediment samples were collected from the five lakes in the study area and connecting water streams. The samples were analyzed by XRF spectrometer for toxic elements. The studies reveal that the stream sediments with in the KIDA and the impounded Noor Mohammed Lake down stream have high concentration of some of the toxic elements like chromium, nickel, lead, arsenic, zinc etc. The geology of the area indicates that the study area consists of residual soil of acidic rocks, which are predominantly of Archaean gneisses and granites having low to medium concentrations of chromium and nickel. The source of these high concentration of elements like lead 2,300 mg/kg, copper 1,500 mg/kg, arsenic 500 mg/kg, chromium 500 mg/kg etc. cannot be derived from the surrounding acidic rocks and may be attributed to the industrial effluents released in the ditches and random dumping of hazardous solid waste. It was observed that the metal concentrations increased in the streams during the dry season (pre-monsoon period). After the monsoon rains, the metal concentrations in the streams were reduced by half which may be due to dilution. The eroded sediments are deposited in the lake where very high concentrations were encountered. Overflowing of the lake will spread the contamination further downstream. The lake sediments will remain as a major source of contamination by desorption to the water phase regardless of what happens to the effluent discharge in the KIDA. However, some samples showed enrichment of lead, arsenic and nickel during post-monsoon, which were collected near the dumpsite due to the leaching of toxic elements from the dump site to the lakes. Some of the toxic elements like nickel and copper have not shown any dilution but have increased after the rains, which could be due to the leaching of arsenic from the dumpsite to the lake along with rainwater. Geochemical maps showing the distribution of heavy/trace elements in streams and lakes are prepared and presented in this paper. Effect of toxic elements on the health of the residents in the surrounding residential areas is also discussed.

Keywords Heavy metals · Contamination · Lake sediments · Katedan · Hyderabad

Introduction

The hazardous effect of toxic metals on environment and human health has been of great concern during the last couple of decades. The spatial distribution and temporal behavior of metals in sediments is essential information for environmental research (Marvin et al. 2002; Obiajunwa et al. 2002). Sediments are indicators of environmental contamination of water bodies by heavy metals and toxic compounds. Monitoring of sediments is important for tracing the spreading and impact of pollution related changes as lake/stream sediments act as sinks of pollutants and accumulate heavy metals from the surrounding

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geogenic or anthropogenic sources (Acero et al. 2003; Casas et al. 2003; Pekey 2006).

Sediments play an important role in the pollution pattern of river systems. Metals in surface waters have a strong affinity for the particulate phase, which facilitates their elimination from the water column and their accumulation in sediments (Ramamurthy and Rust 1978). While sediments are important sinks for pollutants, they can also release them back into the ecosystem when changes occur in environmental conditions such as pH, redox potential or the presence of organic chelators (Forstner 1981). The concentrations of heavy metals will show exponential increase with time, because there is no activity to funnel out the sediments and dilute the effect of pollution (Pekey 2006). Trace metals derived from natural inputs and anthropogenic emissions are ubiquitous in the global environment. Sediment contamination is often caused by human activities such as electroplating, dying, battery industries, mining and many other industrial processes which have metal residues in their waste and surface run-offs. This increase will pose more threats, as ultimately it will make its way laterally and vertically through the sediments, thereby polluting groundwater. Sediments serve as sink and reservoirs foe a variety of environmental contaminants (Williams et al. 2001; Zhou et al. 2004; Rheaume et al. 2000). It has been recognized that aquatic sediments absorb persistent and toxic chemicals to levels many times higher than the water column concentrations (Casper et al. 2004; Linnik and Zubenko 2000).

The main aim of the present study, which is the first comprehensive investigation of heavy metal sediment contamination in Katedan Industrial Area, is to document the spatial distribution of heavy metals and identify possible sources of sediment-bound heavy metals.

Study area

The Katedan Industrial Development Area (KIDA) is one of the thirteen industrial development areas developed on the outskirts of Hyderabad city by Andhra Pradesh Industrial Development Corporation in the year 1965. The study area in and around KIDA is situated on south of Hyderabad city. It lies between the Longitude 780 25′ to 780 27′ and Latitude 170 17′ 30″ to 170 20′ 13″ falling in Survey of India Toposheet No. 56 K/7 (Fig. 1) situated on Hyderabad–Bangalore National Highway NH7. There are about 300 industries dealing with dying, edible oil production, battery manufacturing, metal plating, metal alloys, plastic products, chemicals etc. located in the area. These industries can be categorized as small, medium and large industries. Most of these industries, directly release their effluents into nearby ditches and streams and the solid waste is randomly dumped on open land, along the roads
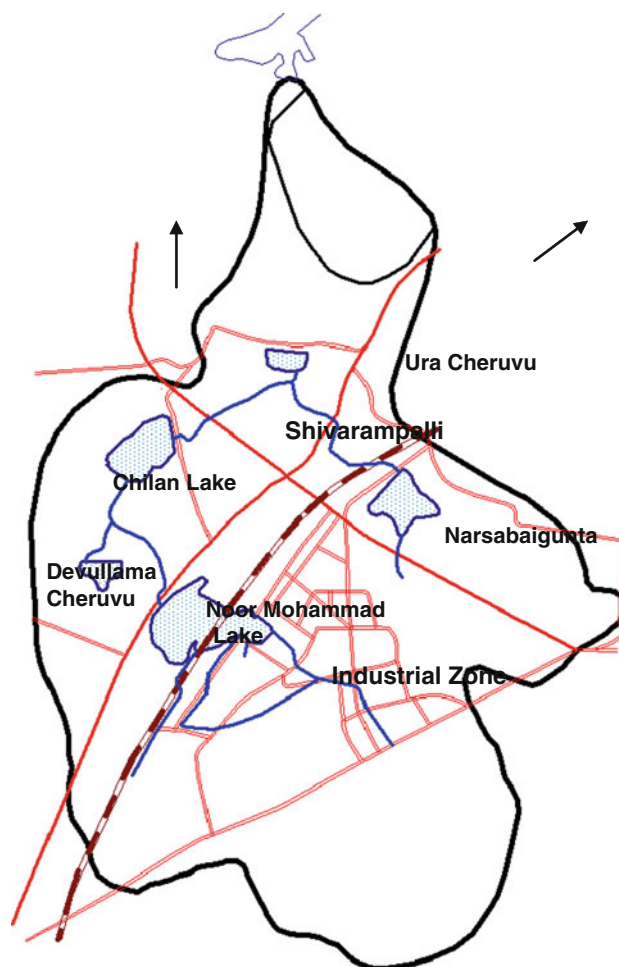

Fig. 1 Location map of Katedan Industrial Area and water shed

and lakes. The industrial effluents contain appreciable amounts of inorganic and organic chemicals and their byproducts. Most of the industries are small scale and do not have any sewage lines. They do not have proper wastewater treatment plants and discharge industrial effluents in unlined channels and streams. Indiscriminate random dumping of domestic and industrial waste has become a routine practice, increasing the levels of toxic elements in soil, water and stream sediments.

The area consists of granites and pegmatite of igneous origin belonging to the Archaean age. The granites are pink and grey in color, hard massive to foliated and well jointed.

These rocks possess negligible primary porosity but are rendered porous and permeable due to secondary porosity by fracturing and weathering, and fractured zones are locally forming potential aquifers.

The highest elevation recorded in the study area is 570 m above MSL and the lowest being 520 m above MSL. The hillocks in the area are characteristic of granitic terrain. The area under investigation is semi arid. The area

receives an average annual rainfall of 750 mm from the southwest and northeast monsoon. The maximum temperature rises to 43° during mid summer and reaches minimum to 10° during winters.

Hydrogeology

The area comprises of five lakes viz. Noor Mohammad Lake, Chilan Lake, Ura Cheruvu, Narsabaigunta, and Devullama Cheruvu. Small streams interconnect these lakes. The groundwater in the Archaean granites occurs in the weathered and fractured zones under water table and in semi-confined conditions. The depth of weathering and fractured zones dominantly controls the occurrence and the movement of groundwater in these rocks. Water level fluctuates annually in almost all the bore wells. The annual rise in the groundwater level is due to infiltration/percolation from rainfall and locally by seepage of water from surface storage tanks. The depth of the bore wells range from 100 to 200 m. Water levels usually rise in post-monsoon season with water table fluctuating between 1 and 15 m bgl and during pre-monsoon season water levels usually decline and the water table fluctuates between 10 and 25 m.

Methodology

Sample collection

Around 95 sediment samples were collected during pre- and post-monsoon season along the streams (nalas/creek) and lake periphery from a depth of 0–10 cm covering entire study area. Bottom sediments were also collected from these lakes from a depth of 1–3 m with the help of augers to address the above objectives.

Sample preparation

The sediment samples were air dried and kept in an oven for 2 days at 60°C temperature. The dried sediments were then disaggregated with mortar and pestle and sieved through a 2 mm sieve. The samples were ground in agate swing grinding mill to make the sample homogeneous and to get accurate analytical data, as it is essential that the surface layer should be representation of the bulk specimen. Weighing of sample is accomplished using analytical balance with precision as low as 0.0001 g. Pressed pellet is prepared by using collapsible aluminum cups (Govil 1985). These cups are filled with boric acid and about 1 g of the finely powdered sample is put on the top of the boric acid and pressed under a hydraulic press at 20 tons pressure to get a pellet.

Instrumentation

Elemental composition was determined using a wavelength dispersive X-ray fluorescence spectrometer, type Philips MagiX PRO model PW 2440 XRF with an Rh 4 kV tube. Its high level performance enables a very sensitive and accurate determination of major and traces elements (Si, Al, Na, Mg, Ca, Fe, P, S, As, Ba, Co, Cd, Cu, Mo, Ni, Pb, Rb, Sr, V, Zn and Zr). With the PW 2440 it is possible to scan the elements of interest from Boron to Uranium. The MagiX PRO is a sequential instrument with a single goniometer-based measuring channel covering the complete elemental range. The instrument is microprocessor controlled for maximum flexibility. The spectrometer operating conditions for major and trace elements are given in the Table 1.

International reference materials from US Geological Survey, Canadian Geological Survey (SO-1, SO-2, SO-3, and SO-4), International Working Group, France and National Geophysical Research Institute, India (NGRI-D & NGRI-U) were used to prepare the calibration curves for major and trace elements and to check the accuracy of the analytical data (Govil and Narayana 1999; Rao and Govil 1995). Concentrations of different elements in the reference materials used in the studies for the preparation of calibration curves are provided in Table 2.

Results and discussions

The sampling sites of the sediments are shown in Fig. 2. Measured chemical analysis data is summarized in Table 3. Maximum concentrations of potentially toxic elements in sediments are As-400, Cr-500, Cu-1486, Ni-271, Pb-2000, Zn-3327, Zr-827 mg/Kg, respectively (Figs. 3, 4, 5, 6, 7, 8, 9). The streams in the industrial area during the pre-monsoon, show very high concentrations of arsenic, lead, zinc and copper. High concentrations of chromium, cadmium and nickel are located in the lower reaches of one of the feeder streams. During the monsoon, the concentrations of lead and zinc remain high while arsenic, chromium, nickel, cadmium and copper are reduced. Studies reveal varying amount of pollution in the lakes depending upon the input from industries and urban settlements. The level of enrichment was very severe in the lake sediments of Noor Mohammad and Narsabaigunta, while it is not so great in Devullama, Chilan, & Ura lakes. The sources of these toxic elements in the Noor Mohammad lake is from the industries comprising of Batteries, Textile/Dye, Pharmaceutical, Metal Alloy, and Plastic industries which release its effluents directly to the lake. Studies revealed that domestic inputs being derived mainly from activities such as washing, bathing and from faeces to be the dominant sources of

Table 1 Instrumental conditions used in PW 2440-XRF analytical technique

Channel	Type	Line	X-tal	Collimator (μm)	Detector	kV	mA	Angle (°2T)	Bg1 (°2T)	PHD LL	PHD UL	Counting Time (s)	Line Overlap/
As	Gonio	KA	LiF 220	150	Duplex	40	90	48.71	0.99	30	63	100	Cd/alpha
Cr	Gonio	KA	PX 9	150	Duplex	40	70	69.38	0.77	30	70	100	Nil
Cu	Gonio	KA	LiF 220	150	Duplex	40	90	65.5	0.86	10	76	100	Nil
Pb	Gonio	LA	PX 9	150	Duplex	40	90	33.89	0.94	20	63	100	Nil
Ni	Gonio	KA	LiF 220	150	Duplex	40	80	71.22	0.85	38	66	100	Nil
Zn	Gonio	KA	PX 9	150	Duplex	40	80	41.74	0.91	26	63	100	Nil
Zr	Gonio	KA	LiF 220	150	Duplex	40	80	32.01	0.81	30	76	100	Ba/alpha

Table 2 Concentration values for reference materials

Element	SO_1 certified	SO_1 observed	SO_2 certified	So_2 observed	SO_3 certified	SO_3 Observed	SO_4 certified	SO_4 observed
As	2.05	1.96	1.17	1.14	2.51	2.20	7.40	6.60
Cr	170	163	12.3	12.1	27.0	28.3	64.0	64.1
Cu	61.0	58.8	8.07	7.74	17.0	16.3	21.0	19.1
Ni	82.0	84.9	8.05	7.89	14.0	13.1	24.0	24.2
Pb	20.0	18.6	20.0	19.8	13.0	13.1	14.0	12.6
Zn	140	135	115	114	48.3	47.5	94.0	92.6
Zr	84.0	82.7	760	758	156	154	270	265
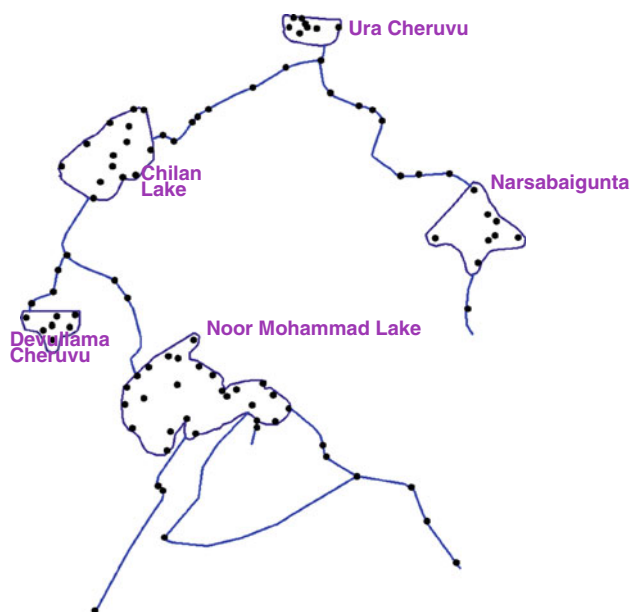
Fig. 2 Sample location map

copper, zinc, arsenic, and lead in Narsabaigunta. A linear correlation exists between arsenic and lead indicating simultaneous enrichment with the same pattern of dispersion behaviour.

From Table 2, it is clearly seen that Noor Mohammed Lake is acting as a sink for contaminants with 4–10 times higher concentrations than the other lakes downstream i.e., Chilan and Ura lakes. It was noted that the dumping of solid waste along the western shore at some places and reclaiming land by filling solid waste contributes directly to the raise of sediments concentration in Noor Mohammed Lake like many other lakes (Mucha et al. 2003; Rubio et al. 2000; Glasby et al. 2004). Lake Narsabaigutta is located in downstream residential area with a few industries. Raw sewage and stagnant water is dominating this lake but high concentrations of arsenic and lead are detected in the lake sediments. Soil samples were studied separately (Govil et al. 2008) which also showed high concentrations of toxic elements all over the industrial area and parts of residential area. A particularly interesting deviation from the spatial patterns relates to the relatively low contamination levels found in sediments of the lower basin of Ura lake. Relatively higher sediment contaminant concentration indicated local sources of some contaminants (Sutherland 2000; Wildi et al. 2004). Spatial trends in sediment contamination may have been influenced by industrial activities in the watershed or contaminants even derived through atmospheric deposition can ultimately be deposited in deep water areas. This process is sometimes referred as sediment focussing (Rossmann 2002, Rheaume 2000).

Table 3 Average concentrations of heavy metals in lakes, mg/kg

Lakes	As		Co		Pb		Ni		Cd		Cr		Cu		Zn	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Noor Mohammad	>400	>400	8.1	14.5	709	914	79	234	2	1.2	135	172	137	447	490	1336
Chilan	42	12.4	10	6.25	96	146	46	24	2	1.4	70	70	47	50	244	339
Ura	34	5.6	10	12.8	79	64	32	26	2	1.3	62	87.9	39	52	142	77.5
Devullama	57	–	25	–	142	–	46	–	0.05	–	95	–	36	–	76	–
Narsabaigunta	>400	–	12	–	422	–	31	–	2	–	75	–	95	–	292	–
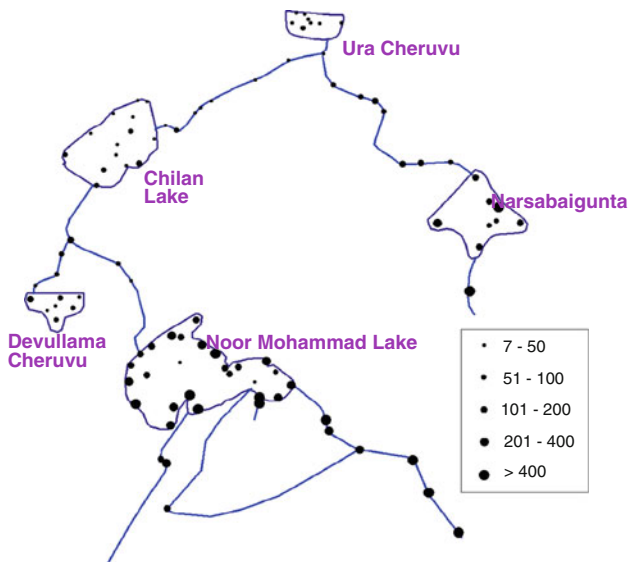
Fig. 3 Distribution of Arsenic in mg/kg
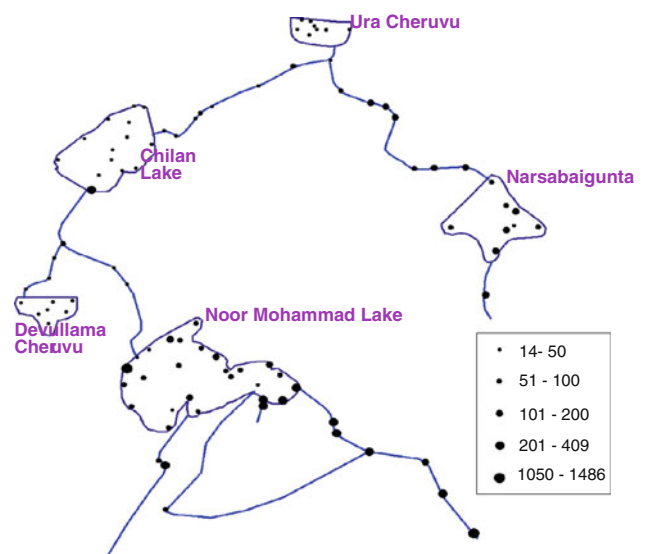

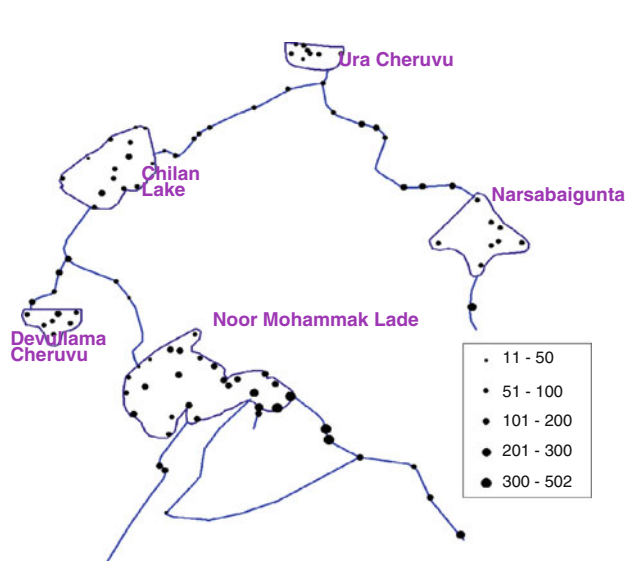
Fig. 5 Distribution of Copper in mg/kg

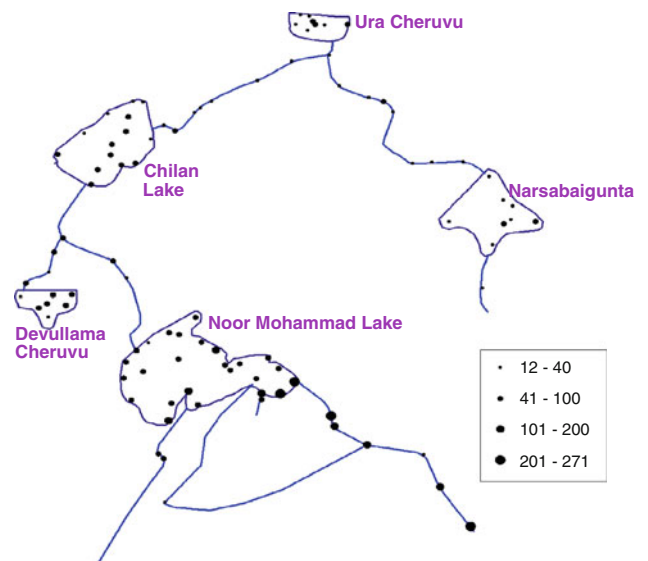**Fig. 4** Distribution of Chromium in mg/kg

Fig. 6 Distribution of Nickel in mg/kg

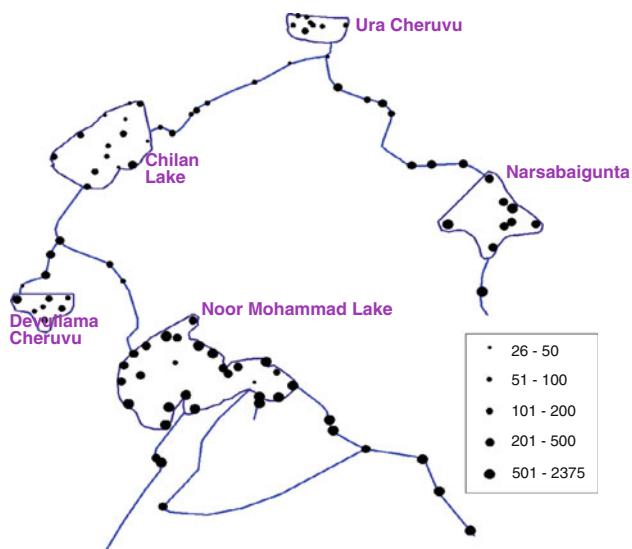Fig. 7 Distribution of Lead in mg/kg

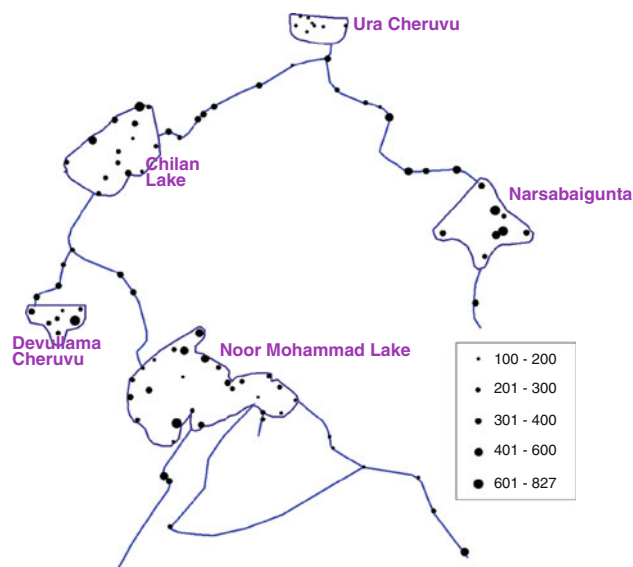Fig. 9 Distribution of Zirconium in mg/kg

Dumping of solid industrial waste

The dumping of solid industrial waste directly on the ground is a major source of contamination. Most of the spreading will take place during the monsoon, through rainwater and wind and toxic elements are transported to the surface water bodies and settle in the lake sediments.

Most of the industries are small scale and do not have any sewer lines or waste water treatment plant. As a result the highly colored and toxic chemical effluents join the Noor Mohammed Lake, a man made feature, thereby polluting the entire study area. Heavy metals are natural constituents of the Earth's crust and are present in varying concentrations in all ecosystems. Human activity has drastically changed the biogeochemical cycles and balance of heavy metals. Heavy metals are stable and persistent environmental contaminants, since they cannot be degraded or destroyed. Therefore, they tend to accumulate in the soil and sediments causing adverse effects on the environment and human health. Exposure to heavy metals has been linked with development retardation, various types of cancers, kidney damage and even death in some instances of exposure to very high concentrations.

Background (reference) data

The background levels of heavy metals in the soil of the surrounding areas away from contamination were determined by the levels that existed in the parent material and by redistribution in the profile during the process of soil formation. The samples were prepared and analysed in the same way as the rest of the samples. The background values i.e. from geogenic sources were found to be
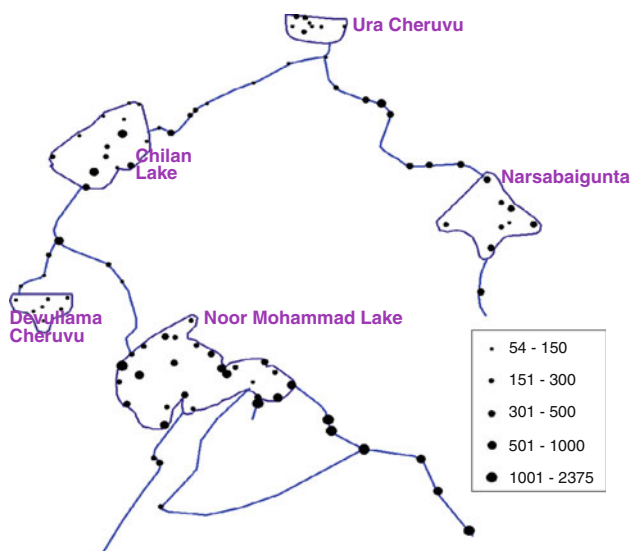

Fig. 8 Distribution of Zinc in mg/kg

Contaminant sources

Primary sources: The following primary sources of contamination exist within the KIDA:

- Dumping of solid industrial waste, randomly in the area.
- Untreated industrial effluents discharged into ditches and streams.
- Emission from smokestacks.

These primary sources create secondary sources, from which contaminants will spread for many years after the primary sources are removed. The secondary sources are:

- Sediments in stream and lake beds
- Subsoil and weathered granite

Table 4 Comparison of data with similar studies

Element	This study	Pote et al. (2008) (Lake Geneva)	An and Kempbell (2003) (Lake Texoma)	Ozturk et al. (2009) (Avsar Dam Lake)	Sunderland (2000)
Cr	337	30	–	110
Co	–	–	15.8	–
Ni	87	17	35.2	439
Pb	620	10	–	175
Cu	727	38	–	258
Zn	–	–	–	368

cadmium 0.2 mg/kg, chromium 35 mg/kg, nickel 28 mg/kg, lead 64 mg/kg, zinc 52 mg/kg and arsenic 13 mg/kg. It is observed that the concentrations of these elements in sediments are very high in comparison to reference values showing the anthropogenic input from the surrounding industries.

Correlation coefficients

Correlation coefficients were calculated for all the trace elements. Strong positive correlation >0.8 was found for As versus Pb, Cr versus Ni, and Cu versus Zn which reveal their common source viz. industrial contamination. Common source viz. anthropogenic activity sinks in the lake sediments of the study area. Weak positive correlation <0.5 was observed among As–Ni, Cr–Zn, Cu–Ni, Ni–Zn and Pb–Zn.

Concentration of toxic elements observed in the present studies are much higher than similar studies carried out by other researchers except the studies of Ozturk et al. (2009) for Geneva lake sediments. A comparative table is produced (Table 4).

Conclusions

The studies reveal varying amount of pollution in the lakes depending upon the input from industries and urban settlements. The results show the continuous accumulation of heavy metals in the bottom sediments of Noor Mohammed Lake which is associated with the sedimentation of suspended solids. The sediments of Noor Mohammad Lake have high concentrations of some of the toxic elements like chromium, nickel, lead, arsenic, zinc etc. The study area is surrounded by acidic rocks, which are predominantly of Archaean gneisses and granites having low concentrations of chromium and nickel. High concentrations of these elements cannot be derived from the rocks in the area and therefore, the source of these elements could be industrial effluents released in the area from the surrounding industries.

Lead concentrations were high in most of the sediment samples during pre-monsoon season. Some samples showed enrichment of lead during post-monsoon, which were collected near the dumpsite. The high concentrations after monsoon may be attributed due to the leaching of elements from the dump sites. Some of the toxic elements like Ni and Cu have also not shown any dilution but have increased after the rains, which could be due to the leaching of arsenic from the dumpsite to the lake along the rainwater. The level of enrichment was very severe in the lake sediments of Noor Mohammed Lake while it is not so high in Devulamma, Chilan and Ura lakes. The increase in heavy metal concentrations of Noor Mohammed Lake is a cause for concern as these metals have the ability to bioaccumulate in the tissues of biota (Zhau et al. 2004; Wilson et al. 2005; Giuliano et al. 2007). These heavy metals enter the food chain and affect the plants, animals, and humans in the area (Jonathan et al. 2004; Larocque and Rasmussen 1998; Obiajunwa et al. 2002, Huisman et al. 1997; Wilson et al. 2005). Nickel and arsenic are known carcinogens and lead causes hypertension. As a remedial measure of contaminated site, all the sediments may be excavated and transported to a landfill site for hazardous waste. The stream bed may be back-filled with plain sand. A treatment plant may be installed to clean the wastewater before it is released in the lakes.

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