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Spatial assessment of Heavy Metal Contamination in the Sediments of Kodaikanal Lake, Tamil Nadu, India

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Abstract: Lake sediments, as basic components of our environment; provide food stuff for living organisms. They also serve as a sink and reservoir for a variety of environmental contaminants. Namely when released into aquatic environment, many anthropogenic chemicals bind (or) adsorb on to particulate matter. Study on the geochemistry of lake sediments in the present area has not been undertaken by previous worker so far. In this article potential environmental risks associated with in the Kodaikanal Lake by quantifying the pollution in sediments. Concentrations of heavy metals in the lake sediments reached with the average values of 105228 mg/kg for Fe, 1402 mg/kg for Co, 451 mg/kg for Cr, 348 mg/kg for 115 mg/kg for Ni, 112 mg/kg for Zn, 67 mg/kg for Cd, 54 mg/kg for Cu and 44 mg/kg for Pb. The enrichment factor (Ef), geoaccumulation index (Igeo) and Contamination factor (Cf) for these metals were indicative of no to extremely sever enrichment, heavily to extremely high contaminationand low contamination to Considerable contamination, respectively. Contamination degree and pollution load index of the samples indicates that they were very high contamination degree with polluted nature. Anthropogenic activities inthe proximity of the Kodaikanal town exhibited high Igeo and EF values. Results of integrated indices of Co, Cr, Mn, Ni, Zn, Cd, Cu and Pb in lake sediments indicated that the sediment qualities are contaminated as a whole and warranted an instantaneous remediation action for the Kodaikanal Lake.
Keyword: Heavy metal, Enrichment factor, Geochemical index, Contamination, Pollution, Lake Sediment.

I. INTRODUCTION

It is progressively more comprehended that the planet earth is facing critical environmental problems with rapid exhaust of natural resources and threatening the survival of most of the ecosystems.Attraction of people towards high altitude lakes explode the increase in population which lead to worldwide concern on environmental and health impacts of contaminated waste and effluent discharge (Vernet, 1991). A legacy of unsustainable development is clearly chronicled in sediments worldwide as the impact of anthropogenic activities has led to a substantial increase in riverine, lacustrine, estuarine and marine sediment metal concentrations. It has been recognized that aquatic sediments absorb persistent and toxic chemicals to levels many times higher than the water column concentration (Caspers et al 2004; Vermeulen and Wepener1999; Linnik and Zubenko, 2000). Namely, when released into the aquatic environment, many anthropogenic chemicals bind or adsorb onto particulate matter. Pollution from heavy metals is regarded as one of the major universal concerns in the natural environment due to its features of being indestructible and the toxic effects on living organisms when exceeding the permissible concentration limits (Mmolawa, et al., 2011). Moreover, heavy metals are stable and persistentenvironmental contaminants in the coastal watersand sediment regardless of whether they are introduced by lithogenic sources, anthropogenic sources or both (Fernandes and Nayak, 2012). Someof the metals, such as cobalt (Co), chromium (Cr), cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) are regardedas the most serious pollutants in the aquatic ecosystem due to their environmental persistence, toxicity and abilityto be incorporated into the food chain (Ololade et al., 2008).The sedimentbound metals might be released into the water body againthrough various processes of remobilization under variableconditions (Yu et al.,2008).Enrichment factor, Igeo accumulation and contamination factor coupled with its degree of contamination and pollution load index are known to make a distinctionbetween the sediment being enriched by anthropogenicor natural input.Therefore,these indexes enable us to gain an integrated picture of themetal contamination in the Kodaikanal lake sediment, thus, determiningeither the sediment presence as natural phenomena, anthropogenicactivities or a combination of both.Thepurpose of this study is to determine the concentration of metals (Co, Cr, Mn, Ni, Zn, Cd, Cu and Pb) in the Kodaikanal lake sediment, besides it estimates the degree of heavy metal input into the system.

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II. MATERIALS AND METHODS

A. Study Area

Kodaikanal is located within the Palani Hills in Dindugal district, Tamil Nadu, south India and falls in between the Latitude 110 19’ 0” N and Longitude 790 31’ 30” E. The Palani Hills are an offshoot of the Western Ghats, which are in part comprised of pristine forests and grasslands that are home to endangered flora and fauna. One of these areas is the Pambar Shola forest, a nature sanctuary protected by the Tamil Nadu State Government, which edges the town of Kodaikanal. It descends in the Achaean formation of the Western part of Tamil Nadu (Fig. 1).

B. Sampling and Analytical procedures

Bottom surface sediment deposits of Kodaikanal Lake were sampled using VanVeen grab sampler. Roughly 1 to 2 Kg (wet weight) of sediments was collected at its site; samples were stored in sealed Ziploc- bags with lake water. Sediment samples are also serves as an excellent tool for establishing the hydrodynamic, the depositional environmental condition, contaminant additions to the water system and the inventories of pollutants. The sediment sample locations are shown in Fig.2 along with its corresponding coordinates.

ICP-Ms technique is used for multi elemental analysis of aqueous samples. It has a wide linear dynamic range and yields simple mass spectra which can be corrected for isotopic abundances of the interfering elements. Replicates of 0.05g samples were weighted and taken in a clean PTEE Teflon beaker. Each sample was moistened with a few drops of water. Then 10 ml of the acid mixture containing a 7:3:1 ratio of HF, HNO_3, and $HClO_4$ was added to each beaker and the sample swirled until completely moistened. The beakers were covered with lids and the samples left standing overnight after adding 5 ml of ^{103}Rh (1µg/ml) as an internal standard. The next day, the beakers were heated on a hot plate at 220º C for about 1 hour, after which the lids were removed, the contents evaporated to near dryness. The evaporation process was repeated after adding 5 ml of the above acid mixture in each case. Finally, the residue was dissolved by gently heating in 20 ml of 1:1 HNO3. Clear solutions were obtained for all samples. After cooling to room temperature, the volume was made up to

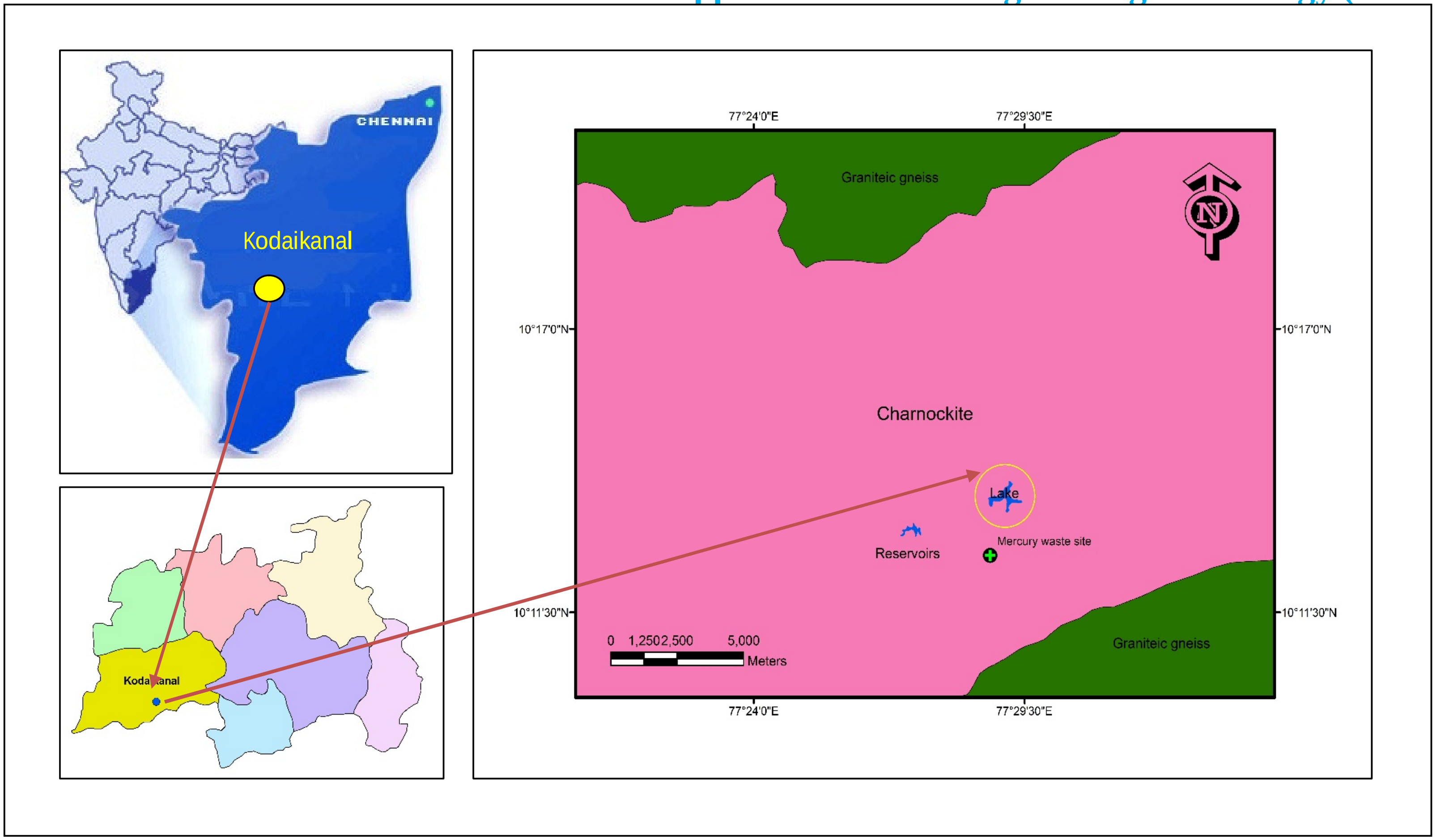

Fig. 1. Study Area Location

250 ml, and these solutions were stored in polyethelene bottles for ICP-MS analysis.Significant trace elements in Kodaikanal Lake sediments were carried out at National Geophysical Research Institute (NGRI), Hyderabad, India in Perkin Elmer SCIEX ELAN @ DRC-II ICPMS.

Class	Value	Soil or sediment quality
0	$I_{geo} \leq =0$	Uncontaminated
1	$0<I_{geo} <1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately contaminated to heavily contaminated
4	$3 < I_{geo} < 4$	Heavily contaminated
5	$4 <I_{geo} < 5$	Heavily to very heavily contaminated
6	$5 <I_{geo}$	Very heavily contaminated

C. Intensity of Heavy metal Pollution

The intensity of contamination in the sedimentsis determined with the help of five parameters - Enrichment Ratio (ER), Geo-accumulation Index (Igeo), Contamination factor, contamination degree and Pollution Load Index (PLI).

1) *Enrichment factor (Ef):* Ef was calculated to determine the levels of metals in sediments of Lake Kodaikanal environment were of anthropogenic origins (Contamination). To identify anomalous metal concentration, geochemical normalization of the heavy metals data to conservative elements, such as Al, Fe and Si was employed. Several authors have successfully used iron to normalize heavy metals contaminants (Schiff and Weisberg, 1999; Baptista Neto et.al, 2000; Mucha et.al., 2003). According to Forstner and Wittmann (1983), in case of Fe, particularly theredox sensitive iron-hydroxide and oxide underoxidation condition constitute significant sink ofheavy metals in aquatic system. Even a low percentage of Fe $(OH)_3$, in aquatic system, has acontrolling influence on heavy metal distribution (Rath 2005). Therefore, Fe is taken as a normalization element while determining enrichment ratio (ER).

According to Ergin et.al, (1991), the metal Ef is defined as follows;

$Ef= (M/Fe)_{sample} / (M/Fe)_{reference}$

Ef values were interpreted as suggested by Birch (2003) where Ef < 1 indicates no enrichment, < 3 is minor; 3-5 is moderate; 5-10 moderately severe; 10-25 is severe; 25-50 is very severe and > 50 is extremely severe.

2) *Geoaccumulation Index (I_{geo}):*

A second criterion to evaluate the intensity of the historical heavy metal pollution in the Kodaikanal Lake sediments is the geoaccumulation index (Igeo) introduced by Muller (1979). The geoaccumulation index (I_{geo}) introduced by Muller (1979) was used to assess the metal pollution in the sediments of Kodaikanal Lake. Igeo is expressed as follows;

$I_{geo} = \log_2 (C_n/1.5 * B_n)$

Where,

C_n – Measured concentration of heavy metal in the sediment.

B_n – Geochemical back ground value in average shale (Turekian and Wedepohl, 1961) of element n, 1.5 is the back ground matrix correction in factor due to lithogenic effects. Geoaccumulation index classes according to Muller (1969) to assess the sediment quality are as follows;

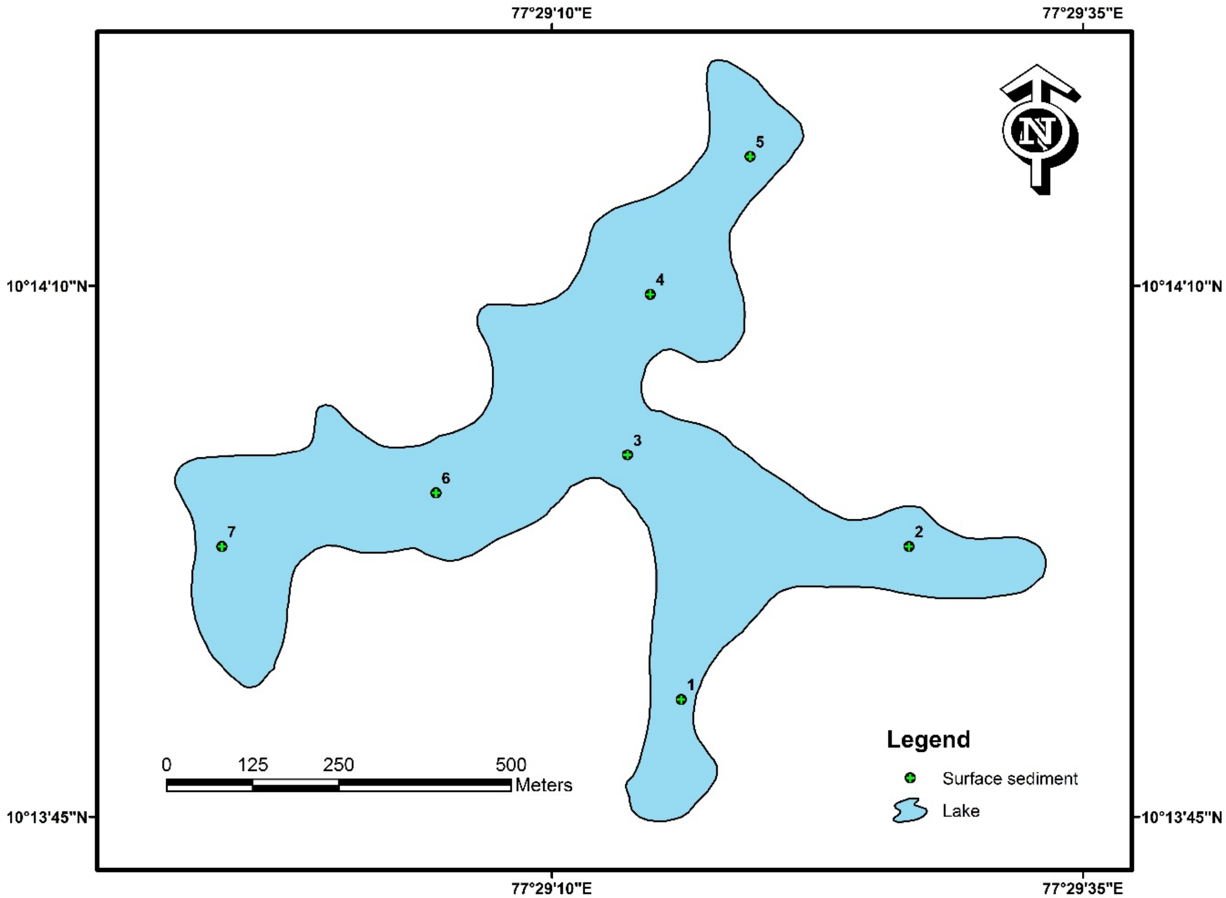

Fig. 2 Sample Location

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3) *Contamination factor (C_f) and Contamination degree (C_d):* Hakanson (1980) had suggested to contamination factor (C^i_f) and degree of contamination (C_d) to describe the contamination of given toxic substances. Cf is calculated by;

$$C^i_f = C^i_{0-1}/C^i_n$$

Where,

Co^i_{-1} is the mean content of the substance

C^i_n is reference value for the substance.

The numeric sum of the *K* specifiescontamination factors which express the overall degree (Hakanson, 1980) of sediment contamination (*Cd*) usingthe following formula:

$$C_d=\sum_{i=1}^{k} cf_i$$

According to the Hakanson classification (1980), $C_f< 1$ designate to low contamination, $1 \leq C_f< 3$ designates moderate contamination, $3 \leq C_f< 6$ designates considerable contamination and $C_f \geq 6$ designates very high contamination factor. The following terminology is adopted to describe the contamination degree base on the Hakanson classification (1980), $C_d< 6$ designate to low contamination degree, $6 \leq C_d<12$ designates moderate contamination degree, $12 \leq C_d<24$ designates considerable contamination degree and $C_d \geq 24$ designates very high contamination degree.

4) *Pollution Load Index (PLI):* Pollution loadindex (PLI), for a particular site, has beenevaluated by following the method proposed by Tomilson et al. (1980). This parameter is expressedas:

$$\mathbf{PLI = n\sqrt{\ } (CF1*CF2*CF3\ldots CFn)}$$

Where, CF is the contamination factor,

where, n is the number of metals (nine in thepresent study) and

CF is the contamination factor.

5) *Spatial Analysis:* All spatial maps were obtained with the Geographical Information System (GIS), ArcView version 10.1 by ESRI Software. The most common application of GIS is to create a grid based map into the spatial format. The interpolation algorithm used was Inverse Distance Weightage (IDW) which assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart.

III. RESULTS AND DISCUSSION

A. Grain Size

The grain size parameters viz., Mean size (MZ) Standard deviation (бi), Skewness (Ski) and Kurtosis (KG) of percentilevalues derived from the cumulative curves following Folk andWard (1957) and the moment technique based upon groupeddata (Friedman, 1967) are most widely used. Grain size analysis shows that all the sediments are medium silt to very fine sand in nature. Table 1 gives the detailed description of the sediments. Since metal concentration increases with decreasing grain size of sediments, indemnity of grain size differences is one of the most important normalization techniques for the detection and quantification of anomalous metal concentrations (Angelidis and Aloupi, 1977). Consequently, the coarse sedimentary fraction plays the role ofdiluents affecting the mass (total) metal absorption. Since the grain size of the sediments are silty clayey in nature, the bulk sediment sample was taken into account for metal analysis in the present study and its relationship with metals were established.

B. Organic matter

Once the metals are released to the environment, they are transferred to the sediments through adsorption onto suspended matter and consequent sedimentation (Hart, 1982). The adsorption and sedimentation process of metals mainly depend on the composition including grain size and level of organic matter, Fe-Mn oxyhydroxides etc., (Jonathan et al., 2003). Decomposition of organic material produces organic ligands that may extract metal from the sediments which can effectively mobilize metals by increasing their concentration in the water (Fergusson, 1990; Taulis 2005) and subsequently to the sediments. Clays have high surface area and can directly trap heavy metals, but they also may act as a substrate for organic matter flocculation (Keil et al., 1994) that in turn

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absorbs metals. Highest percentage of organic matter (16.0) was recorded in the sample 6 and the lowest percentage (7.5) in sample 1. Tam and Wong (2000) suggested that the concentrations of organic matter in the fine grained fraction of the sediments were often higher than that in the sand sized fractions.

Table.1 Description of Sediments

S. No.	Mean size (MZ)	Standarddeviation (бi)	Skewness (Ski)	Kurtosis (KG)
1.	Very Fine Sand	Poorly Sorted	Fine Skewed	Platykurtic
2.	Very Fine Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
3.	Very Fine Sand	Very Poorly Sorted	Near Symmetrical	Platykurtic
4.	Fine Sand	Poorly Sorted	Very Fine Skewed	Platykurtic
5.	Medium Sand	Moderately Well Sorted	Fine Skewed	Leptokurtic
6.	Medium Silt	Poorly Sorted	Near Symmetrical	Mesokurtic
7.	Medium Silt	Poorly Sorted	Fine Skewed	Mesokurtic

C. Intensity of Heavy metal Pollution

Anthropogenic activities have caused important transformations in aquatic environments during the last 150 years. Heavy metals are among the most widespread of the various pollutants originating from anthropogenic activities, particularly from mining and smelting waste sites (Salomons, 1995; Hochella et al., 1999). Such sites typically release large amounts of heavy metals into fluvial systems that can be transported along hydrologic gradients for hundreds of kilometres in relatively short times. The release of heavy metals can occur both in dissolved and particulate form. When released in particulate form or adsorbed to particles, heavy metals can settle down and be deposited in the bottom river sediments under favourable hydraulic conditions provided by natural and reservoir lakes. In order to assess the metal content in lake sediments, it is important to establish the natural levels of these metals. Apart from naturalcontribution, heavy metals may be incorporated into the aquatic system from anthropogenicsources such as solid and liquid wastes of industries. Some degree of contamination maybe caused from fall out of industrial emissions from the atmosphere. However, in the present study area, no majorindustry exists at present and there are a few minor handicrafts apart from the tourism activities.

1) *Enrichment Factor (Ef):* The ranges of concentration (mg/Kg) of the heavy metals in Kodaikanal lake are Pb (20 – 97), Cu (37 – 92), Cr (292 – 544), Zn (57 – 265), Ni (79 – 163), Co (561 – 2699) and Cd (57 – 74), respectively (Table 2).The overall concentration order of heavy metals in thesediment is: Fe>Co > Cr >Mn> Ni > Zn > Cd > Cu >Pb. In order to evaluate the extent of the spatial distribution of heavy metal pollution affecting the Kodaikanal Lake sediments, an enrichment factor (Ef) is calculated. Table 3 gives heavy metal enrichment factor and the fig. 3 represents enrichment factors (Efs) for the sediments, with elements ranked by decreasing order of average enrichment factor. In decreasing order of magnitude, the average Ef values are; Cd (~100.49), >Co (~33.19)> Ni (~2.73) >Cr (~2.25) >Pb (~1.01), > Cu (~0.54) > Zn (~0.53). The spatial distributional patterns of the Ef values are shown in Fig. 4. Cd showed extremely severe enrichment, indicating high Cd concentration and its availability in the recent sediments. Its spatial distributional pattern shows higher Ef value at the location 6. Co shows Sever to extremely sever enrichment, the spatial pattern reveals sample 1 and 6 are extremely enriched, sample 3 and 5 are Very severely enriched and sample 2, 4 and 7 are severely enriched. Ni in the sediments exhibits minor to moderate enrichment, spatial pattern show that the sample 1 and 6 is having moderate Ef and other locations are having minor Ef. Cr in the sediments show minor enrichment and its spatial distributional pattern displays that the sample 3 is having high Ef value within the limit of minor enrichment. Pb document no to minor enrichment, spatial pattern of Ef values of Pb exhibits that the sample 1 and 6 are minor enrichment and rest of the samples are falls under the category of no enrichment. Cu show no enrichment in its opposition to the spatial distribution. No to minor enrichment is observed in Zn in the surface sediments of the Kodiakanal lake, and its spatial archetype shows sample 1 is minor and other are falls under the class of no enrichment. In general the sediments show no, minor, moderate, severe and extremely severe enrichment range. The higher Ef's reflect the influence of anthropogenic activities.

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Table 2 Basic Statistical data of Heavy metal Concentration (ppm) in Kodaikanal Lake Sediments

Metal	Minimum	Maximum	Mean
Fe	102000	109000	105229
Co	561	2699	1402.33
Cr	292	544	451.833
Mn	211	482	348.333
Ni	79	163	115.333
Zn	57	265	112.5
Cd	57	74	67.1667
Cu	37	92	54.5
Pb	20	97	44.6667

Table 3. Enrichment Factor (EF) in Kodaikanal Lake Sediments

S.No	Co	Cr	Mn	Ni	Zn	Cd	Cu	Pb
1	54.51	1.89	0.26	3.22	1.27	108.03	0.53	2.21
2	13.53	1.49	0.22	2.36	0.51	100.82	0.50	0.82
3	38.87	2.80	0.16	2.85	0.42	103.35	0.47	0.79
4	13.67	2.43	0.15	2.30	0.36	98.15	0.89	0.43
5	33.11	2.25	0.18	2.72	0.53	100.45	0.54	1.00
6	62.66	2.28	0.22	3.78	0.26	108.81	0.50	1.17
7	16.00	2.60	0.11	1.83	0.38	83.81	0.36	0.62
Min	13.53	1.49	0.11	1.83	0.26	83.81	0.36	0.43
Max	62.66	2.80	0.26	3.78	1.27	108.81	0.89	2.21
Average	33.19	2.25	0.18	2.73	0.53	100.49	0.54	1.01

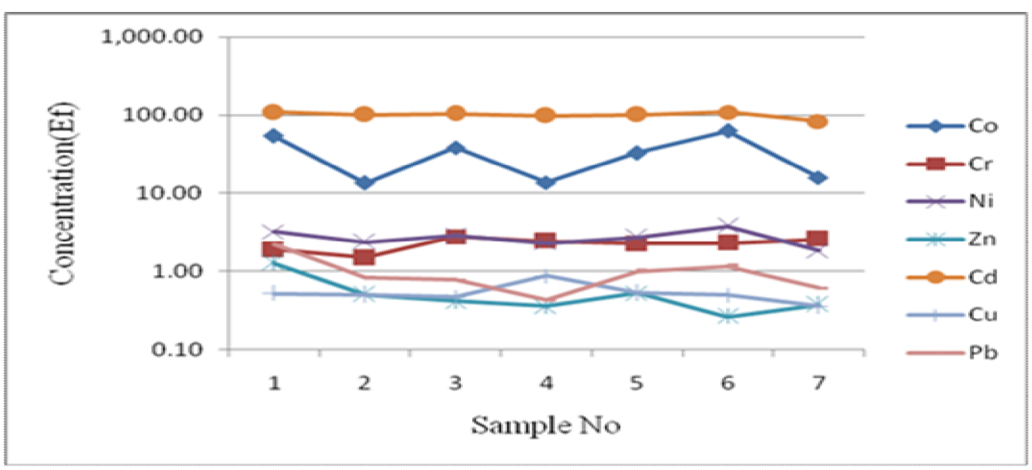

Fig. 3 Enrichment factor in the Kodaikanal Lake Sediments

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2) *Geoaccumulation Index (I_{geo}): The* Igeo accumulation is associated with a qualitative scale of pollution intensity. The calculated Igeo values for Kodaikanal Lake are given in Table 4 and their variations are shown in fig.5. In the sediment samples, Igeo accumulation index of the Kodaikanal Lake are showing the mean values of Igeo accumulation index range is as Mn (17.54) > Fe (16.10) > Cr (14.70) > Co (13.87) > Zn (12.63) > Ni (12.32) > Cu (10.62) > Pb (9.05) > Cd (3.74). The sample of Koodaikanal Lake is heavily contaminated with respect to Cd (Fig. 5). The Igeo accumulation indexes of the other heavy metals like Zn, Cr, Ni, Cu, Pb, Fe, Mn and Co in all locations are falls under class 6 indicating extremely contaminated.

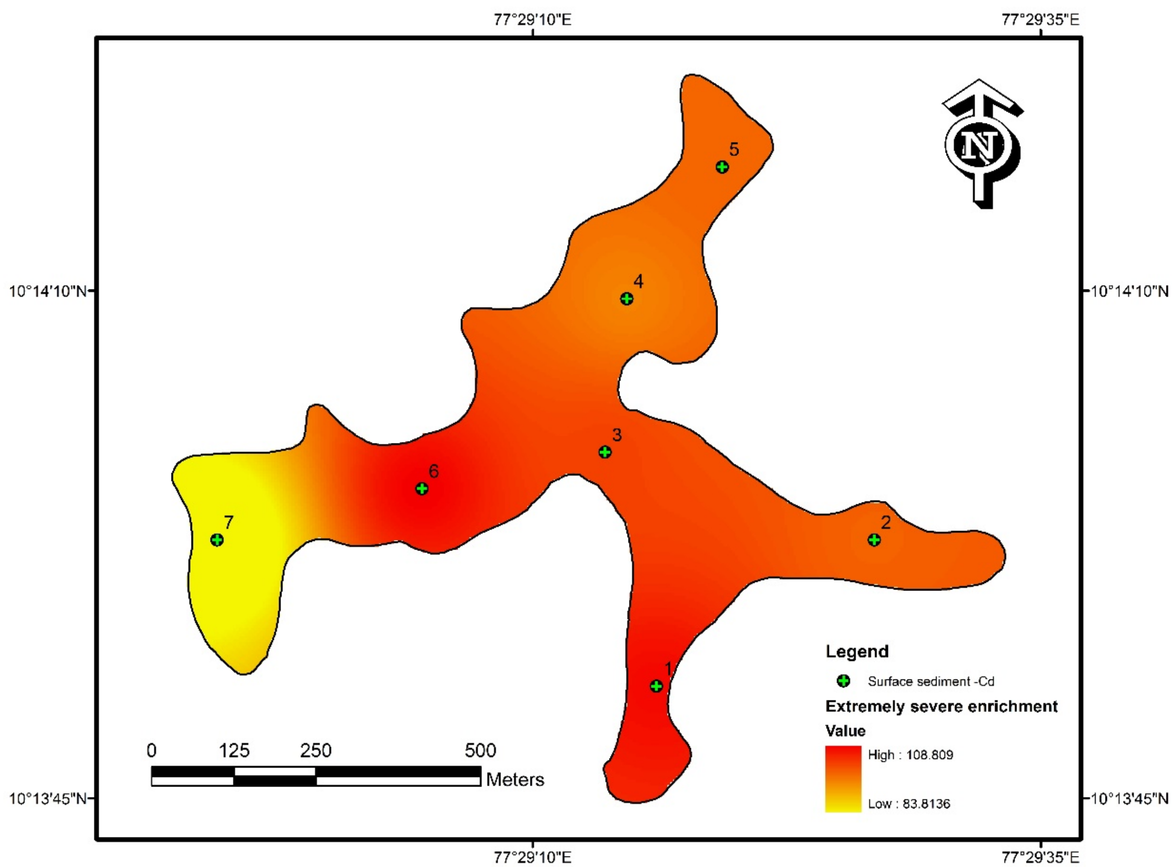

Fig. 4 Spatial Distribution of enrichment Factor in Kodaikanal Lake Sediments

Table 4 Geoaccumulation Index (Igeo) in Kodaikanal Lake

S.No	Fe	Co	Cr	Mn	Ni	Zn	Cd	Cu	Pb
1	16.07	14.81	14.45	18.06	12.57	14.03	3.83	10.61	10.34
2	16.07	12.79	14.10	17.80	12.12	12.71	3.72	10.52	8.91
3	16.05	14.30	14.99	17.34	12.37	12.41	3.74	10.43	8.82
4	16.15	12.89	14.89	17.31	12.16	12.31	3.77	11.43	8.06
5	16.10	14.12	14.73	17.59	12.35	12.80	3.75	10.68	9.22
6	16.12	15.06	14.77	17.84	12.85	11.82	3.89	10.58	9.46
7	16.12	13.09	14.96	16.87	11.81	12.32	3.51	10.12	8.54
Min	**16.05**	**12.79**	**14.10**	**16.87**	**11.81**	**11.82**	**3.51**	**10.12**	**8.06**
Max	**16.15**	**15.06**	**14.99**	**18.06**	**12.85**	**14.03**	**3.89**	**11.43**	**10.34**
Average	**16.10**	**13.87**	**14.70**	**17.54**	**12.32**	**12.63**	**3.74**	**10.62**	**9.05**

3) *Contamination Factor (C_f) and Degree of Contamination (C_d):* Table 5 shows the contamination factor (Cf) of each element and also the degree of contamination (Cd) for each sampling point for the Kodaikanal lake sediments. On the basis of the Cf values ranges of sediments from the lake are classified as, low contamination factor for Mn (0.25 - 0.57); low to moderate contamination factor for Cu (0.82 - 2.04); moderate contamination factor for Ni (1.16 - 2.40) and Zn (0.60 -2.79); low to considerable contamination factor for Pb (1.00 - 4.85); considerable contamination factor for Cr (3.24 - 6.04); and very high contamination factor for Co (29.53 - 142.05) and Cd (190.00-246.67). Calculation of the contamination degree (Cd) for the Kodaikanal Lake sediments indicates that the lake is considered to be a lake with a considerable degree of contamination for the location 2, 4 and 7 (26.55 - 30.21) to very high degree of contamination in the location 1, 3, 5, and 6 (34.63 - 44.83), indicating serious anthropogenic pollution.

Table 5 Contamination Factor (Cf) and Degree of Contamination (Cd) in the Kodaikanal Lake sediments

S.No	Contamination factor (C_f)									Contamination degree (C_d)
	Fe	Co	Cr	Mn	Ni	Zn	Cd	Cu	Pb	
1	2.19	119.42	4.13	0.57	1.97	2.79	236.67	1.16	4.85	41.53
2	2.18	29.53	3.24	0.47	1.44	1.12	220.00	1.09	1.80	28.99
3	2.16	84.00	6.04	0.34	1.72	0.91	223.33	1.02	1.70	35.69
4	2.31	31.58	5.62	0.34	1.49	0.84	226.67	2.04	1.00	30.21
5	2.23	73.81	5.02	0.41	1.70	1.18	223.89	1.21	2.23	34.63
6	2.27	142.05	5.18	0.49	2.40	0.60	246.67	1.13	2.65	44.83
7	2.27	36.26	5.90	0.25	1.16	0.85	190.00	0.82	1.40	26.55
Min	**2.16**	**29.53**	**3.24**	**0.25**	**1.16**	**0.60**	**190.00**	**0.82**	**1.00**	**26.55**
Max	**2.31**	**142.05**	**6.04**	**0.57**	**2.40**	**2.79**	**246.67**	**2.04**	**4.85**	**44.83**
Average	**2.23**	**73.81**	**5.02**	**0.41**	**1.70**	**1.18**	**223.89**	**1.21**	**2.23**	**34.63**

4) *Pollution Load Index (PLI):* Tomilson et al., (1980) has employed a simple method based on pollution load index to assess extent of pollution by metals in sediments. Table 6 gives PLI calculation and the results shows that the Kodaikanal lake sediments are polluted with Fe, Mn, Cr, Co, Zn, Ni, Cu, Pb and Cd. The above findings and the combination of heavy metal contamination and

Table 6 Pollution load index in the Kodaikanal Lake sediments

S.No	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Fe	2.19	2.18	2.16	2.31	2.23	2.27	2.27
Co	119.42	29.53	84.00	31.58	73.81	142.05	36.26
Cr	4.13	3.24	6.04	5.62	5.02	5.18	5.90
Mn	0.57	0.47	0.34	0.34	0.41	0.49	0.25
Ni	1.97	1.44	1.72	1.49	1.70	2.40	1.16
Zn	2.79	1.12	0.91	0.84	1.18	0.60	0.85
Cd	236.67	220.00	223.33	226.67	223.89	246.67	190.00
Cu	1.16	1.09	1.02	2.04	1.21	1.13	0.82
Pb	4.85	1.80	1.70	1.00	2.23	2.65	1.40
PLI	**2123.40**	**271.15**	**486.34**	**292.27**	**650.60**	**940.33**	**170.51**

pollution is shown in table 7, and it exhibits that the metals like Fe, Mn, Cr, Co, Zn, Ni, Cu, Pb and Cd are of contaminated and polluted state in the Kodaikanal Lake. High Cu content in the sediment samples, as revealed from the three parameters, could be mainly due to anthropogenic factors along with dispersion or lithogenic influx from the upper catchment.

Also be attributed predominantly to the contribution from domestic waste discharges. Results of Geo-accumulation evaluation indicated that Cd was mainly on the contaminated degree. However, ecological risk caused by Cd was considerable due to its high toxicity. On the otherhand, Zn accumulated more than any other metal but its ecological risk was relatively low due to its low toxicity. Further, where stagnant condition prevails at the bottom of the lake, the dissolved oxygen is completely removed. As a result, free metallic complexes are formed which influence the solubility of metal 'lead' by forming insoluble complexes. These complexes tend to strip the water of its metal content and enrich the bottom sediments with the metal (Mehrotra et al. 1991).

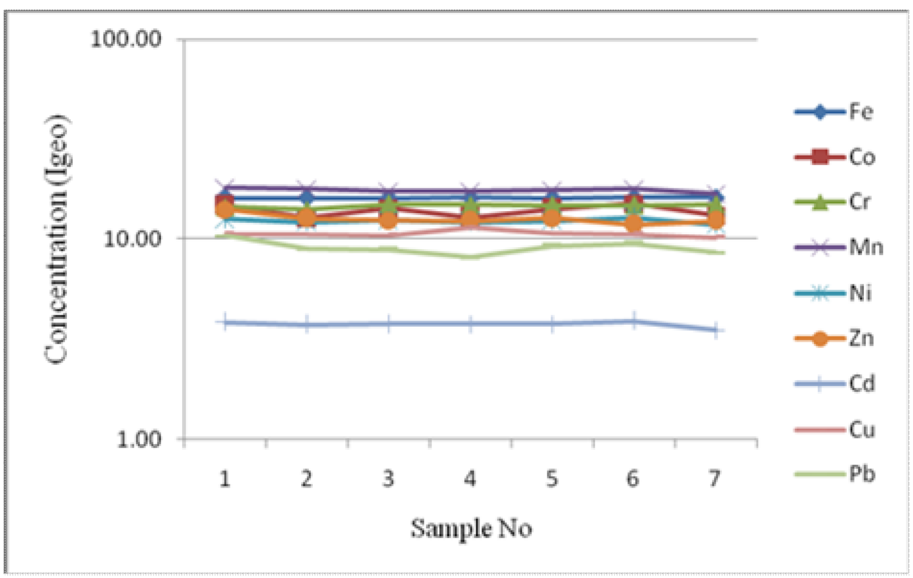

Fig. 5. Igeo accumulation Index in Kodaikanal Lake Sediments

Table 7. Heavy metal Pollution Evaluating factors combination

	Enrichment factor (E_f)	I_{geo}	Contamination factor (C_f)	Pollution Load Index (PLI)	Contamination degree (C_d)
Co	Severe to Extremely severe enrichment	Very highly contaminated	Very high contamination factor	Polluted	Considerable degree of contamination To Very high degree of contamination
Cr	Minor enrichment	Very highly contaminated	Considerable contamination factor	Polluted	
Mn	No enrichment	Very highly contaminated	Low contamination factor	Polluted	
Ni	Minor to Moderate enrichment	Very highly contaminated	Moderate contamination factor	Polluted	
Zn	No to Minor enrichment	Very highly contaminated	Moderate contamination factor	Polluted	
Cd	Extremely severe enrichment	Heavily contaminated	Very high contamination factor	Polluted	
Cu	No enrichment	Very highly contaminated	Low to Moderate contamination factor	Polluted	
Pb	No to Minor enrichment	Very highly contaminated	Low to Considerable contamination factor	Polluted	

IV. CONCLUSION

The bottom surface sediments of Kodaikanal Lake are fine grained sediments. The calculation of enrichment factors revealed that sediments are substantially enriched in heavy metals, in some case up to ten times above background levels. The main source of contamination is the domestic waste which discharges into the lake and carries organic and inorganic (heavy metals) contaminants. Atmospheric deposition may also contribute to the accumulation of Pb, Cu, Zn, and other metals in the lakes' sediments. Contamination assessment based on Geo-accumulation Index (Igeo) showed that metals were in the contaminated to moderately contaminated degrees, and were in the decreasing order of: Ni > Zn > Cu > Cd > Pb > Cr. The assessment results showed that Cd was the only metal posing a potentially high risk to environment. Overall these data show that the natural environment surrounding the Kodaikanal Lake is severely contaminated by heavy metals (Cd, Pb, Zn, and Cu). Precautionary actions should be considered in order to prevent the dispersion of pollution and avoid population exposures. Calculating these risks urges for an immediate remediation plan.

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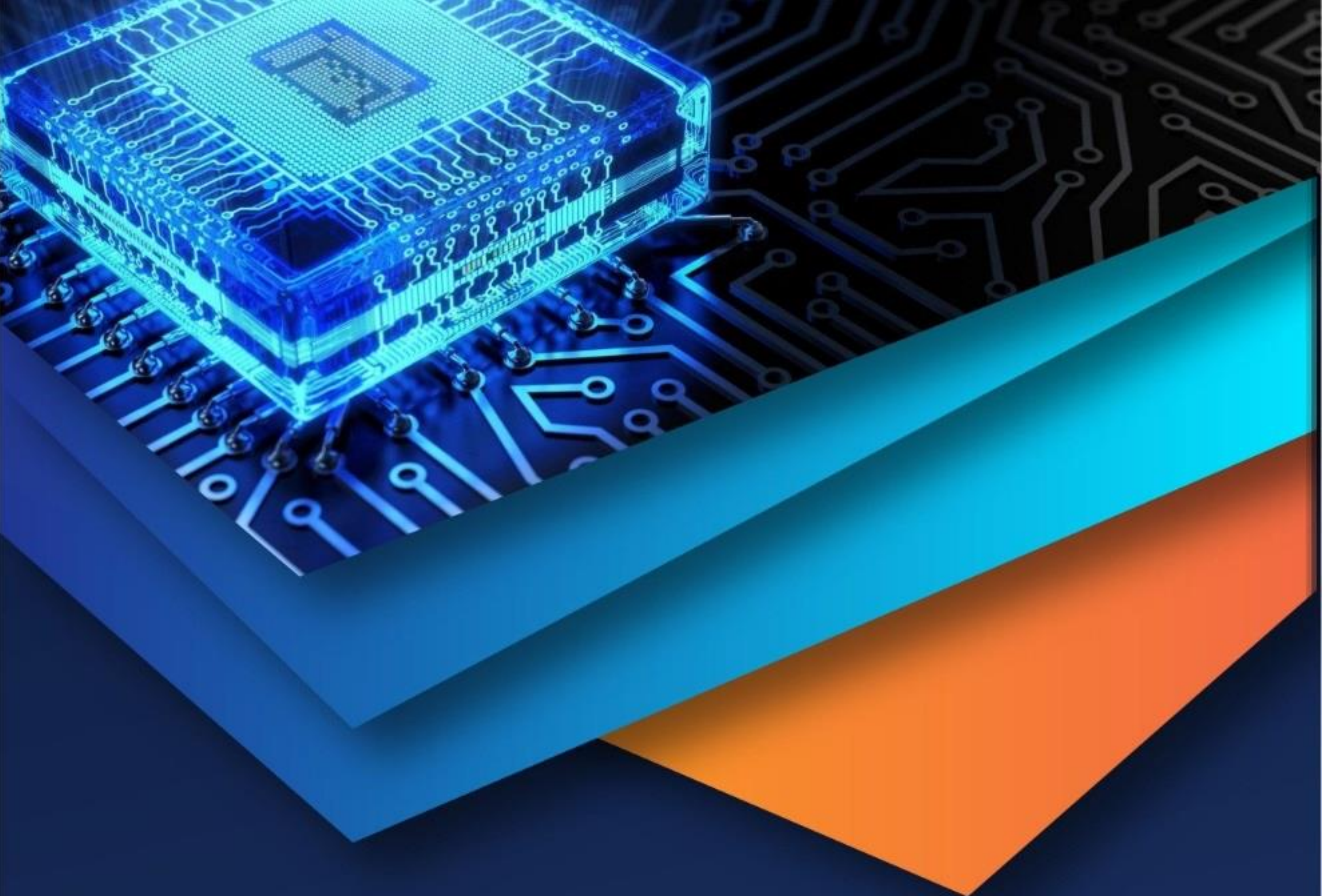

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