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ECOLOGICAL RISK ASSESSMENT OF A TROPICAL LAKE SYSTEM

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Abstract: Risk analysis of urban aquatic systems due to heavy metals turns significant due to their peculiar properties viz. persistence, non-degradability, toxicity, and accumulation. Akkulam Veli (AV), an urban tropical lake in south India is subjected to various environmental stresses due to multiple waste discharge, sand mining, developmental activities, tourism related activities etc. Hence, a comprehensive approach is adopted for risk assessment using modified degree of contamination factor, toxicity units based on numerical sediment quality guidelines (SQGs), and potentialecological risk indices. The study revealed the presence of toxic metals such as Cr, Cd, Pb and As and the lake is rated under 'low ecological risk' category.

Keywords: Contamination factor; degree of contamination; ecological risk assessment; heavy metals; risk indices; toxicity unit.

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INTRODUCTION

Aquatic systems, as basic components of our environment, provide food and shelter for flora and fauna as well as act as a sink for a wide variety of pollutants. Aquatic sediments, especially in urban environment, accumulate metal pollutants from various sources to much higher concentrations than corresponding water columns. The main contributors include weathering of rocks and soils and multiple anthropogenic activities resulting discharge of industrial and urban wastes into water bodies (Singh *et al.,* 2005). Among these pollutants, heavy metals have been of great concern due to their toxicity, abundance, persistence, and subsequent accumulation in aquatic habitats (Kaushik *et al.,* 2009; Lin *et al.,* 2003; Singh *et al.,* 2005; Yuen *et al.,* 2012). These adsorbed contaminants may be later released into the water column with changing environmental conditions and may pose a threat to biota (Junhong *et al.,* 2011).

Although determination, spatial distribution, and enrichment of heavy metals in lake systems have been extensively discussed (Abraham & Parker, 2008; Fatma *et al.,* 2009; Swarnalatha *et al.,* 2013a, Swarnalatha *et al.,* 2013b), very few researchers (Krupadam *et al.*, 2006) focus on the purpose of risk assessment. A study of metal distribution and enrichment may not reveal the actual burden caused by these pollutants on a lake system. So, the environmental risks of heavy metals in sediments have been, and will remain to be, an important issue of great concern and significance (Krishna *et al.,* 2009; Siyue & Quanfa, 2010)

Akkulam Veli (AV) Lake, a shallow tropical lake in Thiruvananthapuram city (**Fig. 1**) in south India is polluted with heavy metals especially Zn and Pb (Swarnalatha *et al.,* 2013).

The waste disposal system of the city appears unscientific and is ill-maintained due to inappropriate waste management and lack of urban planning and implementation. The Kannamoola stream which passes through the thickly populated areas of Thiruvananthapuram city carries huge quantities of urban wastes (including sewage and garbage from multitude sources like residence, flats, hospitals and hotels) and is finally joining Akkulam part of lake. The embankment situated between two sections of AV Lake interrupt the flow from Akkulam to Veli. The lake water is almost stagnant with little flushing out and is currently in a hyper-eutrophic condition. Apart from high pollution load, the lake is home to different varieties of edible fish, otter, and varieties of bird population including migratory species. The observed sharp reduction of their dwindling population prompted us to undertake a risk analysis of this fragile ecosystem. Thus the main objective of the present study was to examine the risk contribution of each heavy metal assessed using parameters like degree of contamination, toxicity units, and ecological risk indices.

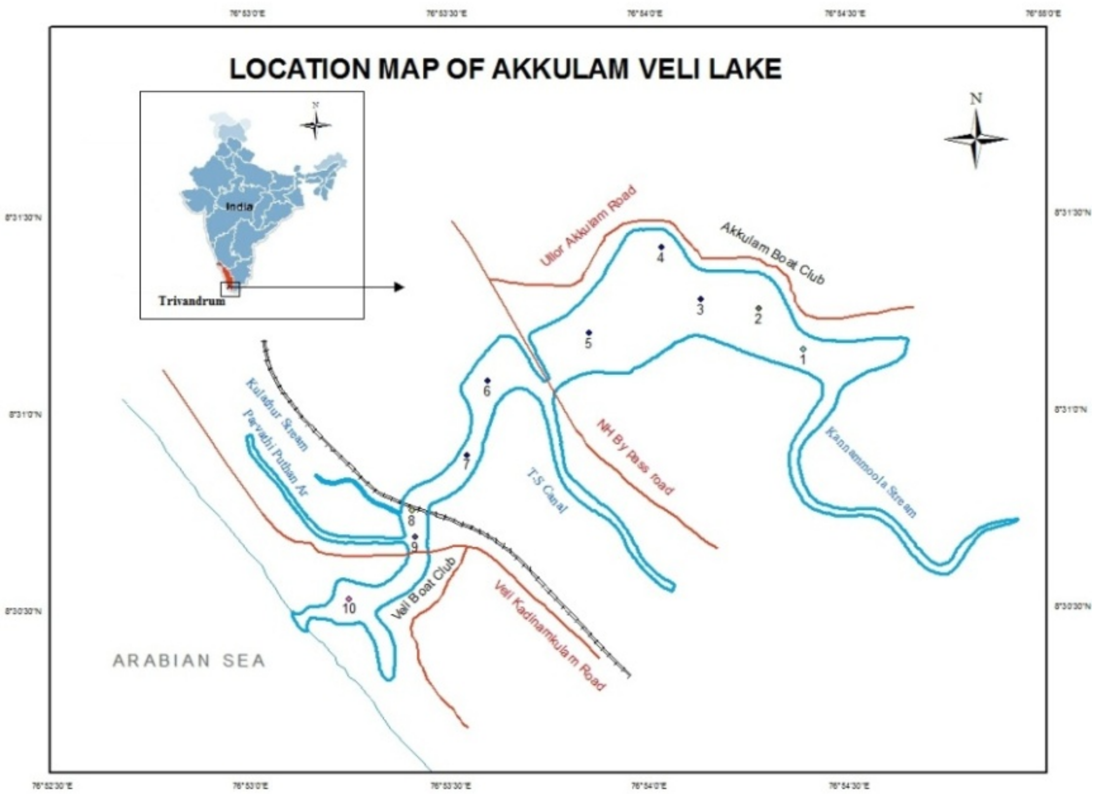

Fig. 1 Location map showing positions of sampling stations.

MATERIALS AND METHODS

Sample collection and analysis

This study considers the heavy metals concentrations of surface sediment samples collected in three consecutive seasons; Pre-monsoon (May, 2011; n = 14), monsoon (September, 2011; n = 11) and post monsoon (January 2012; n = 12). Upper sediments (0–15 cm depth) were taken using Van Veen grab samplers (Swarnalatha *et al.,* 2013a). De-ionised water is used throughout for the preparation of reagents and digestion. Only analytical grade chemicals and standard solutions were used. Heavy metals such as Cr, Co, Ni, Cu, Zn, Pb, Fe and Mn were detected by X-ray fluorescence (XRF) spectrophotometer using the LOI values. Metals such as cadmium, arsenic and mercury were determined using ICP- AES.

Comparison of metal concentrations

Numerical sediment quality guidelines (SQGs) can be used for assessing the degree to which the pollutants can adversely affect the aquatic organisms. The metal concentrations were thus compared with TEL/PEL guidelines (MacDonald *et al*., 2000) and ERL/ERM (Long *et al.,* 1995).

Modified degree of contamination

The methods suggested by Hakanson *et al.* (1980) was used to find out the degree of contamination (Cd) and modified degree of contamination (mCd), which can describe the toxicity of a metal (Harikumar *et al.,* 2010; Abraham & Parker, 2008). An overall indicator of contamination, denoted as 'degree of contamination' Cd is based on the calculation of contamination factor (CF) for each pollutant. It is a measure of the degree of overall contamination in surface layers as given in **Eq. (1)**:

$$\text{Cd} = \sum_{i=1}^{n} \text{CF} \qquad (1)$$

where n = number of analysed elements and i = ith element (or pollutant) and CF = Contamination factor. CF is determined as the ratio of metal concentration in sediment to the metals' background value (Swarnalatha *et al.,* 2013a,b). Average shale values (Turekian and Wedepohl, 1961) are used as background values. Modified degree of contamination (mCd) is the sum of all the contamination factors (CF) for a given set of estuarine pollutants divided by the number of analysed pollutants. It averages the contamination of all elements at a particular site by a single value and is determined as per **Eq. (2)**

$$\text{mCd} = \frac{\sum_{i=1}^{n} \text{CF}}{n} \qquad (2)$$

For the classification and description of the modified degree of contamination (mCd) in estuarine sediments, the following classification can be used. The degree of contamination can be assessed as shown in **Table 1**.

Table 1 Modified degree of contamination and its effects

mCd levels	Contamination status
mCd<1.5	Nil to very low degree of contamination
1.5 ≤ mCd < 2	Low degree of contamination
2 ≤ mCd < 4	Moderate degree of contamination
4 ≤ mCd < 8	High degree of contamination
8 ≤ mCd < 16	Very high degree of contamination
16 ≤ mCd < 32	Extremely high degree of contamination
mCd ≥ 32	Ultra high degree of contamination

Assessment of risk indices

Toxic units were used to normalize the toxicity caused by various heavy metals as the ratio of metal concentration to its corresponding Probable effect value (PEL). The PEL developed by McDonald et al, 1996 is better in predicting toxicity than ERLs and TELs (Long *et al.,* 1998, Junhong *et al.,* 2011, Konstantinos *et al.,* 2002). Risk indices were developed based on Hakanson (1980) for evaluating ecological risk of aquatic systems (Krupadam *et al*., 2006; Yuebing *et al*., 2010).

This procedure was used to evaluate the ecological risks due to anthropogenic heavy metal pollution. Thus the ecological risk index (RI), was based on the assumption that sensitivity of aquatic systems depends on its productivity. RI values and the corresponding effects are shown in **Table 2**. RI of a given contaminant (Hakanson, 1980) is determined by the formula:

$$\text{RI} = T_{rf} * \text{CF} \qquad (3)$$

where T_{rf} = the toxic-response factor for a given substance with values for each element in the order Zn = 1, Cr = 2, Co = Cu = Ni = Pb = 5, As = 10, and Cd = 30. CF represents contamination factor of a single metal pollutant. The sum of individual potential risks (RI) represents the potential ecological risk index (PERI) of the water body:

$$\text{PERI} = \Sigma\text{RI} = \Sigma(T_{rf} * \text{CF}) \qquad (4)$$

Table 2 Risk index levels and their effects

Risk index	Effects
< 150	Low ecological risk
150–300	Moderate ecological risk
300–600	Considerable ecological risk
> 600	Very high ecological risk

RESULTS AND DISCUSSIONS

Mean heavy metal concentrations

Concentrations of heavy metals such as Cr, Co, Ni, Cu, Zn, Pb, As and Cd in the surface sediments of AV lake are summarized in **Table 3**. Mercury was found undetectable in all the samples. As, was found more distributed in the Akkulam part of the lake than seaward side. Cd concentration was in the range of 0 to 0.95 mg/kg and was below detectable limits in some samples. As and Cd are carcinogenic materials and poses a potential threat to aquatic systems (Wei *et al.*, 2010).

The source of As and Cd seems to be the urban drains reaching the Akkulam lake which is carrying wastewaters including sewage effluents, unauthorized discharges from residences ,shops, workshops, garages, service station etc. As and Cd was found mostly distributed in Akkulam sediments. Cd, Cu, Cr and Ni are toxic pollutants used in small amounts in petrol and diesel (David *et al.*, 2000). It can be seen that the average concentrations of As and Cd were all less than TEL/PEL and ERL/ERM values whereas average concentrations of Cr and Ni were exceeding TEL/PEL and ERL/ERM values. Cr and Ni are specific pollutants providing evidence of industrial pollution, but are largely present in sewage discharges and open urban drains. Results shows that mean concentrations of Cu and Zn were higher than TEL/ERL values, though lower than PEL/ERM levels. Cu and Zn are associated with high organic matter content which may be induced by the fine-grained texture of sediments in this region (Swarnalatha *et al.,* 2013a).

Assessment of degree of contamination

Degree of Contamination and Modified degree of contamination, mCd of sediments was determined based on Abrahim and Parker (2008) (**Table 4**). Cd can make an integrated assessment of the overall contamination by metallic pollutants. It was found that the Cd values ranged from 0.31–2.04. The minimum value was observed in the Veli side of the lake and the maximum at Akkulam side. 23 out of 35 observations were having mCd values below 1.5, indicating 'nil to very low degree of contamination'. The rest of the stations indicated 'low degree of contamination' with mCd values from 1.5–2. These results are in agreement with previous results reported earlier that the Akkulam side of the lake is more polluted than Veli side (Sheela *et al.*, 2010; Swarnalatha *et al.,* 2013a). In this study it was found that 63.6% of observations in the Akkulam side recorded mCd > 1.5 indicating 'low degree of contamination' whereas only 33.3% of observations in Veli side were under 'low degree of contamination'. Hence the results are found to be consistent with previous findings. Cd and mCd values can be used for getting an overall assessment of the lake as it is integrating the contributions of all observed metal concentrations. The effects of individual pollutants can be recognized only by assigning sufficient weightages based on their contamination effect.

Table 3 Descriptive Statistics of heavy metals (mg/kg) in Akkulam Veli lake sediments

Metal	Mini	Maxi	Mean	S.D	Var	Skew	Kurt	TEL	PEL	ERL	ERM
Cr	49	642	183.17	133.90	17928.4	1.73	2.90	37.3	90	80	145
Co	0	59	19.97	17.80	316.97	0.93	-0.41				
Ni	5	259	83.77	63.21	3995.95	1.35	1.27	35	36	30	50
Cu	3	126	53.80	32.63	1064.52	0.57	-0.45	35.7	197	70	390
Zn	19	279	123.40	68.33	4669.07	0.81	0.08	123	270	120	270
Pb	18	103	59.05	18.95	359	0.04	0.57	18	91.3	35	110
As	0	7.66	1.43	2.25	5.08	1.50	1.18	5.9	17	33	85
Cd	0	0.95	0.27	0.23	0.05	0.90	0.85	0.596	3.53	5	9
Hg	BDL	BDL									
Fe(%)	1.66	10.26	6.09	2.67	7.11	-0.19	-1.19				
Mn	0	488	218.54	139.42	19438.3	0.34	-1.01				

Min = Minimum values, Max = Maximum values, S.D = Standard deviation, Var = Variance, Skew = Skewness, Kurt = Kurtosis, TEL = Threshold effects level, PEL = Probable effect level, ERL = Effects range low, ERM = Effects range median, and BDL = Below detectable limit.

Table 4 Average degree of Contamination and mCd

Metals	Cr	Co	Ni	Cu	Zn	Pb	As	Cd	Fe	Mn	Cd	mCd
Values	2.04	1.06	1.20	1.20	1.30	2.94	0.11	0.91	1.30	0.26	12.21	1.22

Assessment of toxic units

Potential acute toxicity of contaminants in sediment samples can be estimated as the sum of toxic units (ΣTU), defined as the ratio of the determined concentration to PEL values (Pedersen *et al.,* 1998). It was reported earlier that PEL values are better for predicting toxic nature of metals than ERL/ERM values (Konstantinos *et al.,* 2002). A bar chart showing percentage contribution of each heavy metal to the sum of toxic units **(Fig. 2**) shows that major toxicity contributions in the lake are by Nickel (40%) and Chromium (35%).

High Cr contents in clay-minerals (illite) may be attributed to increased developmental activities in the lake vicinity, weathering of soils, and trapping from strongly reducing sediments. Ni has a similar behavior as that of Cr. The least contribution of toxic units is by Cd (1.23%). The percentage contributions of toxic units based on PEL is in the order Ni > Cr > Pb > Zn > Cu > As > Cd. The contribution towards toxicity for metals such as Cu, Zn, Pb, As and Cd in the 3 seasons has shown only slight variations (**Table 5**) whereas Cr and Ni show significant increase in toxicity in the post monsoon season.

It was observed that toxicity contribution of Arsenic from Akkulam side in three seasons was 100%, 87%, and 100%, respectively. This indicates that the source of As solely depending on the effluents conveyed to the lake by means of Amayizhanchan canal on the Akkulam side.

Assessment of Potential ecological risk index (PERI)

In order to get a more accurate assessment of heavy metal pollution in terms of ecological risks, potential ecological risk indices were determined (Hakanson, 1980). PERI represents the sensitivity of the biological risk caused by the toxic substance and illustrates the potential ecological risk caused by the overall contamination (Zhihao *et al.,* 2011). RI and PERI values in different seasons in the Akkulam side and Veli side of the lake are shown in **Table 6**.

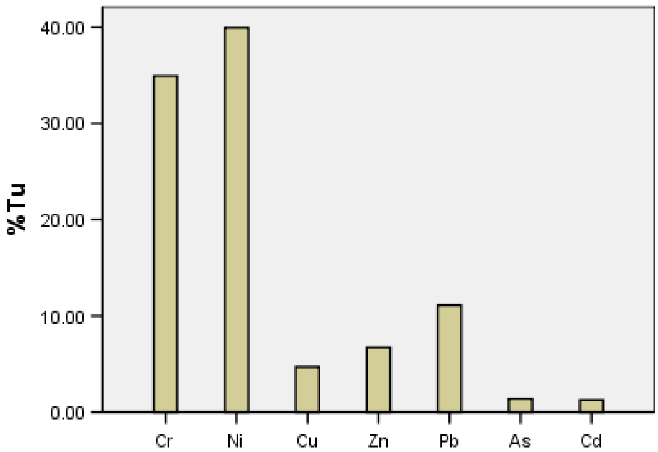

Fig. 2 Toxicity contribution of different heavy metals.

Table 5 Contribution to Toxicity units (ΣTu) of different metals

Metal	May11	Sep11	Jan12
Cr	16.4	12.58	42.26
Ni	16.56	16.28	48.61
Cu	2.98	3.73	2.85
Zn	4.3	4.95	4.46
Pb	7.01	6.79	8.84
As	1.04	0.77	0.97
Cd	0.74	1.32	0.46

Table 6. Risk indices and Potential ecological risk index in various seasons in surface sediments of Akkulam Veli lak

Season	Risk indices of various heavy metals in different seasons								PERI	Remarks
	Cr	Co	Ni	Cu	Zn	Pb	As	Cd		
May 11										
Akkulam	3.16	11.91	4.72	7.11	1.42	14.81	3.4	43	89.53	Low ecological risk
Veli	2.24	2.92	2.77	4.09	0.96	11.19	0.01	10	34.18	Low ecological risk
AV lake	2.52	5.69	3.37	5.02	1.10	12.31	1.05	20.15	51.21	
Sep 11										
Akkulam	2.76	13.51	5.49	9.70	1.93	17.33	2.89	33.67	87.28	Low ecological risk
Veli	2.11	4.8	3.33	6.56	1.33	12.88	0.17	45.5	76.67	Low ecological risk
AV lake	2.29	7.18	3.92	7.41	1.49	14.09	0.91	42.27	79.56	
Jan12										
Akkulam	5.42	3.49	8.11	7.44	1.83	15.38	3.16	34	78.82	Low ecological risk
Veli	8.97	2.44	13.75	4.67	1.07	20.04	0	3.71	54.65	Low ecological risk
AV Lake	7.68	2.82	11.70	5.68	1.34	18.34	1.15	14.73	63.44	

The average RI of metals for three seasons were found to be Cr–(2.52, 2.29, 7.68), Co–(12.31, 14.09, 18.34), As–(1.05, 0.91, 1.15), and Cd–(20.15, 42.27, 14.73). Cr, Ni and Pb had a significant increase in their risk indices in the post monsoon season whereas all other metals showed only slight climatic variations The PERI values in all seasons were found to be < 150 and hence AV lake sediments comes under 'low ecological risk'. PERI values in the Akkulam portion were the same throughout the year which clearly indicates contribution from anthropogenic sources. PERI values in the Veli portion of the lake were subjected to significant seasonal variations, with maximum values in the monsoon season indicating lithogenic contribution of heavy metals to sediments. Tapi estuary, which is heavily polluted with heavy metals from industrial effluents is having RI values of 250–350 (Krupadam *et al.,* 2006) whereas a RI value of 12.3 was reported in the surface sediments of Yingkou bay in China (Zhihao *et al.,* 2012).

CONCLUSIONS

This study demonstrate that AV lake sediments are polluted with heavy metals especially Cr, Ni, Co, Cu, Zn, Pb, As and Cd. Impacts of these metal pollutants were further investigated with the help of SQGs, degree of contamination, and risk indices. On a toxicity point of view the significant contributors are Ni, Cr and Pb.

Even though As and Cd are making less contributions towards toxicity units, it is necessary to control their external sources by reducing inflow of wastewater into the lake. The distribution of As and Cd is found to be more in the Akkulam region than Veli side. This clearly indicates source of these metals as the drain carrying urban wastes of all sorts are reaching the lake at the mouth of Akkulam portion. It could be inferred that the lake as a whole is subjected to 'low ecological risk' which basically demand urgent action from the concerned authorities for limiting wastewater inflow into the lake and for conserving this stressed ecological system.

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