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Pollution Characteristic and Health Risk Assessment of Toxic Chemicals of Surface Water in Surha Lake, India

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Abstract
The Surha Lake is located in the Jai Prakash Narayan bird sanctuary in U.P state, India. It supports the livelihood of a large number of species and economically important for local people. The present study is focused to assess the pollution characteristic of water quality and ecological risk of toxic chemicals using metal index (MI), Nemerow pollution index (NPI) and risk assessment index (RAI). The results indicate that the water quality of the lake is not suitable for drinking as MI>1 and NPI>3 with respect to drinking water and also has unacceptable risk of cancer to human health as RAI>1. However, the water is suitable for agricultural purpose as MI<1 and NPI<3, with respect to water quality for inland environmental discharge. Therefore, it has been suggested that water must be properly treated before use for drinking and proper conservation measure should be adopted to reduce the concentration of toxic chemicals in water of the Lake.

Keywords: MI, NPI, RAI, Surha Lake.

1. Introduction
Water is a vital and essential natural resource which can be utilized for various purposes. In the recent time, rapid urbanizations, industrialization and agriculture activities near the water bodies has resulted in a significant increase in contamination by heavy metals, which are the major environmental risk of macro and micro-invertebrates, fish, vegetations and humans [1]. The untreated discharges of effluents into a water body (which contains toxic metals that have strong bio-accumulation capacity and are environmental persistence) impairs the aquatic ecosystems and enter into the aquatic food chain, causing the sub lethal effects or loss of local fish populations and diseases in human [2-3]. Therefore, the special attentions need to be paid on such toxic trace elements. Although some trace elements (such as iron, chromium, copper, etc.) are essential, but in excess concentration, they may be lethal. On the other hand, the elements (such as arsenic, cadmium, mercury, lead, etc.) can be toxic even in very small concentrations [4-6]. The analysis of such dissolved toxic metals in water is a valuable tool for assessment of pollution and significant degree of contamination in a particular ecosystem [7-9]. In recent years, ecological health risk assessment or the probability of occurrences of adverse human health effects has become a widely used methodology to evaluate and classify the potential risks resulting from exposure to toxic environmental pollutants persistent in different environmental compartments such as water [10], soil and air [11-13]. A number of approaches have been developed world wide which describes the ecological risk, among which ecological risk index is the most recurrent. The purpose of the present study is to characterize the status of Surha Lake in U.P, India by analyzing the concentration of trace metals and derive the

ecological risk to human health. A number of studies have been conducted earlier related to the aqua status [14], diversity of fishes [15], identification of molluscan fauna, zooplanktons, and diversity of aquatic insects [16-17] in catchment of Surha Lake, while the analysis of trace metal has not been considered yet.

2. Materials and Methods

2.1.Study site details

Surha Lake is located in the Indo-Gangetic plain in the area of Jai Prakash Narayan Bird Sanctuary of district Ballia in U.P, India (Figure 1). It is an ox-bow lake. During the rainy season, it receives major water supply. In addition, three small streams Gararai, Madha and Katehar nala also supply water from Ganga and Saryu River (Ghaghra River). The lake is surrounded by extensive agricultural land and fishing in the lake is the main source of income for the large local population of district Ballia. The water sampling for analysis of toxic metals has been performed considering eleven sampling locations during pre and the post monsoon season (2014–15) in the Surha Lake. The Salient features of Surha Lake has been shown in Table 1 and the location map of all sampling locations (L1, L2, L3…..L11) considered in the study is represented in Figure 1.

Table 1. Salient features of Surha Lake in U.P, India

S. No.	Salient features	Description
1.	Location	Ballia distict of U.P
2.	Coordinates	$26^o40'$ to $26^o42'$ E and $84^o11'$ to $84^o14'$ N
3.	Catchment Area	34.329 km^2
4.	Area of lake	11.23 km^2
5.	Maximum depth	7 m
6.	Annual average rainfall	1000 mm
7.	Temperature range	4^0C in winter to 43^0C in summer

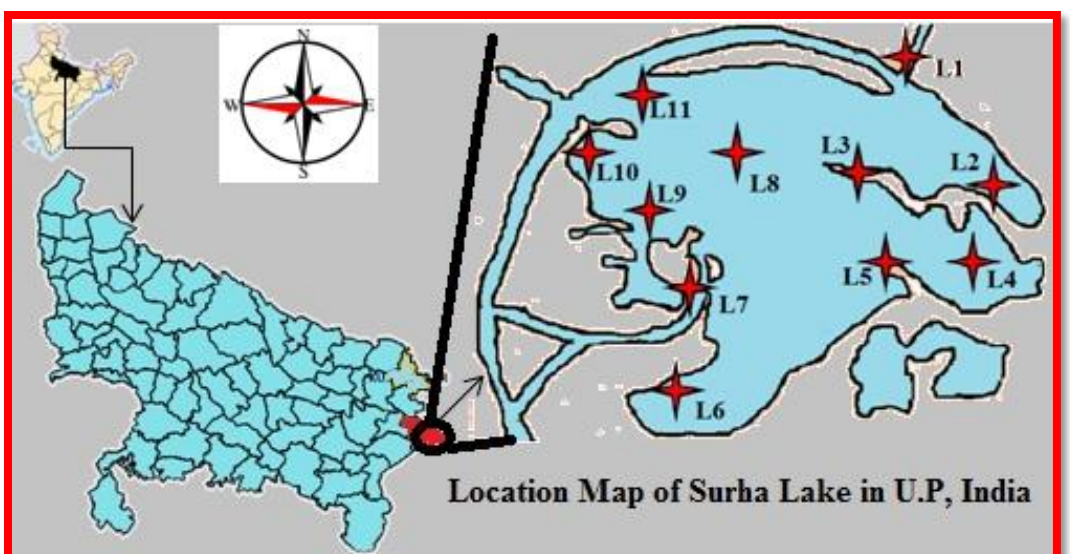

Figure 1: Map of sampling locations in Surha Lake of U.P, India

2.2.Data collection and analysis

The water samples were collected from L1, L2, L3…..L11 sampling locations in Surha Lake during wet and dry season in year 2014-15 to assess the ecological risk of toxic metals in surface water. The sub surface water samples were collected and preserved at 4°C for laboratory analysis of toxic chemicals like nitrate (NO_3), nitrite (NO_2), Fe, Cu, Zn and Cr using the Hach Spectrophotometric analytical methodology, as per the APHA [18] and the concentration measurement was performed in mg/l unit. Three observations were made for each water sample and the results are shown in Table 2 in terms of the mean concentration and standard deviation (SD) and graphically shown in Figure 2.

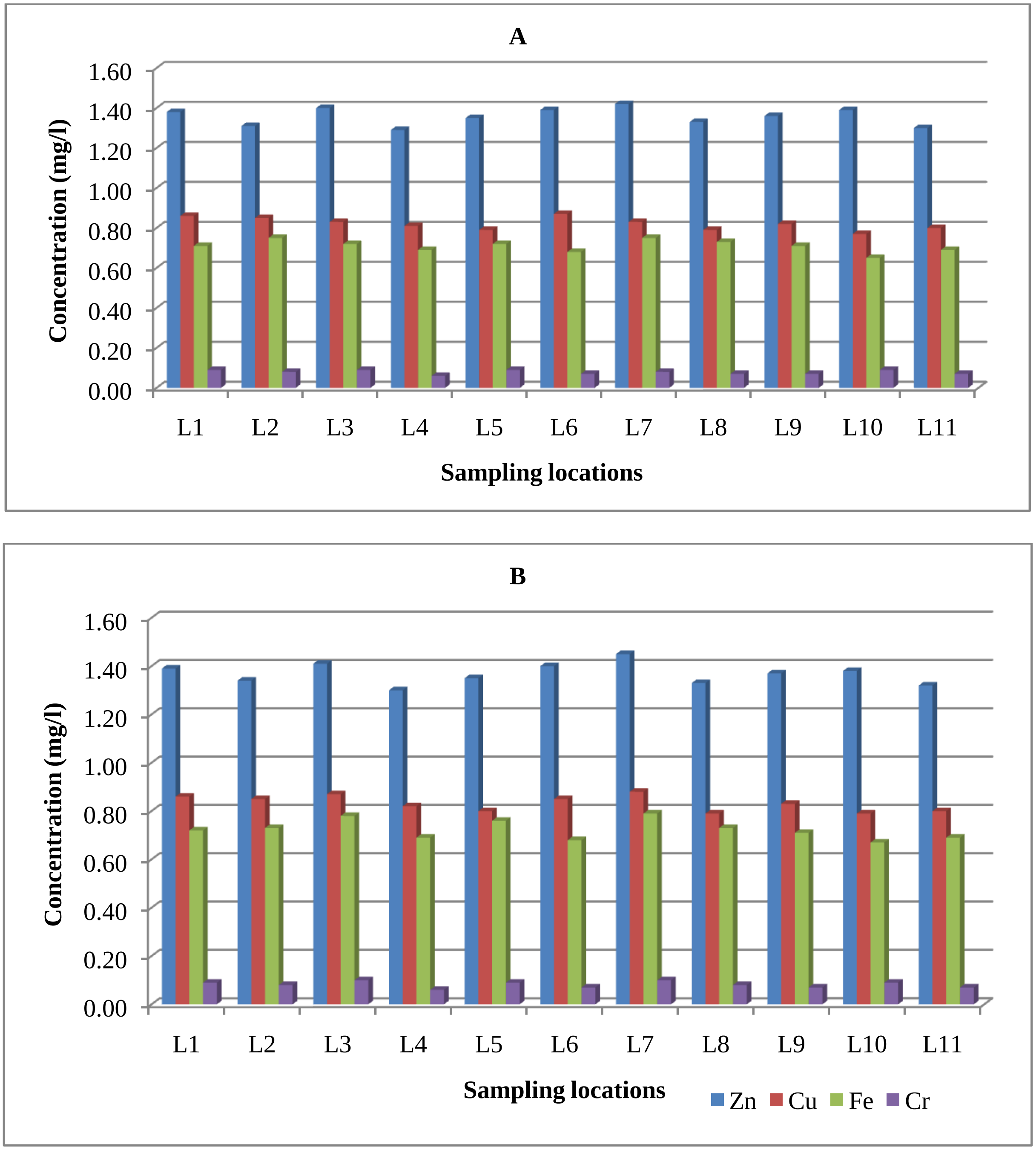

Figure 2: Graphical representation of the concentration of metals analyzed during Wet (A) and Dry (B) season

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Table 2. Mean, standard deviation, units and analysis methodology of toxic chemicals

Sampling locations	Fe Concentration (Mean ± SD)		Cu Concentration (Mean ± SD)		Zn Concentration (Mean ± SD)		Cr Concentration (Mean ± SD)		NO_3 Concentration (Mean ± SD)		NO_2 Concentration (Mean ± SD)	
	Wet months	Dry months	Wet months	Dry months	Wet months	Dry months	Wet months	Dry months	Wet months	Dry months	Wet months	Dry months
L1	0.68±0.03	0.69±0.03	0.86±0.03	0.86±0.03	1.38±0.02	1.39±0.02	0.10±0.03	0.10±0.03	3.27±0.25	4.27±0.25	0.05±0.02	0.06±0.02
L2	0.72±0.03	0.70±0.03	0.85±0.03	0.85±0.03	1.31±0.02	1.34±0.02	0.09±0.03	0.09±0.03	3.37±0.25	4.37±0.25	0.05±0.02	0.06±0.02
L3	0.69±0.03	0.75±0.03	0.83±0.03	0.87±0.03	1.41±0.02	1.41±0.02	0.10±0.03	0.11±0.03	3.97±0.25	4.97±0.25	0.05±0.02	0.05±0.02
L4	0.66±0.03	0.66±0.03	0.81±0.03	0.82±0.03	1.29±0.02	1.30±0.02	0.07±0.03	0.07±0.03	3.37±0.25	4.37±0.25	0.05±0.02	0.05±0.02
L5	0.69±0.03	0.73±0.03	0.79±0.03	0.80±0.03	1.36±0.02	1.35±0.02	0.10±0.03	0.10±0.03	4.07±0.25	5.07±0.25	0.04±0.02	0.06±0.02
L6	0.65±0.03	0.65±0.03	0.87±0.03	0.85±0.03	1.39±0.02	1.40±0.02	0.08±0.03	0.08±0.03	3.27±0.25	4.27±0.25	0.05±0.02	0.06±0.02
L7	0.72±0.03	0.76±0.03	0.83±0.03	0.88±0.03	1.43±0.02	1.45±0.02	0.09±0.03	0.11±0.03	4.07±0.25	5.07±0.25	0.05±0.02	0.05±0.02
L8	0.70±0.03	0.70±0.03	0.79±0.03	0.79±0.03	1.33±0.02	1.33±0.02	0.08±0.03	0.09±0.03	3.37±0.25	4.37±0.25	0.05±0.02	0.06±0.02
L9	0.68±0.03	0.68±0.03	0.82±0.03	0.83±0.03	1.36±0.02	1.37±0.02	0.08±0.03	0.08±0.03	3.37±0.25	4.37±0.25	0.05±0.02	0.06±0.02
L10	0.62±0.03	0.64±0.03	0.77±0.03	0.79±0.03	1.39±0.02	1.38±0.02	0.10±0.03	0.10±0.03	3.47±0.25	4.47±0.25	0.05±0.02	0.06±0.02
L11	0.66±0.03	0.66±0.03	0.80±0.03	0.80±0.03	1.30±0.02	1.32±0.02	0.08±0.03	0.08±0.03	3.37±0.25	4.37±0.25	0.05±0.02	0.06±0.02

Table 3. Standard permissible concentrations of metals [19-20]

S. No.	Metals	SDW (mg/l)	SID (mg/l)
1.	Fe	0.30	3.00
2.	Cu	0.05	3.00
3.	Zn	5.00	5.00
4.	Cr	0.05	0.10

2.3. Assessment methodology

The toxic chemicals data obtained during laboratory testing of water samples were used to evaluate metal index (MI), pollution index (PI) and risk index (RI). The MI and PI were calculated to assess water contamination due to metals (Fe, Cu, Zn and Cr) in the lake water with reference to the standard permissible concentration of toxic metals in drinking water (SDW) prescribed by BIS [19] and WHO [20] and also with respect to standard permissible concentration of toxic metals for inland environmental discharge (SID). RAI is evaluated to identify the problem related to human health which can arise due to toxic chemicals (metals, NO_3 and NO_2) present in the lake water, if that water is used for drinking. The standard permissible concentrations of metals are shown in Table 3.

2.3.1. Metal Index (MI)

MI is evaluated to classify the total trend of present status of water quality based on metal (Fe, Cu, Zn and Cr) concentrations [21-22]. The concentration of a metal is compared to its respective standard permissible value. Higher the MI worse will be the quality of water. MI >1 is a threshold of warning [23]. It is mathematically expressed as:

$$MI = \sum_{i=1}^{n} C_i / S_i \qquad \text{(Equation 1)}$$

C_i is the concentration of individual metal; S_i is maximum permissible concentration

2.3.2. Nemerow pollution index (NPI)

The NPI, a single factor index is evaluated to determine the magnitude of toxicity contributed by an individual metal to an area [24]. It has been widely applied to reflect the environmental quality and assess the total pollution level in a water body. It is mathematically expressed as:

$$NPI = \sqrt{\left(\frac{1}{2}\left(\left(\frac{C_i}{S_i}\right)_{max}^2 + \left(\frac{C_i}{S_i}\right)_{average}^2\right)\right)} \qquad \text{(Equation 2)}$$

The water quality classification range of PI is: PI≤1 (not contaminated); 2<PI≤3 (slightly contaminated); and PI>3 (severely contaminated).

2.3.3. Risk assessment index (RAI)

It is evaluated to estimate the probability of occurrences of adverse human health effects due to exposures to environmental hazards over a particular time period. According to Lee *et al*. [25], ecological risk assessment involves identifying hazards, dose response (toxicity), exposure assessment, and risk characterization. The RAI evaluation comprises the average daily dose (ADD) as an estimate of magnitude, duration and frequency of human exposure to each toxic chemical in the environment for each water sample [26] as:

$$ADD = C_i \times IR \times ED \times EF / BW \times AT \qquad \text{Equation 3}$$

Where, IR, ED, EF, BW and AT has been classified with respective measurement units and values in Table 4.

Furthermore, the two other factors have been reported for characterization of non-carcinogen risk as a reference dose (RFD) and for characterization carcinogenic risk as a slope factor (SF) [31]. According to RAIS database [30], only RFD has been reported for all five toxic chemicals, considered in the present study, shown in Table 4. The ADD and RFD values of each toxic chemical are used to calculate the hazard quotient (HQ) of individual chemical at each sampling site using the following equation as:

$$HQ = ADD/RFD \qquad \text{Equation 4}$$

Table 4. Parameters to evaluate the Average daily dose (ADD) mg/kg-day value

S. no.	Risk Parameters	Symbols	Units	Values	References
1.	Exposure duration	ED	Years	30	[27]
2.	Exposure frequency	EF	Days/year	350	[27]
3.	Average time	AT	Years	68.13	[28]
4.	Body weight	BW	Kg	51.9	[28]
5.	Ingestion rate	IR	L/day	2	[29]
6.	Reference chronic dose	RFD	Mg/kg-day	Fe (0.7); Zn (0.3); Cu (0.04); Cr (0.003); NO_3 (1.6); NO_2 (0.1).	[30]

Thereafter, the individual HQs are summed to derive RAI which is the measure of risk due to mixture of chemicals as:

$$\mathrm{RAI} = \sum \mathrm{HQ} \quad \text{...... Equation 5}$$

The RAI range of classification is usually expressed in terms of non-carcinogenic and carcinogenic health risk based on the quantification of potentially chemicals. RAI<1 means an acceptable risk of cancer while RAI>1 means unacceptable risk of cancer.

3. Results and Discussions

Based on the calculation of MI and NPI with reference to SDW, it had been revealed that the water quality of Surha Lake was beyond the threshold warning and severely contaminated at all sampling locations, i.e. MI >1and NPI >3, as shown in Table 5. Therefore, the water of the lake is not suitable for human drinking purpose.

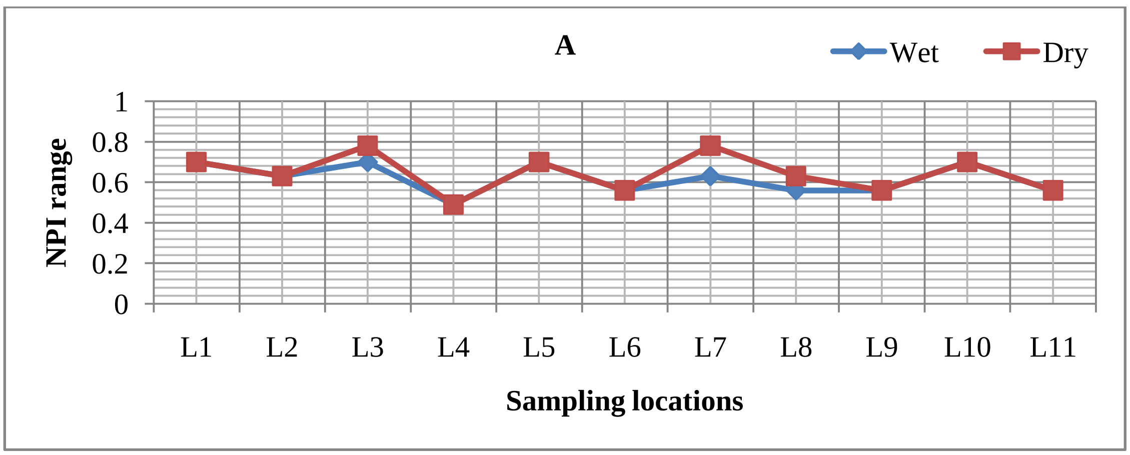
Table 5. Assessment of trace metals contamination with respect to SDW and risk analysis

Sampling locations	MI		NPI		Water contamination	RAI		Risk of cancer to human health
	Wet months	Dry months	Wet months	Dry months		Wet months	Dry months	
L1	5.41	5.42	12.75	12.75	Severe	2.62	2.65	Unacceptable
L2	5.34	5.33	12.60	12.60	Severe	2.45	2.49	Unacceptable
L3	5.27	5.57	12.32	12.92	Severe	2.60	2.83	Unacceptable
L4	4.99	5.04	11.99	12.13	Severe	2.11	2.15	Unacceptable
L5	5.07	5.15	11.73	11.89	Severe	2.56	2.60	Unacceptable
L6	5.34	5.24	12.87	12.58	Severe	2.34	2.34	Unacceptable
L7	5.25	5.63	12.31	13.07	Severe	2.47	2.85	Unacceptable
L8	4.97	5.02	11.71	11.72	Severe	2.24	2.42	Unacceptable
L9	5.11	5.16	12.15	12.29	Severe	2.28	2.32	Unacceptable
L10	4.91	5.03	11.43	11.72	Severe	2.52	2.57	Unacceptable
L11	4.99	4.99	11.85	11.85	Severe	2.25	2.28	Unacceptable
Average	5.15	5.23	12.15	12.32	Severe	2.40	2.50	Unacceptable

However, the MI and NPI value with reference to SID was found in range MI<1 and NPI<1 respectively at all sampling locations, shown in Table 6. It signifies that lake water is not contaminated and hence it can be used for agricultural, fishery, forestry etc. purposes. In order to check the variation of pollution due to the toxic metals, graph had been plotted between the NPI value, evaluated during wet and dry season, shown in Figure 3.

Table 6. Assessment of trace metals contamination with respect to SID

Sampling locations	MI		NPI		Water contamination
	Wet months	Dry months	Wet months	Dry months	
L1	0.42	0.43	0.70	0.70	No
L2	0.40	0.40	0.63	0.63	No
L3	0.42	0.46	0.70	0.78	No
L4	0.34	0.34	0.49	0.49	No
L5	0.42	0.42	0.70	0.70	No
L6	0.37	0.37	0.56	0.56	No
L7	0.40	0.46	0.63	0.78	No
L8	0.37	0.39	0.56	0.63	No
L9	0.37	0.37	0.56	0.56	No
L10	0.41	0.42	0.70	0.70	No
L11	0.36	0.37	0.56	0.56	No
Average	0.39	0.40	0.62	0.64	No



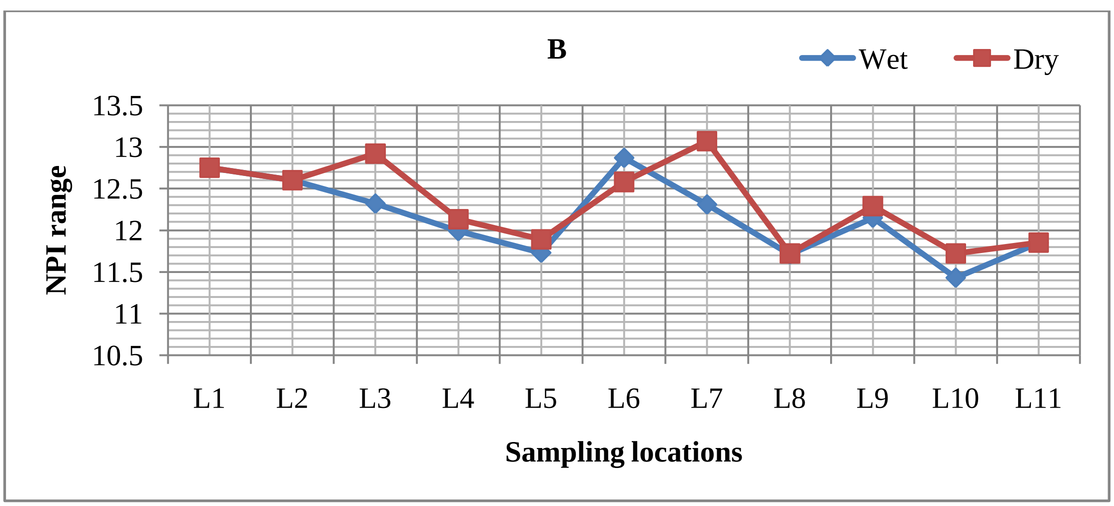


Figure 3: Variation of trace metals contamination at various sampling locations ((A) with respect to SID; (B) with respect to SDW).

The major variation in contamination was found at location L3 and L7 where an increase in pollution level had been reported during dry season. It may be due to the constant input of waste water through Katihar and Medha nallas which joins the lake at L3 and L7. Also, during the dry season water in the lake gets reduced, i.e. less dilution of water, which may be the cause of increase in NPI value during dry season [14]. Further, ecological risk of toxic chemicals had been assessed using RAI at all sampling locations shown in table 5. The RAI values at all locations were found in range of RAI>1, which signifies the unacceptable risk of cancer to human health if lake water is used for drinking and bathing purpose. Hence, based on the result obtained of MI, NPI and HI, it has been recommended that the water of the lake is suitable for agricultural activities, while a suitable conservation measure like maintaining a proper supply of water into the lake and checking the direct flow of nutrients in agricultural runoff is required to make the lake water suitable for drinking and bathing, which it can be achieved by constructing bunds around the lake etc.

Conclusions

The result obtained from the evaluation of MI and NPI with respect to SDW indicates that lake water quality is not suitable for drinking purpose as it is severely contaminated during wet and dry season. Average MI value during wet and dry season was 5.15 and 5.23, respectively and average NPI value was 12.15 and 12.32, respectively i.e. MI>1 and NPI>3. MI and NPI result with reference to SID was found in range MI<1 and NPI<1 at all sampling locations, which signifies that lake water could be used for irrigation of cereal crops like rice, wheat etc. and fisheries. Further, the average RAI was evaluated as 2.40 and 2.50 during wet and dry season respectively, which is an indication of unacceptable risk of cancer to human health if lake water is used for drinking and bathing purpose. Therefore, it has been suggested that the concerned authority should prepare and implement a conservation plan which include measures to maintain the proper supply of water into the lake, and checking the direct flow of nutrients in agricultural runoff by constructing bunds, buffer strips etc. around the lake. The present study would be beneficial to stakeholders and policy makers in strategizing the conservation plan and for public awareness.

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