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Evaluation of Water Quality Pollution Indices for Heavy Metal Contamination Monitoring in Surface Water of Sutlej River (India)

Onkar Singh Brraich and Reetu Jassal*

Department of Zoology and Environmental Sciences, Punjabi University, Patiala – 147002, Punjab, India; singhonkar@yahoo.com, rreetu1@gmail.com

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Abstract

Globally, heavy metal contamination in aquatic environment is a growing dilemma and currently reached at an alarming rate. Surface water receives metal contamination both naturally and anthropogenically. A study was conducted during October 2018 – Dec 2019 to examine the present status of heavy metal pollution in the river Sutlej (Downstream junction of Buddha Nullah), Punjab. The prime thrust is to determine the heavy metal concentrations (Arsenic, Nickel, Cadmium, Cobalt, Chromium, Boron, Manganese, Copper, Iron, Lead and Zinc) of surface water from two points at the location site and to determine the water quality indices (Heavy metal pollution index, heavy metal evaluation index and degree of contamination). Heavy metal analysis has been done using inductively coupled plasma atomic emission spectrophotometer. The results of this study showed that the average concentration of heavy metals such as As, B, Cd, Co, Cr, Cu, Fe, Mn, Ni, Zn and Pb were 0.123µg/l, 0.144 µg/l, 0.047 µg/l, 0.059 µg/l, 0.189 µg/l, 0.281µg/l, 1.424µg/l, 0.097µg/l, 0.291µg/l, 0.904 µg/l and 0.631 µg/l respectively. The overall mean concentration of heavy metals was observed in the following order Fe >Zn>Pb>Cu>Ni>Cr>B>As>Mn>Co>Cd. The HPI and HEI (water quality indices) for As, Fe, Mn, Ni, Zn, Pb, Cd, Cr and Cu were 503.05, 55.55 respectively. It is concluded that the study area is critically polluted with heavy metals that are lethal to aquatic life and humans.

Keywords: Domestic Waste, Heavy Metal Pollution, Industrial Wastewater, Water Quality Index

1. Introduction

Water, the precious national asset is the major constituent of the ecosystem. During the last few decades, aquatic resources are being polluted at an alarming rate due to extensive urbanization, growing human populations and expanding industrial sector (e.g., mining, metallurgical, incineration, pesticide, etc.) which results in the release of a large number of heavy metals into the aquatic resources that consequently, assembled in sediments, being biomagnified through the food chain[36,13]. Typically, water quality is assessed by comparing physical, chemical and biological characteristics of a water sample with water quality guidelines or standards. If the values of these parameters occur beyond the permissible limits it becomes harmful for living organisms[6]. Heavy metals are a group of metals and metalloids whose densities are <5 g/cm^3[21]. Defaulting the natural biogeochemical cycles and the long-term persistence in soils and water makes heavy metals a global concern[7]. Aquatic organisms have the capability to accumulate heavy metals from diverse sources including sediments, discharge of wastewater, soil erosion and runoff and landfill sites[1]. Heavy metals enter the aquatic food chain by direct consumption of water and food through the digestive tract and by non-dietary routes through permeable membranes such as the muscle and gills[25]. Fishes are often at the top of the aquatic food chain and may accumulate huge amounts of metals from the water[15]. In human beings, even minor exposure

*Author for correspondence

of these lethal metals can cause DNA alternation which adversely affects the cell cycle regulation[1].

Ludhiana in Punjab is the largest industrial hub; several small and big industries including textiles, dying industries, industries dealing with paints, leather units, agrochemical companies, and cement plants are located along the bank of the river Sutlej[4]. Untreated domestic and industrial sewerage of the city is emptied into Buddha Nullah, which serves as a reservoir containing elevated levels of toxic chemical which further discharged into the river Sutlej[11]. So, to check the effects of heavy metals on aquatic life and human health, water contamination evaluation and monitoring is required[13]. Therefore, in this study, we apply a combination of multivariate statistics with computation of heavy-metal contamination indexes to evaluate the quality status of the downstream junction of Buddha Nullah (stretch of the Sutlej river) and to determine the concentrations of Arsenic (As), boron (B), cadmium (Cd), cobalt (Co), nickel (Ni), iron (Fe), zinc (Zn), copper (Cu), lead (Pb), chromium (Cr), manganese (Mn) in water to distinguish different degrees of water pollution.

2. Materials and Methods

2.1 Study Area

The studied site is present at latitude 30°57'53."N and longitude 75°28'48" E. (Figure 1) on river Sutlej near village Khurshedpur onJagroan-Nakkodar road (downstream junction of Buddha Nullah). The collection was done from 2 sitesunder the bridge on Sutlej river.

2.2 Water Sampling

Water samples were collected from October 2018 to December 2019 in five different seasons of Punjab from two sites in the downstream junction of Buddha Nullah[16]. Sampling was performed according to a standard procedure[2]. The surface water samples were systematically filtered through cellulose nitrate filter paper to remove suspended solids and collected in polypropylene cleaned plastic bottles of one-liter capacity. At the sampling time, these bottles were washed with the respective site of water. The samples were collected in such a way that no bubbles were allowed. 1 ml of concentrated nitric acid was added to it for preservation to prevent metal adsorption on the inner surface of the container and stored at 4^0C before the analysis. Heavy metal analysis has been done using inductively coupled plasma atomic emission spectrophotometer **(ICPE-9000, Shimadzu, Japan).**

2.3 Indexing Approach

Pollution indices are generally considered as a valuable tool for the comprehensive assessment of the degree of contamination. The indexing concept represents the quality criteria of water with respect to selected parameters.



Figure 1. Location of sampling sites (dots) on river Sutlej.

2.3.1 Heavy Metal Pollution Index (HPI)

This index indicates the overall quality of water with respect to heavy metals and is based on the weighted arithmetic quality mean method and developed in two steps. First by establishing a rating scale for each selected parameter giving weightage and second by selecting the pollution parameter on which the index is to be based. The rating value is between zero to one and its selection depends upon the significance of individual quality considerations or it can be assessed by making values inversely proportional to the recommended standard (Si) for the corresponding parameter[24].

In computing the HPI for the present water quality data, the concentration limits i.e. the standard permissible value (*Si*) and highest desirable value (*Ii*) for each parameter were taken from the WHO standards. HPI is calculated from the equation below

The index is calculated according to Eqs. (1) and (2) as follows:

$$HPI=\frac{\sum_{i=1}^{n} W_i.Q_i}{\sum_{i=1}^{n} W_i.Q_i} \quad (1)$$

$$Q_i=\sum_{i=1}^{n} \frac{M_{i(-)}I_i}{S_i-I_i} \tilde{n}100 \quad (2)$$

where, **Qi** is the sub-index of the ith parameter. **Wi** is the unit weightage of the ith parameter, and n is the number of parameters considered. **Mi** is the monitored value of the heavy metal of the ith parameter, Ii is the ideal value (maximum desirable value for drinking water) of the ith parameter; **Si** is the standard Value (highest permissive value for drinking water) of the ith parameter. The sign (–) indicates the numerical difference of the two values, ignoring the algebraic sign. HPI 100 indicated that high heavy metal pollution (critical pollution index). If the HPI values of water samples were greater than 100, water is not potable.

2.3.2 Heavy Metal Evaluation Index (HEI)

It represents the overall quality of surface water with a focus on heavy metals[8] and the index is calculated from the following equation:

$$HEI=\sum_{i=1}^{n} \frac{H_c}{H_{mac}} \quad (3)$$

where,

H_c = the monitored value of the parameter.

H_{mac} = the maximum admissible concentration of the parameter.

2.3.3 Degree of Contamination (C_d)

This method is the estimation of the water quality by the calculation of the degree of contamination and computed separately for each sample of water analyzed, as a sumof the contamination factors of individual components beyond the upper permissible value was taken as the Maximum Admissible Concentration (MAC). Hence, the $\mathbf{C_d}$ summarizes the collective effects of several quality parameters considered harmful to household water. The $\mathbf{C_d}$ is calculated from the equation below**:**

$$C_d=\sum_{i=1}^{n} C_{fi} \quad (4)$$

$$C_{fi}=\frac{C_{Ai}}{C_{Ni}}-1 \quad (5)$$

where, $\mathbf{C_{fi}}$, $\mathbf{C_{Ai}}$ and $\mathbf{C_{Ni}}$ represent contamination factor, analytical value and upper permissible concentration of the ith component, respectively (N denotes the 'normative value'). The resulting Cd value which are grouped into three categories as: Cd< 1 (low), Cd= 1-3 (medium) and Cd> 3 (high)[17].

2.3.4 Statistical Analysis

Pearson's correlation matrix has been used for statistical analysis to sort associationsbetween selected heavy metals in water samples with the help of SPSS software.

3. Results

The water samples were collected to analyze eleven heavy metal ions during five different seasons (winter, spring, summer, rainy and autumn). The descriptive statistics of the heavy metal indicators have been compared with the required and permissible limits of drinking water quality of (WHO[31]) in Table 1 for the downstream junction of Buddha Nullah.The Table 1 clearly reveals the overall mean concentration of the heavy metals in the following

Table 1. Mean Concentrations of Heavy metals from the sampling sites (Site A, Site B)

Site	Season	Arsenic (As)	Boron (B)	Cadmium (Cd)	Cobalt (Co)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Manganese (Mn)	Nickel (Ni)	Zinc (Zn)	Lead (Pb)
Downstream Junction of Buddha Nullah	Winter	0.062	0.144	0.053	0.032	0.062	0.296	2.563	0.144	0.042	1.009	0.587
	Spring	0.14	0.129	0.039	0.074	0.234	0.106	0.075	0.087	0.037	1.479	0.694
	Summer	0.16	0.143	0.078	0.082	0.298	0.599	1.987	0.085	1.049	0.987	1.011
	Rainy	0.13	0.162	0.019	0.049	0.162	0.123	1.071	0.073	0.039	0.144	0.234
	Autumn	0.098	0.218	0.012	0	0	0.124	1.450	0.032	0.029	0.899	0.901
Mean± SD (mg/l)		0.12± 0.03	0.16± 0.03	0.04± 0.02	0.04± 0.03	0.15± 0.12	0.25± 0.19	1.43± 0.9	0.08± 0.03	0.24± 0.01	0.90± 0.45	0.69± 0.30
WHO (2011) Permissible Limits(mg/l)		0.05	_	0.005	0.02	0.05	0.02	1	0.05	0.02	1	0.05

Table 2. Correlation coefficient matrix of heavy metals in water

	Arsenic	Boron	Cadmium	Cobalt	Chromium	Copper	Iron	Manganese	Nickel	Zinc	Lead
Arsenic	1										
Boron	0.30446	1									
Cadmium	0.281309	0.66914	1								
Cobalt	0.758125	0.84596	0.674543	1							
Chromium	0.86033	0.72838	0.642788	0.981241	1						
Copper	0.306234	0.33302	0.901998	0.477731	0.5165372	1					
Iron	-0.51338	0.11276	0.440016	-0.28589	-0.301129	0.611267	1				
Manganese	-0.38524	0.72949	0.583662	0.302244	0.1366443	0.314109	0.44863	1			
Nickel	0.608221	0.26731	0.797773	0.588168	0.6767043	0.93165	0.33334	0.01766498	1		
Zinc	0.016681	0.33838	0.390915	0.244161	0.1833199	0.119029	0.18792	0.218226538	0.095779	1	
Lead	0.207082	0.17465	0.450688	0.051588	0.1344423	0.542829	0.19676	-0.24086564	0.596271	0.624536	1

Table 3. Standard values applied for calculation of HPI and HEI

Metals	Wi	Ii	Si	MAC
As	0.02	10	50	50
Cd	0.3	3	5	3
Cr	0.02	50	50	50
Cu	0.001	2000	1000	1000
Fe	0.005	200	300	200
Mn	0.02	500	100	50
Ni	0.05	20	20	20
Zn	0.0002	3000	5000	5000
Pb	0.7	10	100	1.5

W Weightage (1/MAC)

S Standard permissible in ppb

I Highest permissible in ppb

MAC Maximum admissible concentration/upper permissible (Adapted from Siegel[28])

Table 4. The calculated C_d, HPI, HEI of the mean values of Heavy Metals from the sampling sites i.e., Site A and Site B (Downstream Junction of Buddha Nullah)

Heavy Metals	Heavy Metal Pollution Index (HPI)	Heavy Metal Evaluation Index (HEI)	Degree of Contamination (C_d)
Arsenic(As)	2.75×10^{2}	2.4×10^{0}	1.4×10^{0}
Cadmium(Cd)	1.85×10^{3}	1.33×10^{1}	1.233×10^{1}
Chromium(Cr)	1×10^{1}	3×10^{0}	7×10^{-1}
Copper(Cu)	1.75×10^{2}	2.5×10^{-1}	7.5×10^{-1}
Iron(Fe)	1.23×10^{3}	7.15×10^{0}	6.15×10^{0}
Lead(Pb)	7.555×10^{2}	4.6×10^{2}	4.59×10^{2}
Nickel(Ni)	2.2×10^{1}	1.2×10^{1}	1.1×10^{1}
Zinc(Zn)	1.05×10^{2}	1.8×10-^{1}	8.2×10^{-1}
Manganese(Mn)	1.05×10^{2}	1.6×10^{0}	6×10^{-1}
Maximum	1.85×10^{3}	4.6×10^{2}	4.59×10^{2}
Minimum	1×10^{1}	1.6×10^{0}	6×10^{-1}
Average	5.0305×10^{2}	5.555×10^{1}	5.475×10^{1}

order: Fe>Zn>Pb>Cu>Ni>Cr>B>As>Mn>Co>Cd. It was also observed that lead, copper was, cadmium; chromium, arsenic, nickel and manganese were much higher than the desirable standards. The correlation coefficient amongstselected heavy metals has been calculated in the present study. Statistical analysis shows both positive and negative correlations among different metals (Table 2). It is clear from the results that copper is positively correlated with most of the other metals whereas cobalt (Co) is negatively correlated with other metals. Chromium and Cobalt are highly correlated with each other. The Heavy metal Pollution Index (HPI) of Cd, Cr,Cu, Fe, Mn, Ni, Pb and Zn have been calculated with range 10–1850 and the average mean concentration value was 503.05 of all metals, including all the seasons by applying standard parameters and constants as shown in Table 3. Theresults of pollution evaluation indices are shown in Table 4. It was observed that the HPI for all metals except Ni and Cr were above the critical limit of 100 proposed for drinking water. To assess the composite quality of heavy metal pollution, (HEI) was calculated. The mean value of HEI was 55.55. The study clearly indicates the surface water of the downstream junction of Buddha Nullah falls within the high zone of pollution. The range and mean values of C_d were 0.6–459 and 54.75 respectively. The value of the contamination index exceeds 3, suggesting that water is highly polluted.

4. Discussion

Heavy Metals are major environmental pollutants asthey cannot be degraded by natural processes and persist in soil and sediment from where they are released gradually into water bodies as sink causing cytotoxic, mutagenic and carcinogenic effects in animals[29]. However, industrialization has a serious threat to the water bodies of Punjab[30]. Aquatic organisms have the capability to accumulate heavy metals from diverse sources including soil erosion and runoff, air depositions of dust and aerosol, and wastewater discharge[14]. Fishes are especially sensitive to heavy metals and can succumb to less than 1 mg lead/L [19].

The Sutlej River receives heavy metal contamination from diverse sources which continues throughout the year. The overall dataof some heavy metals (Arsenic, Nickel, Cadmium, Cobalt, Chromium, Boron, Manganese, Copper, Iron, Lead, and Zinc) obtained from the sample survey during the present course of work was the concentration was above permissible units and could be lethal to aquatic biota. The elevated concentration is posing a big threat to precious biodiversity existing there. Similarly, Giri and Singh[10] states that concentrations of the metals such as Ba, As, Cr, Al, Co, Mn, Cu, Fe, V, Ni, Se, and Zn) in the surface water of Subamarekha river exhibited higher levels in the pre-monsoon season.Brraich and Jangu[4] found an elevated concentration of Cd, Cu, Pb, Cr, Ni, Co and Fe in surface water of Harike wetland due to dying industries, cement factories, pesticides and insecticides factories, leather industries, print manufacturing plants and tanneries. Similar, study on the water quality functioning of eastern UK Rivers draining into the North Sea was done by Neal *et al.*[18]. Likewise, theconcentrations of Cd and Pb were found to be above the permissible level inthe surface waters of river Dzindi, Madanzhe and Mvudi in Thohoyandou, South Africa[20]. During present investigations it was found that the mean concentration of zinc, lead, copper, nickel, chromium and arsenic were above permissible limits prescribed under WHO standards. Khan *et al.* [12] found similar observations in the surface water near NLC Corporation due to the industrial waste.

In the present investigations, it was found that maximum concentration of Pb, Cu, and Cd and As were far above the threshold limits recommended by WHO in all respective seasons which reflects the relative impact of agricultural sources, domestic sewage and industrial discharges together. Therefore, elimination of these heavy metals is necessary from the aquatic bodies to protect human health as well the aquatic flora and fauna. Brraich and Kaur[5] reported that the accumulation of harmful metal Pb in fishes lead to aquatic organisms obstruct the growth, metabolic and reproductive efficacy and causes mortality of, especially fishes. Few metals such as As the present study found that Fe and Ni were high during winter; it may be due to the effect of rains in the area similar with the findings of Phiri*et al.*[22]. The earlier studies had ensured that the precipitation is especially responsible for metal pollution in surface water[32]. Thus, the present study is an attempt to distinguish the heavy metal concentration in the downstream junction of Buddha Nullah. If heavy metal contamination continued unabated, it not only damages the aquatic flora and fauna but also the human beings as they depend on agricultural products. As these agricultural lands are irrigated by these water bodies.

Aslam *et al.*[3] has well documented that the comprehensive estimation of environmental contamination by means of heavy metal analysis for oysters' reefs at Hab River Delta, Balochistan, Pakistan and found the determined indices indicates the contribution of each heavy metal in the increased pollution load and evidence emerging pollution level due to industrialization.

In the present research, it was found, HPI value is far above the critical value of 100 for drinking water as proposed by Prasad and Bose[23]. The aquatic bodies beyond the critical limit of 100 are considered as contaminated[27]. It was observed that all the considered metals were beyond the permissible limits which affect the overall quality of river Sutlej due to the industrial activities, runoff from farm areas and domestic sewage. Theresult of indices revealed that the mean HEI for all the metals was 55.55 which indicates that the water quality falls within high zone of pollution. The degree of contamination (Cd) was used as a reference to estimate the level of heavy metal pollution. In the present investigation, the range and mean values of C_d were 0.6- 459 and 54.75. The value of the contamination index is above 3, signifying that water is highly polluted. Hence, it is recommended that there should be proper waste disposal system and waste should be treated before entering into the river. Educational and awareness programs should be launched to control pollution.

5. Conclusion

The present study outlines major problems associated with heavy metal pollution in the river Sutlej. The **C_d**, **HEI** and **HPI** demonstrated that the downstream junction of Buddha Nullah of the river Sutlej was critically highly polluted and the measures to decrease the metal content in the water are required for the river and its future restoration.This study provides a wealth of data on heavy metals and recommends that sources of heavy metals in the water should be closely monitored, industrial effluent and domestic sewage discharge should be reduced to conserve the valuable flora and fauna of river Sutlej, as Punjab lacks the quality monitoring of surface water.

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7. Conflict of Interest

Authors declare that they have no conflict of interest.

8. References

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