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Evaluation of the Water Quality and Distribution of Heavy Metals in the Gomti River Flowing Through the Urban Region of Lucknow, India

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Abstract

The physicochemical properties and heavy metals contents of the Gomti River water (GRW) samples collected from five selected sites covering a stretch of ~31 km in Lucknow, Uttar Pradesh, India were ascertained. The sites were Ghaila Pul, Mehndi Ghat, Shaheed Smarak, Kukrail Junction, and Bande Dam, represented as S1, S2, S3, S4, and S5, respectively, following from upstream to downstream. S1 was considered as a reference site. The values of pH, temperature, total dissolved solids (TDS), electrical conductivity (EC), turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total hardness (TH), total chloride (TC), total alkalinity (TA), total acidity (TAC), total free CO_2, total NO_3, and NO_2 differed with sites. The Fe, Co, Ni, Cu, Al, Zn, As, Mo, Cd, Cr, and Pb levels were also investigated. Except for Zn and Cu, all other metals were detected beyond the levels allowed by the BIS (2012) and Organization of Economic Corporation and Development (OECD, 2020) for water bodies. Further, the current finding suggests that the discharge of untreated industrial, agricultural, and domestic effluents into the Gomti River is unendurable.

Keywords: Bureau of Indian Standards, fishery water bodies, heavy metals, OECD, physicochemical properties

Introduction

A significant tributary of the Ganga River, also known as Adi Ganga is the Gomti River that originates in Uttar Pradesh, India, close to Madhotaal Pilibhit, in the southern Himalayan Mountains [1]. The Gomti River drains a catchment area of ~2, 5800 km^2 and has a total length of ~730 km in Uttar Pradesh [2]. One of the several factors contributing to the Gomti River pollution is the discharge of 325 million liters per day (MLD) of untreated domestic, industrial, and municipal waste as well as anthropogenic activities [3]. Anthropogenic activities, industrialization, and socioeconomic development have led to the direct release of 26 drains into the river stream, which might change the water quality [4]. Heavy metal (HM) toxicity in aquatic ecosystems has become a global concern. HMs quickly integrated into the food web and cannot be eliminated through self -sanctification; they worsen the aquatic and human body systems by altering the physiological functions [5−7]. The sources of HM contamination are anthropogenic processes like mining, household drainage systems, industrial wastewater discharge, geographical weathering, and soil runoff [8]. Due to their long half-life and lack of biodegradability, toxicants pose a significant environmental threat [9]. During the processes of adsorption and coprecipitation, a certain amount of metal ions remain in the water as impurities [1]. Although certain metals such as Mn, Cu, Zn, Ni, Fe, and Co are considered essential elements as they participate in copious biological and physiological processes, their excessive quantities cause toxic malfunctions. In contrast, many hazardous elements such as, Cd, Cr, and Pb are toxic in trace levels [10]. In other terms, while Cr and Pd are harmful even in minute amounts enriching surface water with essential micronutrients like Fe and Zn can also have deleterious effects [11]. Thus, the identification and quantification of HMs in the aquatic environment and ascertaining their hazardous effects on aquatic life is of utmost concern. In the present study, the quality of GRW along with HM pollution was assessed.

Materials and Methods

Study area and sample collection. In the present study, five sampling stations of Gomti River were selected using Google Earth at intervals starting from 26.90246N and 80.874702E to 26.83379N and 80.992714E (Figure 1) in the upstream–downstream direction. These stations were S1: Ghaila Pul, S2: Mehndi Ghat, S3: Shaheed Smarak, S4: Kukrail Junction, and S5: Bande Dam, Lucknow region, India (Figure 1). S1 where the Gomti River enters into the city was considered as a reference site, and where the river exits as S5. All five sites were nearly equidistant. The water samples from each site were collected in 5 L PVC bottles in triplicates from 11:26 AM–1.00 PM during May (summer season). They were pretreated with 5% HNO_3 followed by washing thrice with double distilled water. The sampling was done as per the American Public Health Association (APHA, 2012) [12] guidelines [11, 13].

Chemicals and reagents. High-grade chemicals formulated by Qualigens were used for the estimation of physicochemical parameters (Thermo Fisher Scientific India Pvt. Ltd Mumbai, India). Inductively coupled plasma-mass spectrometry (ICP-MS) was utilized for the detection of HMs by using the periodic table mix 1 for ICP-MS for standardization (Lot: BCCB9855; Sigma-Aldrich).

Estimation of the physicochemical parameters. The samples were passed through a filter paper to separate the solids, which may interrupt sample preparation. The filtrates were stored at 4 °C. The physicochemical parameters such as pH (HM digital pH-80 hydro tester/ B00TAQS1HY), as well as electrical conductivity (EC), total dissolved solids (TDS), temperature (°C) and TDS (Meter Digital Water Test Meter/B07ZMCH5LF [AI-3SKV-CEW9]), were estimated simultaneously at the sites. Turbidity was measured by a WM/0121MM digital turbidity meter. Total dissolved oxygen (DO), total biochemical oxygen demand (BOD), total hardness (TH), total alkalinity (TA), total acidity (TAC), and total nitrite and nitrate (NO_3 and NO_2) were determined through titration following the standard methods for the examination of water and wastewaters (APHA, 2017 [14] and chloride test by Mohr's method.

Determination and validation of HMs. The samples collected were prepared through triple acid digestion using HNO_3:HCl:H_2SO_4 (3:1:1) [15] for metal detection via the ICP-MS technique (Agilent 7900 at the central research facility of the Indian Institute of Technology, New Delhi). The levels of each metal species (%) were calculated assuming permissible concentration of each to be 100.

Statistical analysis. Data were represented as their mean values ± SD (standard deviation). One-way analysis of variance (ANOVA) was applied to certain if the differences between the water quality parameters and traditional metal values (BIS, 2012) [16] were statistically significant at $p < 0.05$ by using Excel.

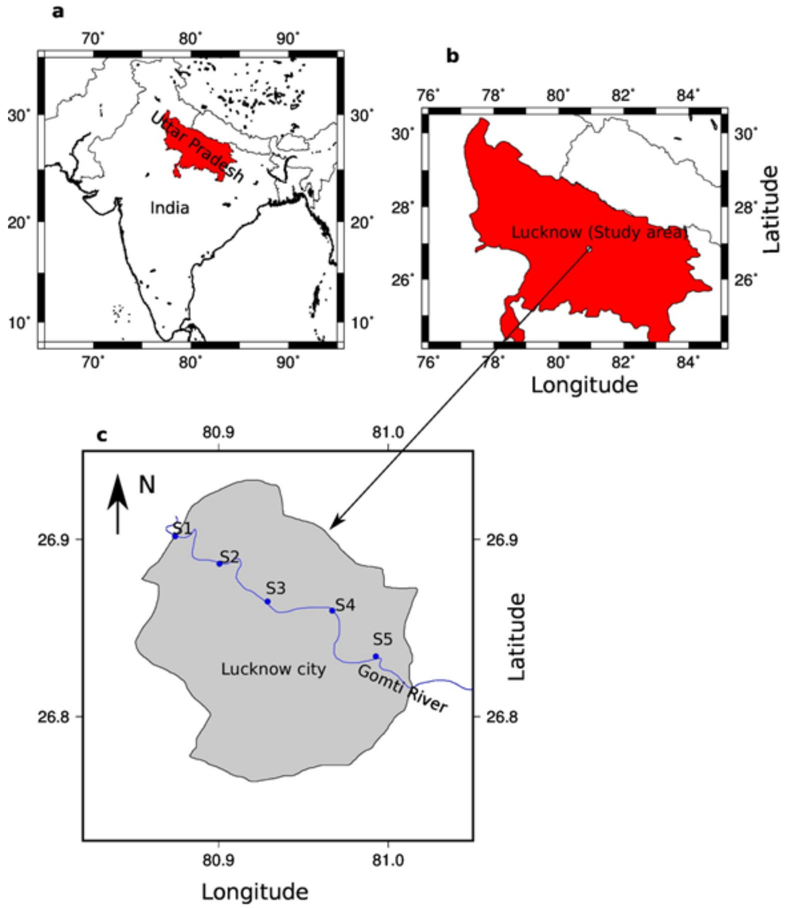

Figure 1. A Map Indicating the Water Sampling Sites in the Gomti River, Lucknow, Uttar Pradesh, India

Results and Discussion

Physicochemical analysis. Table 1 shows the physicochemical properties of the Gomti River Water (GRW) samples. The values of pH, temperature, TDS, EC, turbidity, total DO and BOD, TH, TC, TAC, total free CO_2, as well as total NO_3 and NO_2, varied with sampling locations (Table 1). The GRW samples were basic with pH values ranging from 7.40 to 8.56. The DO concentrations at S3, S4, and S5 were lower than the recommended levels (BIS, 2012 [16], unlike those at S1 and S2 (Table 1). Correspondingly, the BOD amounts were higher at S2, S3, S4, and S5 compared to S1 suggesting the amounts of organic pollutants in the river to be more than those allowed by BIS, 2012 [16] (Table 1). The total DO and BOD concentrations ranged from 1.33 to 25.46 and 1.08 to 13.22, respectively. In addition, the EC and turbidity levels also surpassed the allowed limits at the downstream spots (S3, S4, and S5) compared to the upstream ones (S1 and S2) (Table 1). Previous investigations have reported the TDS (mg/L) and pH values of the Gomti River were in the range between 204.00–425.66 and 7.13–8.66 respectively, during the summer months [17, 18]. Further, in the current work, the TC, TH, EC, and turbidity levels were in the range of 25.22–64.06 mg/L, 8.32–9.99 mg/L, 408–851.33 µS cm^{-1}, and 3.00–19.00 NTU, respectively during May at various sites. The TC amounts followed the trend of S1 > S2 > S4 > S5 > S3, TH of S3 > S4 > S5 > S2 > S1, EC of S4 > S3 > S5 > S2 > S1, and turbidity of S5 > S4 > S3 > S2 > S1, respectively. The TC, TH, and turbidity were within the permissible limits prescribed by BIS (2012) [16], except EC. Excluding S1, the free CO_2 at the rest of the four sites ranged between 01.12 and 2.20 mg/L. Similarly, the TAC values ranged from 84. 66 (S2) to 161.60 mg/L (S4). The total nitrate and nitrite values ranged between 8.33 to 13.00 mg/L and 0.71 to 0.94 mg/L, respectively (Table 2). The total nitrate was noticed to be under the levels prescribed by BIS (2012) [16] unlike total nitrite.

Table 1. Average Values of the Physicochemical Characteristics of the Gomti River Water Samples Collected at Various Sites While Flowing Through Lucknow

	Physicochemical Parameters					
Parameters	**Ghaila Pull (S1)**	**Mehndi Ghat (S2)**	**Shaheed Smarak (S3)**	**Kukrail Junction (S4)**	**Bande Dam (S5)**	**BIS (2012)#**
pH	**8.56 ± 0.06 ↑**	8.26 ± 0.05	7.4 ± 0.10	7.56 ± 0.06	7.56 ± 0.15	6.5-8.5
Temp	31.53 ± 0.06	30.3 ± 0.26	32.2 ± 0.36	34.36 ± 0.70	37.33 ± 0.57	NR
TDS	204.00 ± 0.00	219.3 ± 6.35	425.66 ± 0.57	425 ± 0.00	340.60 ± 12.00	500
EC	**408 ± 0.00 ↑**	**425.6 ± 0.57 ↑**	**850.66 ± 1.15 ↑**	**851.33 ± 0.57 ↑**	**695.6 ± 2.30 ↑**	300
Turbidity	3.00 ± 0.00	4.00 ± 0.00	**12.00 ± 0.00 ↑**	**13.00 ± 0.00 ↑**	**19.00 ± 0.00 ↑**	5
DO	**25.46 ± 1.28 ↑**	**6.66 ± 1.40 ↑**	4.14 ± 0.1	02.00 ± 0.40	1.33 ± 0.30	5
BOD	1.08 ± 0.48	**13.22 ± 1.00 ↑**	**11.34 ± 0.28 ↑**	**05.59 ± 0.50 ↑**	**5.48 ± 0.40 ↑**	5
Total hardness	64.06 ± 5.25	56.00 ± 5.29	26.66 ± 10.69	29.33 ± 4.16	25 ± 4.65	300
Total chloride	08.65 ± 1.52	8.323 ± 1.45	9.99 ± 1.00	08.323 ± 0.76	9.85 ± 0.15	250
Total alkalinity	9.00 ± 3.00	–	–	–	–	200
Total acidity	–	84.66 ± 12.22	118 ± 8.00	161.6 ± 23.09	32.73 ± 2.36	200
Total free CO_2	–	01.83 ± 0.56	1.12 ± 0.04	2.2 ± 0.00	2.20 ± 0.00	NR
Total NO_3	8.33± 1.52	9.66 ± 2.08	11.33± 0.57	12.00 ± 1.00	13.00 ± 1.00	45
Total NO_2	0.71± 0.05	0.78± 0.02	0.84 ± 0.04	0.93 ± 0.04	0.94 ± 0.02	NR

TDS = Total Dissolved Solids (mg L^{-1}), DO = Dissolved O_2 (mg L^{-1}), BOD = Biochemical O_2 Demand (mg L^{-1}), Free CO_2 = Free CO_2 (mg L^{-1}), NO_3 = Nitrate (mg L^{-1}), NO_2 = Nitrite (mg L^{-1}), DO = Dissolved Oxygen (mg L^{-1}), Temperature (°C), EC = Electrical Conductivity µS/cm, Turbidity (NTU)
Values are represented as the means ± S.D
NR indicates limits for metals not recommended by the BIS (2012)
#BIS stands for the Bureau of Indian Standards for drinking water (2012)

Table 2. The Metal Concentrations (mg/L) in the Gomti River Water at Five Sampling Sites in Lucknow, Uttar Pradesh, India

	Ghaila Pull (S1)		Mehndi Ghat (S2)		Shaheed Smarak (S3)		Kukrail Junction (S4)		Bande Dam (S5)		BIS (2012)
S.No	Metals	Concentration	Metals	Concentration	Metals	Concentration	Metals	Concentration	Metals	Concentration	
1.	Al	**2.78 ± 0.01↑**	Al	**1.32 ± 0.009 ↑**	Al	**0.98 ± 0.04 ↑**	Al	**0.90 ± 0.01 ↑**	Al	**45.30 ± 1.26** ↑	0.2
2.	Cr	**0.91 ± 0.06 ↑**	Cr	**0.78 ± 0.01 ↑**	Cr	**0.48 ± 0.01 ↑**	Cr	**0.50 ± 0.01 ↑**	Cr	**0.64 ± 0.008** ↑	> 0.05
3.	Fe	8.21 ± 0.20	Fe	6.44 ± 0.10	Fe	4.73 ± 0.16	Fe	7.30 ± 0.30	Fe	61.15 ± 3.60	NR
4.	**Co**	0.01 ± 0.0003	Co	0.01 ± 0.0002	Co	0.008 ± 0.001	Co	0.009 ± 0.001	Co	0.04 ± 0.00	NR
5.	Ni	**0.47 ± 0.003 ↑**	Ni	**0.44 ± 0.004 ↑**	Ni	**0.42 ± 0.005 ↑**	Ni	**0.31 ± 0.003 ↑**	Ni	**0.38 ± 0.004** ↑	> 0.02
6.	Cu	0.43 ± 0.0004	Cu	0.05 ± 0.002	Cu	0.05 ± 0.0003	Cu	0.05 ± 0.0003	Cu	0.23 ± 0.002	1.5
7.	Zn	1.81 ± 0.05	Zn	1.77 ± 0.01	Zn	1.34 ± 0.02	Zn	1.72 ± 0.05	Zn	2.65 ± 0.04	15
8.	As	**0.29 ± 0.004 ↑**	As	**0.31 ± 0.007 ↑**	As	**0.10 ± 0.002 ↑**	As	**0.15 ± 0.008 ↑**	As	**0.26 ± 0.006** ↑	0.05
9.	Mo	0.10 ± 0.001	Mo	0.11 ± 0.003 ↑	Mo	0.07 ± 0.001	Mo	0.03 ± 0.002	Mo	0.03 ± 0.004	NR
10.	**Cd**	**0.16 ± 0.001 ↑**	**Cd**	0.003 ± 6E-05	**Cd**	**0.03 ± 0.002 ↑**	**Cd**	**0.04 ± 0.001 ↑**	Cd	**0.06 ± 0.003** ↑	0.003
11.	**Pb**	0.01 ± 0.0005	**Pb**	**0.05 ± 0.001 ↑**	**Pb**	**0.06 ± 0.002 ↑**	**Pb**	**0.04 ± 0.001 ↑**	**Pb**	**0.01 ± 0.004** ↑	0.01

Heavy metal concentration (Mean and SD; mg L^{-1}) compared to the BIS (2012) permissible limits
BIS (2012) indicates the permissible limits for heavy metals

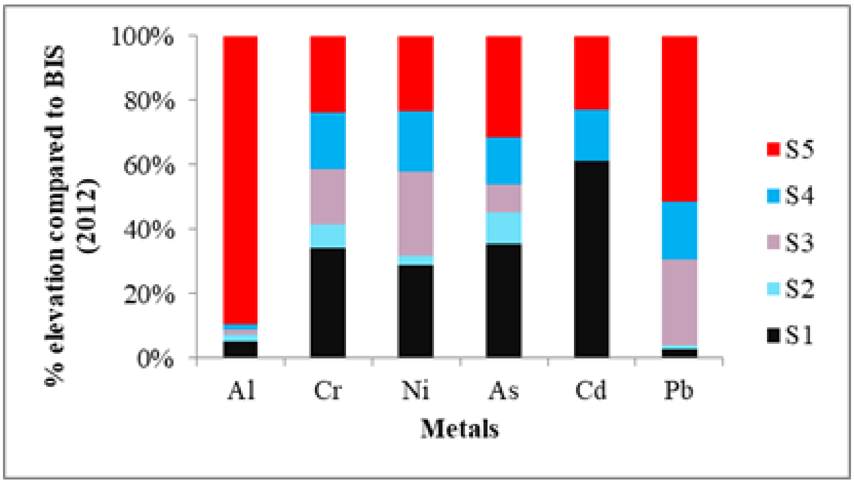

Figure 2a. The Elevated Metal Concentrations (%) Compared to the BIS (2012) Levels

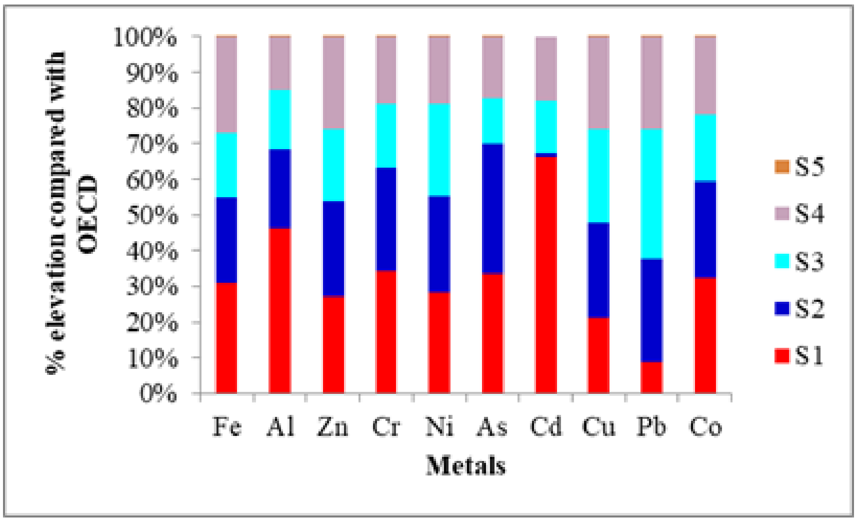

Figure 2b. The Elevated Metal Concentrations (%) Compared to the OECD (2020) Limits

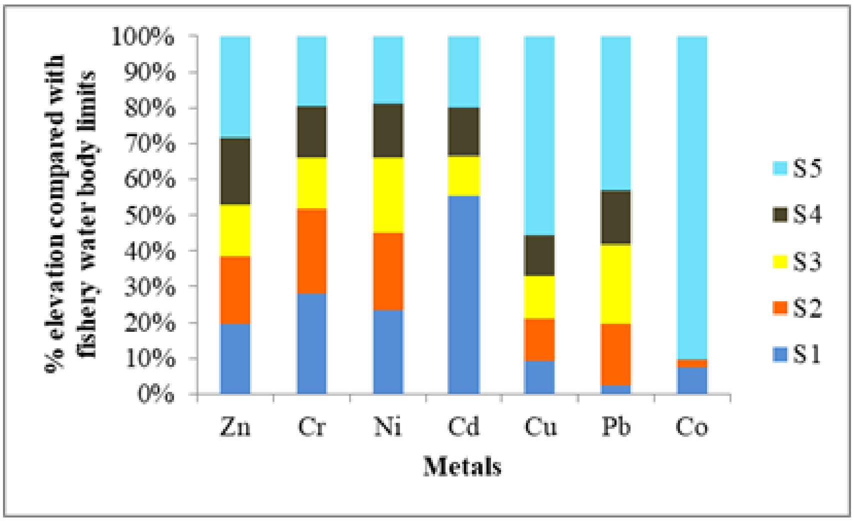

Figure 2c. The Elevated Metal Concentrations (%) Compared to the Limits Recommended by the Fishery Water Bodies

HM analysis. Rivers are one of the ultimate sources of ecological biodiversity and sustainability for life forms. However, due to industrialization and uncontrolled urbanization, they receive massive amounts of toxins including metals. Though metals contribute significantly to enhancing human lifestyle with competitive ease and less expenditure, still their discard into the aquatic ecosystems through various types of effluents creates survival challenges for most aquatic animals, including fish. Further, as fish are consumed extensively, therefore metals might cause devastating health effects in humans. Therefore, in the current work attempts have been made to monitor the water quality and analyse the contamination of the GRW by metals.

The estimated concentrations (mg/L) of eleven metals such as Fe, Al, Zn, Cr, Ni, As, Mo, Pb, Cu, Cd, and Co in the GRW samples are depicted in Table 2. They varied with sampling locations. The metal levels (%) in the GRW followed the pattern of Fe (55.38) > Al (18.79) > Zn (12.26) > Cr (6.14) > Ni (3.17) > As (1.95) > Cd (1.09) > Mo (0.71) > Cu (0.29) > Pb (010) > Co (0.08) at S1 while at S2 the order was Fe (57.07) > Al (15.65) > Zn (11.69) > Cr (6.86) > Ni (3.94) > As (2.79) > Mo (0.94) > Cu (0.47) > Pb (0.42) > Co (0.09) > Cd (0.02). Similarly, at S3, the sequence was Fe (56.96) > Zn (16.14) > Al (11.86) > Cr (5.80) > Ni (5.13) > As (1.29) > Mo (0.90) > Pb (0.70) > Cu (0.63) > Cd (0.43) > Co (0.09) while at S4, it was Fe (65.38) > Zn (15.65) > Al (11.86) > Cr (5.80) > Ni (5.13) > As (1.29) > Mo (0.90) > Pb (0.70) > Cu (0.63) > Cd (0.43) > Co (0.09). Finally, at S5, the levels were Fe (55.12) > Al (40.82) > Zn (2.39) > Cr (0.58) > Ni (0.34) > As (0.23) > Cu (0.21) > Pb (0.04) > Mo (0.08) > Cd (0.05) > Co (0.04). It was noted that at a majority of the sampling stations, the GRW was particularly contaminated with elevated amounts of Fe, Al, Zn, Cr, Ni, and As while the levels of the rest of the metals studied were comparatively lower. Interestingly, the observation of elevated total amounts of five metals (Fe, Al, Zn, Cr, Ni, and As) from S1 (entry point), subsequently to S3 and S4, and finally to the S5 (exit point) from 95.75%–98.40% indicated more consistency of certain elements. Markedly high Cd levels have also been recorded in the Gomti River (Khan et al., 2021) [8]. The Cd levels in GRW ranged from 0.04–1.05 mg/L [18]. For other rivers like the Ganges, [19] Cd value was recorded 2.92 μg/L at Kanpur, Uttar Pradesh. Out of the eleven metals studied, Fe concentration was found to be the highest in the surface water at all the sites while Co was found to be the lowest at all the sites except at S2 where Cd was the least.

The order of Fe, Al, Zn, Cr, Ni, and As followed a similar hierarchy at S1, S2, and S5 while those at S3 and S4 followed the pattern of Fe, Zn, Al, Cr, Ni, and As (Figure 2a,2b,2c). However, the remaining metals followed a random distribution at the five sites (Table 2). The cumulative levels (%) of the remaining five metals namely Cd, Mo, Cu, Pb, and Co were comparatively higher in S2 (4.77), S1 (4.24), and S4 (3.40) (Figure 2c). Figures 2a, 2b, and 2c indicates the comparison of these changes to the guidelines of the BIS (2012) [16] and the Organization of Economic Corporation and Development (OECD, 2020) [20] for the testing of chemicals safety for aquatic ecosystem. Interestingly, the EC levels were comparatively lower at S1 than the others. Still, among the eleven elements, the concentrations of Cr, Ni, As, Cd, and Mo were highly elevated. They may be a consequence of industrial effluents bearing huge amounts of toxic substances directly draining into the Gomti River; meanwhile, other factors such as exponential growth in population, unplanned urbanization, extensive agricultural and tourism activities, and riverfront construction have also added to the pollution load in GRW in Lucknow region leading to disturbances in the flora and fauna of the riverine ecosystem [8, 11, 21].

Conclusion

GRW is highly polluted due to the discharge of untreated industrial effluents. The amounts of HMs are enough to disrupt the aquatic flora and fauna. The tremendous inflation in population with unplanned urbanization has created problems related to sanitation, excessive utilization of riverine resources, and improper discarding of waste. Consequently, the generation of various kinds of effluents from agricultural, domestic, industrial, and ritual practices ultimately drains into the river Gomti. As a result, varied amounts of toxic substances such as organic and inorganic chemicals get mixed with the river water, altering its quality and potentially damaging its ecological biodiversity (aquatic flora and fauna). However, because the compositions of the various effluents generated from different industries varied, diverse physicochemical characteristics of the GRW have been observed in each cities within state and across years. Consequently, the patterns of metal bioaccumulation in tissues of aquatic creatures also varied depending on the extent of their bioavailability in the river water, feeding patterns, tropic transfer, and species. Even though some parameters were within the permissible range, the direct dumping of agricultural, domestic, and mill loads should be prohibited. According to this study the parameters and pollutants, such as EC, pH, DO, BOD, turbidity, As, Cr, Ni, As, Cd, and Pb were above the standard threshold limits. The rapid development of industries leads to a deterioration in the river's aquatic health, which makes it unfit for the survival of aquatic organisms. The dumping of untreated waste should be avoided and major actions should be taken.

Acknowledgment

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