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# Potential ecological risk assessment of heavy metals in surface sediments of Bagmati river, Kathmandu valley, Nepal

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## ABSTRACT

This study aims to determine the distribution and potential ecological risk of heavy metals and to identify the possible sources of heavy metal contamination in the surface sediments of the Bagmati River in Kathmandu, Nepal. The sediment samples were analyzed for their pH, electrical conductivity (EC), organic matter (OM), texture, and heavy metal concentration of Cu, Zn, Cd, and Pb. Various indices such as contamination factor (CF), geoaccumulation index ($I_{geo}$), modified degree of contamination ($mC_d$), pollution load index (PLI), and potential ecological risk index (RI) were calculated to assess the risk of heavy metals. The sediment exhibited a slightly alkaline pH, with significant variation in EC along different river sections. The OM levels were moderate in the upstream and high in the middle and downstream. The sediment was predominantly sandy and loamy sandy in composition. The concentration of Pb was below the limit of detection (<0.01 µg/g) in all sediment samples. The ecological risk associated with Cu, Zn, and Cd in the sediment is categorized as low to moderate based on the RI. The Hierarchical Cluster Analysis (HCA) indicates that the upstream has less heavy metal pollution than the middle and downstream sections. There are significant positive correlations between Cu, Zn, and Cd in terms of their concentration. The Principal Component Analysis (PCA) suggests anthropogenic activities, such as the mixing of municipal and domestic sewage, hospital waste, and industrial activities, may serve as sources of heavy metals in the river sediment. It is necessary to regularly monitor the sediment and water of Bagmati River to identify the sources of heavy metal pollution and record changes in the level of contamination.

**Keywords:** Bagmati River; Nepal; Sediment; Heavy metals; Ecological risk

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## INTRODUCTION

Heavy metal accumulation in aquatic environments such as lakes, rivers, wetlands, and estuaries is a significant global issue (Talukder et al. 2022). Rivers provide of variety of economic, cultural, and ecological services, including navigation, ecotourism, aquaculture, agriculture, biological habitat, and ecological defense (Chen et al. 2022). However, most surface water sources like rivers are contaminated by industrial, agricultural, and household sewage, runoff, and atmospheric deposition. Heavy metals naturally occur in the environment, but when introduced into the environment, they get concentrated and behave as environmental pollutants (Vu et al. 2018). They have been identified as a major hazard to environmental quality and human health because of their toxic, bio-accumulative, and non-degradable nature in the environment (Yang et al. 2017).

Several studies have indicated that heavy metals such as lead (Pb), copper (Cu), chromium (Cr), and cadmium (Cd) play a significant role in the material exchange processes of living organisms in water, soil, and biological environments (Tham et al. 2021). The accumulation of heavy metals in sediments and aquatic environments is a major cause for concern, possessing a serious threat to aquatic organisms (Nour et al. 2019). Sediments play a major role as both the primary source and repository for heavy metals, serving as critical mediums for the transportation and storage of potential toxic metals (Yan et al. 2010). However, physical, chemical, and biological processes in sediments may release toxic metals into water column, increasing the pollution levels (Zhang et al. 2017). The heavy metal concentration in sediments is primarily regulated by factors such as sediment composition and particle size. In general, clay minerals tend to contain higher concentration of metals compared to carbonate sediments (Khadka et al. 2015).

Urban rivers are particularly vulnerable to metal contamination due to inputs from various sources within their catchment. The inflow of inputs from urban environments increases the risk of metal contamination in the water bodies (Waziri, 2023). Rapid industrialization and urbanization are leading to heavy metals pollution in urban rivers (Ali et al. 2022). The Bagmati River is one of the significant rivers of Nepal originating in the central northern mountains that flows through the urban regions of the Kathmandu Valley (Kayastha, 2015). Even though the river holds significant religious, cultural, historical, and economic importance, it is heavily contaminated because of inappropriate solid waste disposal along its banks and the disposal of untreated or inefficiently treated sewage and wastewater directly into the river (Adhikari et al. 2021; Kannel et al. 2007; Khadka et al. 2015; Regmi et al. 2017; Shah and Chaturwedi, 2019). The quality of the Bagmati River water is being adversely impacted by issues such as low levels of dissolved oxygen, bacterial pollution, and metal toxicity. These factors are not only affecting the water quality but also contributing to the degradation of sediment quality in the Bagmati River (Mishra et al. 2017). The significant problem of heavy metal contamination in the sediment of the Bagmati River requires intensive investigation. Ecological risk assessment (ERA) involves in evaluating the impact of specific stressors on the environment, accounting both short and long-term harm in an ecosystem (Chen et al. 2013). It provides a framework for systematically and cost-effectively examining polluted sediments, incorporating various assessment methods (Chapman and Mann, 1999).

Numerous researches have been conducted to evaluate the water quality status of the Bagmati River (Acharya and Pant, 2021; Adhikari et al. 2019; Adhikari et al. 2021; Baniya et al. 2019; Mahat et al. 2020; Pal et al. 2019; Shah and Chaturwedi, 2019). However, there are limited data available regarding the distribution as well as ecological risks of heavy metals in the river sediment. In addition, river sediment is complex and plays an important role in maintaining the health of the environment. Therefore, this study aims to characterize heavy metal concentrations, evaluate the ecological risk posed by heavy metals, assess the ecological risk indices associated with heavy metal contamination, and identify potential sources in the surface sediments of the Bagmati River in Kathmandu, Nepal.

## MATERIALS AND METHODS

### Study sites and samples

The study was carried out on the 25 km stretch of the Bagmati River flowing inside the Kathmandu Valley from Sundarijal (85°25'38.33"E - 27°46'15.88"N) to Chovar (85°17'41.51"E - 27°39'36.82"N) (Fig. 1). Bagmati River is a spring-fed river and flows from the Shivapuri Hills of Mahabharat Range. Chovar is the outlet of Bagmati Catchment that drains an area of 595.4 km$^2$ and the altitude of the river basin varies between 1178 and 2723 m above mean sea level (Mishra et al. 2017). The sediments in the basin are primarily loam and consist of loose clay, silt, sand, and gravel (Paudyal et al. 2016). The Bagmati River serves several important purposes, including the supply of water for industrial processes, irrigation, recreational activities, as well as playing a significant role in cultural and religious practices.

The sampling sites were selected along the Bagmati River in Kathmandu Valley, starting from upstream (Sundarijal) to downstream (Chovar) using a systematic random sampling approach. In this approach, the first site was randomly selected in the upstream region, and subsequent sites were located at regular intervals of 1.5 km, resulting in a total of 17 sampling sites. A sample from the undisturbed site (85°25'38.33"E and 27°46'15.88"N) was used as a background value for the analysis of risk indices. The selected undisturbed site is the area with no evidence of past and present human activities and no signs of disturbances were observed during sampling. The samples were collected during post-monsoon season in January 2023. About 1 kg of surface sediment samples from Bagmati River were collected from both banks and the middle of the river. The collected samples were carefully labeled and stored in clean polyethylene bags. The samples were then transferred to the laboratory for analysis.

### Sample pretreatment and instrumental analysis

Foreign objects such as leaves, twigs, rocks etc. were separated from the samples. Subsequently, the samples were air-dried at room temperature and prepared for laboratory analysis. The physicochemical parameters pH, electrical conductivity (EC), organic matter (OM), and texture of the sediment samples were analyzed. The pH and EC were determined by using a multiprobe (Hanna Combo HI98129, Romania). The OM was determined by a modified Walkley and Black method (McKeague, 1978). The texture was estimated by mechanical method using soil hydrometer in the laboratory of Central Department of Environmental Science, Tribhuvan University.

The analysis of heavy metals Pb, Zn, Cu, and Cd of the river sediment was conducted in Nepal Environment and Scientific Services, Thapathali, Kathmandu, Nepal which

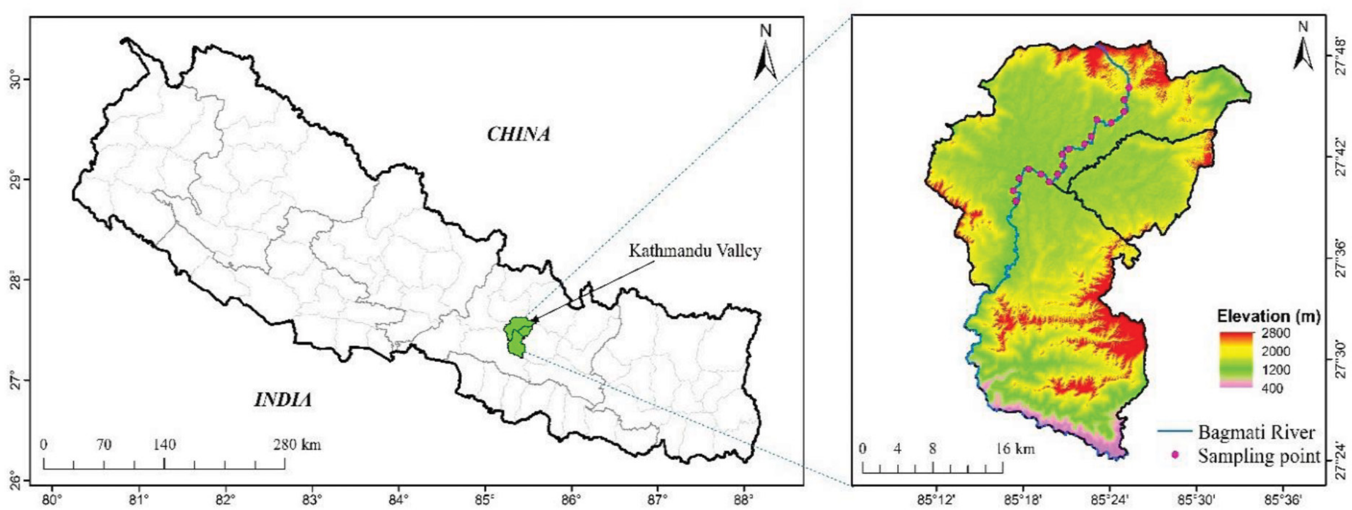


**Fig. 1: Sampling locations in the Bagmati River, Kathmandu Valley, Nepal.**

is accredited by Nepal Bureau of Standards and Metrology, Government of Nepal under Nepal Laboratory Accreditation Scheme. The digestion of the river sediment was carried out as per wet digestion method of USEPA (USEPA, 1986). Using a quantitative tri-acid solution consisting of nitric acid, hydrochloric acid, and perchloric acid, the samples were digested in a beaker. It was followed by heat digestion of the samples on the controlled hot plate and filtration of the sample using Whatman filter paper. An aliquot was then taken and the heavy metals were analyzed using an atomic absorption spectrometer (GBC SavantAA, Australia) in an air-acetylene flame for blank and three consecutive working metal standard solutions. The concentration of each metal was determined by referring to the calibration curve of the spectrometer. Analytical grade (AR) chemicals and reagents were used in all instances. Three replicates of the sediment samples from each site were analyzed in the laboratory. By calculating the relative standard deviation (% RSD), which constantly remained within 5% of the majority of monitored parameters, the precision of the generated data was verified and it was determined to meet the acceptable quality standards.

**Pollution and ecological risk assessment**

To assess the contamination level and ecological risk of heavy metals in the sediment of the Bagmati River, the contamination factor (CF), modified degree of contamination ($mC_d$), geoaccumulation index ($I_{geo}$), pollution load index (PLI), and potential ecological risk index (RI) were used.

**Contamination factor (CF)**

It is an index used to describe the level of contamination of an element. It is defined as the ratio of heavy metal concentration and its background value in the sediment. It was given by Hakanson (1980) as:

$$CF_i = \frac{C_i}{B_i} \quad (1)$$

where,

$CF_i$ is the contamination factor for pollutant, $C_i$ is the heavy metal's concentration in the sediment sample (µg/g), and $B_i$ is the background concentration for this heavy metal from undisturbed site (µg/g)

Four categories of CF are identified as: (CF <1) low contamination factor, (1 ≤ CF < 3) moderate contamination factor, (3 ≤ CF < 6) considerable contamination factor, and (CF ≥ 6) very high contamination factor (Hakanson, 1980).

**Modified degree of contamination ($mC_d$)**

Abrahim and Parker (2008) introduced a revised and more comprehensive version of the Hakanson (1980) equation to determine the overall extent of contamination at a specific sampling location:

$$mC_d = \frac{\sum_{i=1}^{i=n} CF^i}{n} \quad (2)$$

where,

n is the number of metals that are analyzed, i is the $i^{th}$ metal, and CF is the contamination factor

The classification of $mC_d$ (degree of contamination) is: ($mC_d$ <1.5) nil to very low, (1.5 ≤ $mC_d$ < 2) low, (2 ≤ $mC_d$ < 4) moderate, (4 ≤ $mC_d$ < 8) high, (8 ≤ $mC_d$ < 16) very high, (16 ≤ $mC_d$ < 32) extremely high, and ($mC_d$ ≥ 32) ultra-high (Abrahim and Parker, 2008).

**Geoaccumulation index ($I_{geo}$)**

It is a geochemical method for determining metal enrichment over background or baseline values. According to studies, it is an effective method for characterizing the amounts of sediment contamination. It was given by Müller (1969) as:

$$I_{geo} = \log_2 \times \frac{C_i}{1.5\, B_i} \quad (3)$$

where,

$C_i$ is the heavy metal's concentration in the sediment samples, and $B_i$ is the background concentration of the metal

The constant factor 1.5 is used to reduce the impact of any changes in the geochemical background values.

$I_{geo}$ is classified as: $I_{geo}$<0;<1;<2;<3;<4;<5, and >5 indicating uncontaminated, uncontaminated to moderately contaminated, moderately contaminated, moderately to strongly contaminated, strongly contaminated, strongly to extremely contaminated, and extremely contaminated, respectively (Müller, 1969).

**Pollution load index (PLI)**

The PLI is a commonly used index for assessing the contamination level of heavy metals in sediments (Tomlinson et al. 1980).

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots\ldots\ldots \times CF_n)^{1/n} \quad (4)$$

where,

n is the number of heavy metals analyzed and $CF_i$ is the contamination factor for each metal

PLI is classified as: PLI<1; =1 and >1 indicating no pollution, baseline level of pollution, and polluted, respectively (Tomlinson et al. 1980).

**Potential ecological risk index (RI)**

It is among the best methods to assess the level of river sediment pollution. The toxicity of individual metal and the combined impact of various metals were assessed by determining the potential risk of individual metals ($E_r^i$) and the risk index (RI). The index was developed by Hakanson (1980):

$$E_r^i = T_r^i \times CF_i \quad (5)$$

$$RI = \Sigma E_r^i \quad (6)$$

where,

$CF_i$ is the contamination factor and $T_r^i$ is the toxic response coefficient of respective metals.

RI value <150, <300, <600, and >600 indicates low, moderate, considerable, and very high-risk index, respectively (Hakanson, 1980).

$T_r^i$ of Zn, Cu, Cd, and Pb are 1, 5, 30, and 5, respectively(Zhang and Liu, 2014).

**Statistical analysis**

The statistical analysis was performed using Microsoft Excel 2016, IBM SPSS Statistics 25, and R-studio 2022. Before performing the correlation analysis, Shapiro-Wilk normality test was conducted in R-studio to determine the nature of distribution of data. The Spearman correlation test was performed using SPSS to analyze the relationships between physicochemical parameters and heavy metals, as most of the monitored parameters were not normally distributed. Hierarchical cluster analysis (HCA) was performed using Ward's method in SPSS to identify sampling sites with similar concentration of metals and physicochemical parameters. Principal component analysis (PCA) was employed in SPSS to determine the sources of heavy metals in the sediment of the Bagmati River.

## RESULTS AND DISCUSSION

### Physicochemical parameters

The sediment pH in the Bagmati River ranged between 8.5 and 8.7, which indicates that the sediment was slightly alkaline in nature. A study conducted by Pal et al. (2019) in the water quality assessment of the Bagmati River, the pH of the river was observed to range from slightly acidic to slightly alkaline. Heavy metals tend to accumulate in environments with high pH due to the fact that their solubility decreases as the pH increases and vice versa (Kazlauskaite-Jadzevice et al. 2014). The EC in the sediment samples varied widely between 59 and 1405 µS/cm, with a mean of 509 µS/cm. The highest EC was observed in sampling site S14 (Teku Dovan) and the lowest was observed in S1 (Sundarijal, above dam). The EC of the river sediment was noted to rise progressively from the upstream to the downstream of the river. This trend may be attributed to increased anthropogenic activities downstream. The OM content in the sediment samples of the Bagmati River ranged between 2.21 % and 14.34 %, with a mean of 8.21 %. The OM content in the sediment was higher in the middle and downstream of the river. The high OM content can be related to abundance of organic waste remnants, which contribute additional organic matter as they decompose (Tripathi and Misra, 2012). Additionally, the elevated content of OM in the sediment samples of the Bagmati River can be related to anthropogenic activities such as domestic sewage discharge, improper solid waste disposal, and industrial discharges.

The United States Department of Agriculture soil texture triangle was used for demonstrating the sediment texture in the Bagmati River (USDA, 2017). The predominant sediment texture in the river was sandy and loamy sandy, with the majority of sampling sites displaying these characteristics. Sampling site S12 (Sankhamul Park) exhibited silt loam texture, while sampling site S14 (Teku Dovan) had sandy clay loam texture. The distribution of grain size plays a crucial role in determining the spatial variation of heavy metal concentration (Sudhanandh et al. 2011). Coarse-grained sediments like sandy sediments that have a low organic content possess limited capability to retain metal ions (Raj et al. 2013).

### Heavy metals in the river sediment

The concentration of heavy metals (Cu, Cd and Zn) in 17 surface sediment samples of Bagmati River is illustrated in Fig. 2. The concentration of Pb was below the detection limit

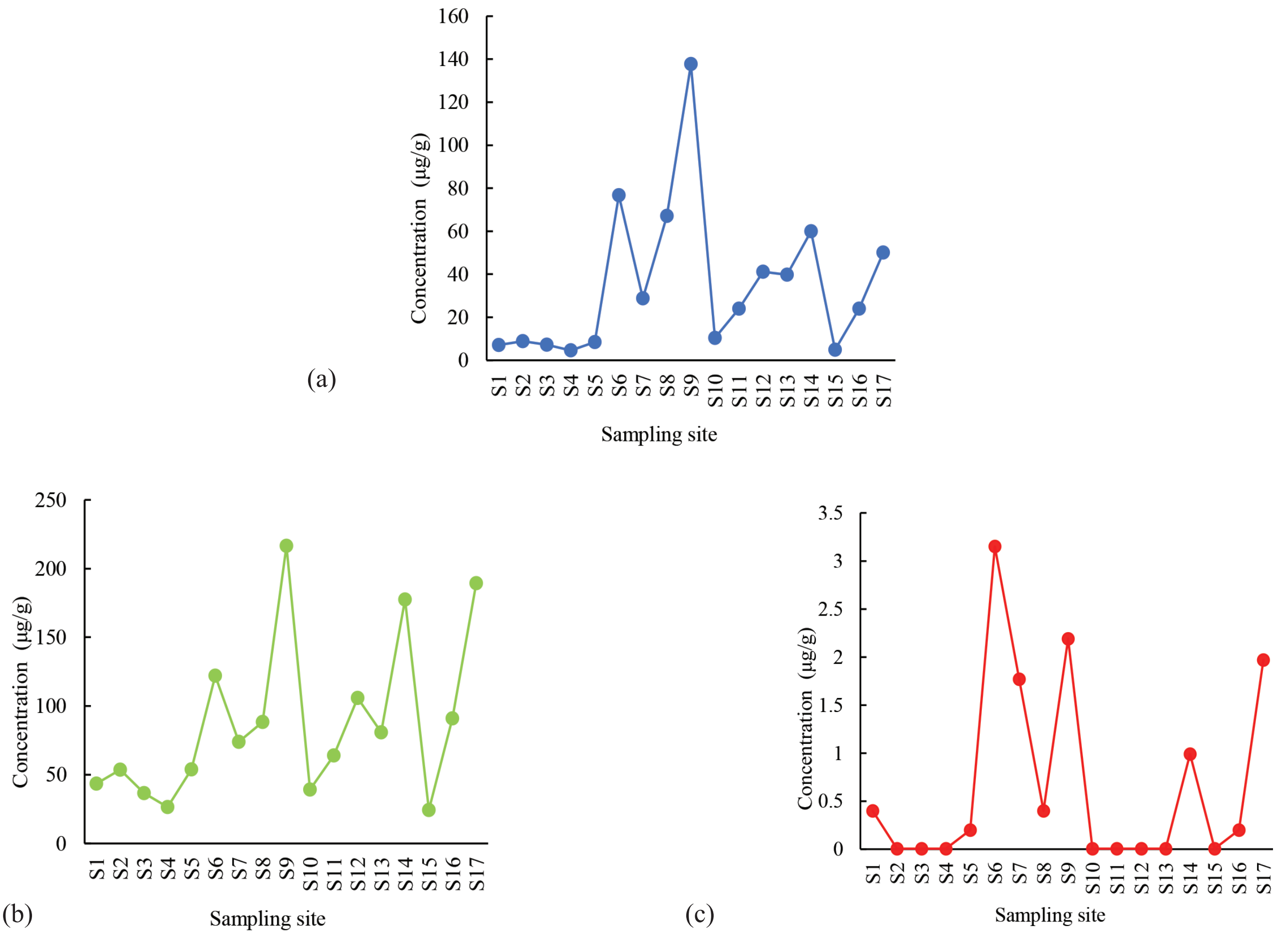


**Fig. 2: Variation of concentration of elements. a) Cu, b) Zn, and c) Cd in the sediment of the river.**

(<0.01 µg/g) in all the sediment samples of the Bagmati River. The mean heavy metal concentrations were in the order of Zn>Cu>Cd>Pb. The concentrations of the heavy metals were compared with Canadian Interim Sediment Quality Guidelines (ISQGs) as described in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (CCME, 1999). The variation of Cu concentration was 4.56 to 137.66 µg/g, with a mean of 35.33 µg/g. The maximum concentration of Cu was in sampling site S9 (Tilganga), whereas the minimum concentration was in sampling site S15 (confluence of Bagmati and Balkhu River). The Cu is considered very harmful to the aquatic ecosystem due to the tendency of aquatic plants to absorb the high concentration of the metal (Ahmad et al. 2020). The Zn concentration varied between 24.35 and 216.53 µg/g. The mean concentration of Zn was 87.50 µg/g. Sampling site S9 showed the highest level of Zn concentration, which indicates that the site is heavily polluted by Zn. The Zn has been demonstrated to have adverse effects on fishes, causing structural damage, impacting hatchability, general health, hematological characteristics, and even influencing fish behavior (Afshan et al. 2014). The concentration of Cd varied from <0.01 to 3.15 µg/g, with a mean of 0.66 µg/g. Even in low concentration, Cd is considered toxic to both the environment and human health. The concentration of Cu exceeded the ISQG (for fresh water) value of 35.7 µg/g in sampling sites S6, S8, S9, S12, S13, S14, and S17, whereas Zn exceeded the ISQG (for fresh water) value of 123.0 µg/g in S9, S14, and S17. The concentration of Cd exceeded the ISQG (for fresh water) value of 0.6 µg/g in sampling sites S6, S7, S9, S14, and S17.

**Assessment of heavy metal pollution in the river sediment**

The mean CF values of Cu, Zn, and Cd are 5.20, 2.07, and 1.70, respectively. The Cu exhibits very high level of contamination in sampling sites S6, S8, S9, S14, and S17 and low level of contamination was in sampling sites S4 and S15. The Zn exhibits low to considerable level of contamination in all sampling sites. Sampling sites S2-S4, S10, and S15 exhibit low level of Zn contamination and considerable level of Zn contamination is in sampling sites S9, S14, and S17. The Cd exhibits very high contamination level in sampling site S6. The remaining sampling sites exhibit low to considerable level of Cd contamination (Fig. 3). Sediment contamination is significantly influenced by the post-monsoon season because it is the time when heavy metals precipitate most from the water column into the sediment as a result of less turbulence, higher concentration of metals, and leaching and surface runoffs (Dash et al. 2021).

Figure 4 represents $I_{geo}$ values of three metals in the sediment samples of the Bagmati River. The $I_{geo}$ value is in the order of Cu>Zn>Cd. The $I_{geo}$ value for Cu ranged from -1.23 to 3.69, indicating uncontaminated to strongly contaminated sediment. The increased presence of Cu contamination in the river sediment can be linked to human activities like urban waste, traffic emissions, and industrial workshops (Fadlillah et al. 2023). The $I_{geo}$ value for Zn is between -1.42 and 1.73, which indicates uncontaminated to moderately contaminated sediment. The $I_{geo}$ value of Cd is in the range of -6.91 to 2.39, indicating uncontaminated and moderately to strongly contaminated sediment in the study area.

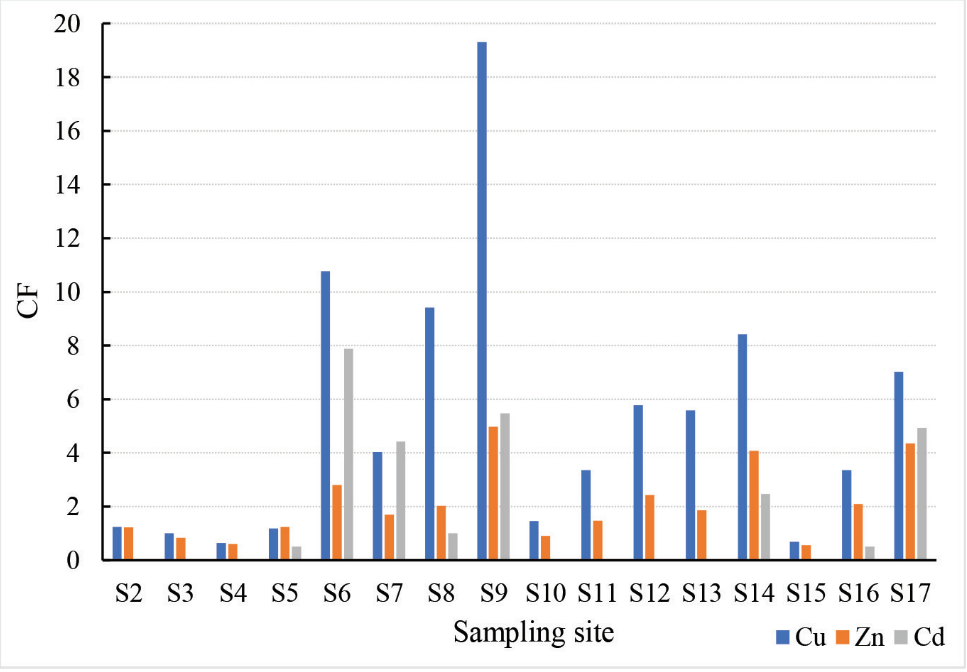


**Fig 3: Contamination factor of Cu, Zn, and Cd of the river sediment.**

Table 1 presents the statistical summary of the computed values of $E_r^i$, $mC_d$, PLI, and RI. The mean $E_r^i$ values of Cu, Zn, and Cd are 26, 2.07, and 51.14, respectively. The mean $E_r^i$ values of Cu and Zn are less than 40, which depicts that the metals exhibit low ecological risks. On the contrary, the mean $E_r^i$ value of Cd is between 40 and 80, which indicates that Cd possesses moderate ecological risk.

**Table 1: Statistical summary of $E_r^i$, mCd, PLI, and RI**

| | $E_r^i$ | | | $mC_d$ | PLI | RI |
|---|---|---|---|---|---|---|
| | Cu | Zn | Cd | | | |
| Min | 3.2 | 0.55 | 0.375 | 0.42 | 0.001 | 4.18 |
| Max | 96.54 | 4.97 | 236.25 | 9.92 | 175.150 | 292.89 |
| Mean | 26.0 | 2.07 | 51.14 | 2.99 | 21.920 | 79.22 |
| SD | 24.98 | 1.35 | 76.27 | 2.74 | 46.7 | 96.54 |

The three metals in sampling sites S2, S3, S4, S5, S10, and S15 exhibits $mC_d$ values less than 1.5 (Fig 5). These values indicate negligible to very low degree of contamination of Cu, Zn, and Cd in the Bagmati River sediment. In contrast, sampling site S9 exhibits very high degree of contamination. Sampling sites S11 and S16 exhibit low levels of contamination, while sampling sites S7, S12, and S13 indicate moderate degrees of contamination. The remaining sampling sites exhibit high degree of contamination.

The presence of heavy metal contamination at these sites can be linked to the accumulation of pollutants from human activities, including sewage, industrial discharge, and the application of fertilizers (Zhang et al. 2019).

The PLI in the sediment of the river ranges from 0.001 to 175.150, with mean of 21.920. The PLI in sampling sites in S2 to S5, S10 to S13, and S15 indicate low appreciable contamination by Cu, Zn, and Cd (Fig 6). The remaining sampling sites exhibit contamination by these metals.

The RI of the studied metals in the sampling sites is illustrated in Fig. 7. The RI value indicates that the study area has low to moderate ecological risk of Cu, Zn, and Cd. Sampling sites S2 to S5, S8, and in S10 to S16 have low level of ecological risk, while sampling sites S6, S7, S9, and S17 exhibit moderate level of ecological risk from the monitored metals. The moderate level of ecological risk in the sampling sites is mainly due to the high concentration of Cd in the sediment. The RI value is in order of Cu>Zn>Cd. Dash et al. (2021) visualized Cd as the major contributor to ecological risk. The study conducted by Islam et al. (2017) in the sediment of an urban river in Bangladesh also revealed a similar case where Cd and Pb exhibited significant potential ecological risk across the majority of the sampling sites in the study area. The finding is further supported by a study conducted by Chen et al. (2022) in Xining Area of Huangshui River, Northwest China where Cd and As were the primary elements responsible for the ecological risk in the study area.

Although the results indicate overall low level of ecological risk in the sediments of the Bagmati River by heavy metals, the continuous input of untreated wastewater might eventually result in adverse and irreversible impact on aquatic ecosystem. The stretch of the river that flows through the core urban area of the Kathmandu Valley showed higher concentrations of elements in comparison to the upstream, with a clear correlation to the population density surrounding the river. The initial assessment of trace metals in the surface water of the Bagmati River indicated a low health risk (Paudyal et al. 2016).

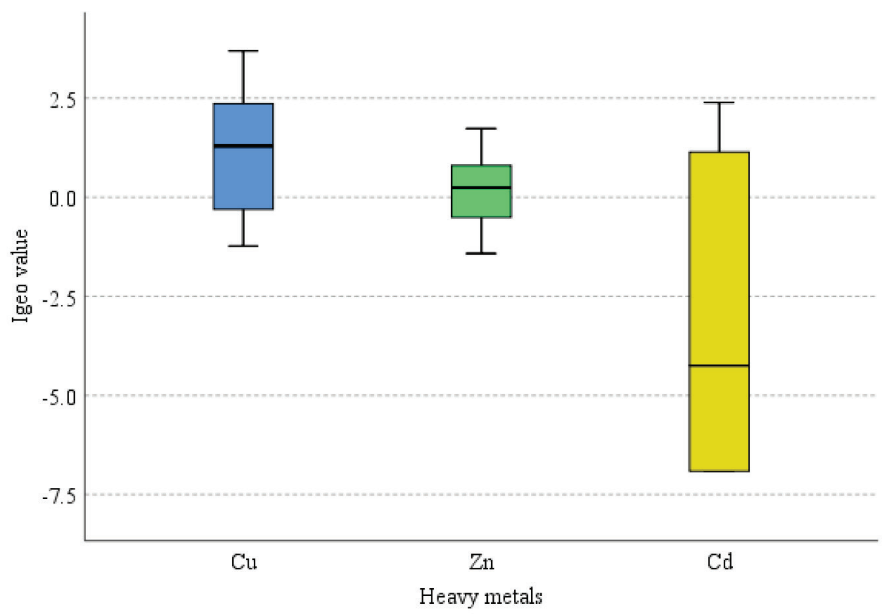


**Fig 4: Geoaccumulation index for Cu, Zn, and Cd the of the river sediment.**

This aligns with the results of the study, where the majority of sampled sites illustrate minimal ecological risk from the heavy metals. The heavy metals have detrimental effects on human health as well as on the environment, including aquatic and terrestrial communities (Kahlon et al. 2018).

**Association among monitored physicochemical parameters and heavy metals**

The Spearman's correlations of the physicochemical parameters and heavy metals in the study area are presented in Table 2. There are significant positive correlations between EC and Cu ($r=0.674$, $p<0.01$), EC and Zn ($r=0.637$, $p<0.01$), OM and Cu ($r=0.725$, $p<0.01$), Cu and Zn ($r=0.914$, $p<0.01$), Cu and Cd ($r=0.644$, $p<0.01$), and Zn and Cd ($r=0.700$, $p<0.01$). The pH has weak negative correlations with all the physicochemical parameters except for clay and sand. The weak negative correlation of pH with heavy metals demonstrates favorable condition for dissolution of the metals in acidic environment to some extent. Kazlauskaite-Jadzevice et al. (2014) indicated that the pH has significant role in dissolving metals in soil. Zeng et al. (2011) also reported that the soil pH showed negative correlation with metals. The OM has significant positive correlations with EC ($r=0.586$, $p<0.05$) and Zn ($r=0.554$, $p<0.05$). Lin and Chen (1998) observed positive correlation between heavy metal concentration and cation exchange capacity in sediments, both of which were influenced by OM content. The Cd exhibits weak positive correlations with EC and OM. Clay exhibits weak positive correlations with all monitored physicochemical parameters and heavy metals. This suggests that fine-grained sediments accumulate trace elements that may be toxic to the aquatic ecosystem (Boguta et al. 2022). Fine-grained sediments like clay, characterized by their high specific surface area, often exhibit higher metal contents primarily because of surface adsorption to the mineral component and organic matter coatings (Bartoli et al. 2012). However, sand has significant

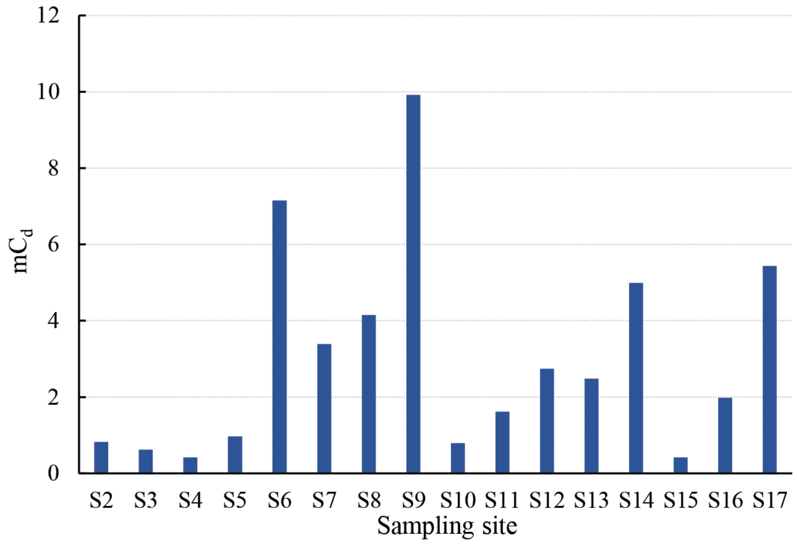


**Fig. 5: The $mC_d$ values in the sediment of the river**

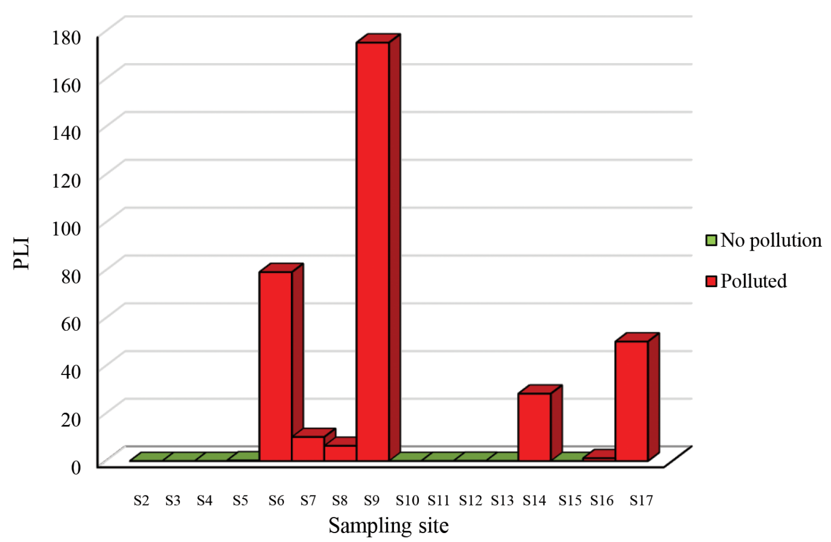


**Fig. 6: The PLI of analyzed metals in the sediment of the river.**

negative correlations with EC (r= -0.612, p<0.01), OM (r= -0.622, p<0.01), Cu (r= -0.684, p<0.01), and Zn (r= -0.583, p<0.05) and weak negative correlation with Cd and clay. The negative correlations of sand with EC, OM, and metals suggest that coarse-grained sediments, characterized by a low organic content, have a limited capability to retain metal ions (Raj et al. 2013).

**Table 2: Correlation matrix of physicochemical parameters and heavy metals of the river sediment**

| | pH | EC | OM | Cu | Zn | Cd | Clay | Sand |
|---|---|---|---|---|---|---|---|---|
| **pH** | 1 | | | | | | | |
| **EC** | -0.116 | 1 | | | | | | |
| **OM** | -0.246 | 0.586* | 1 | | | | | |
| **Cu** | -0.257 | **0.674**** | **0.725**** | 1 | | | | |
| **Zn** | -0.044 | **0.637**** | 0.554* | **0.914**** | 1 | | | |
| **Cd** | -0.331 | 0.396 | 0.451 | **0.644**** | **0.700**** | 1 | | |
| **Clay** | 0.031 | 0.071 | 0.299 | 0.427 | 0.384 | 0.320 | 1 | |
| **Sand** | 0.026 | **-0.612**** | **-0.622**** | **-0.684**** | -0.583* | -0.173 | -0.447 | 1 |

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

**Classification of the river based on heavy metal contamination and identification of its potential sources in the river sediment**

The HCA categorizes the rivers into three clusters (Fig 8) and depicts that the upstream of the river is less contaminated than the middle and downstream. The first cluster includes three sampling sites, namely S9 (Tilganga), S14 (Teku Dovan), and S17 (Manjushree Park, Chovar), where the contamination level is the highest. The elevated contamination level at these sampling sites could be attributed to the disposal of untreated hospital waste into the river, leaching from haphazardly disposed solid waste, and industrial activities occurring in close proximity to the river. In addition, the increased level of heavy metal contamination in S9 (Tilganga) can be linked to the release of heavy metals from the ashes of dead human bodies, a consequence of nearby cremation practices at the location. Mordhorst et al. (2022) conducted a study on the environmental risk associated with heavy metals released from the deceased human bodies into cemetery soil in North and West Germany. The study reports that cemetery soils release heavy metals derived from cremated remains.

The PCA was performed by varimax rotation with Kaiser Normalization. The Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin (KMO) Test were used to assess the reliability of PCA, with the value of 0.692 and 58.398, respectively.

The PC1 and PC2 accounts for 61.954% and 17.231% of variance with 3.717 and 1.034 eigen values, respectively (Table 3). The PC1 has strong loading on EC, OM, Cu, Cd, and Zn, whereas PC2 has strong loading on pH. The results exhibit that all three metals have strong loading on PC1. Likewise, Spearman's correlation analysis depicts that all three metals are significantly positively correlated with each other. This result suggests that all three metals might have same origin. Higher levels of trace metals in the bottom sediments of water bodies may indicate anthropogenic pollution as opposed

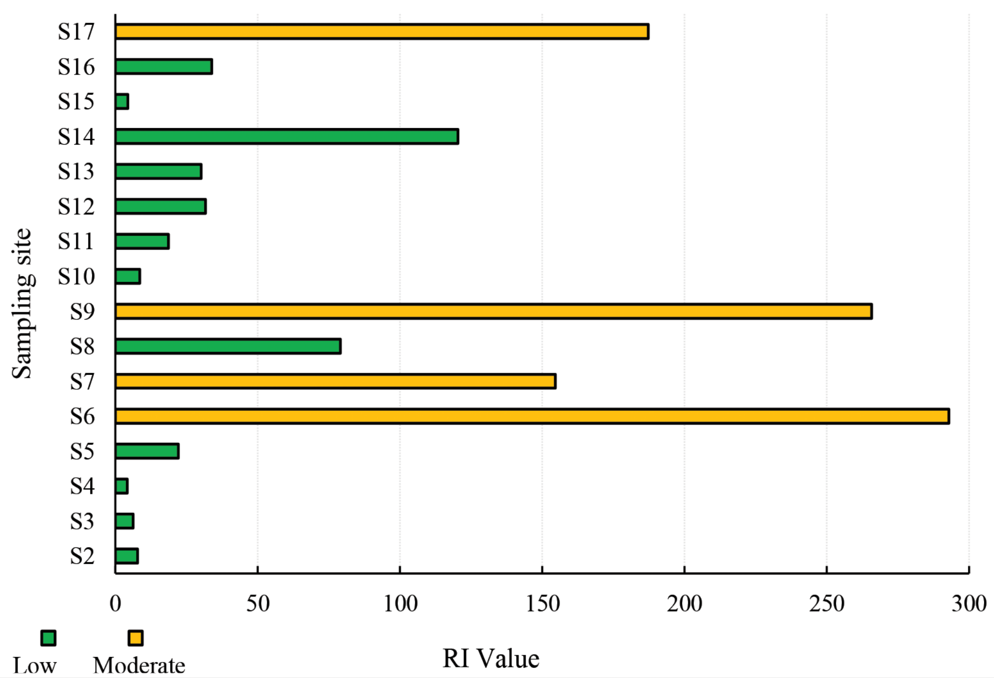


**Fig. 7: Potential ecological risk index (RI) of analyzed metals in the river sediment.**

to sediments being naturally enriched through geological weathering (Wakida et al. 2008). The association between heavy metals and OM in PC1 is explained by relationship of OM with fine-grained sediments such as clay, known for their high specific surface area. These sediments often show higher metal contents primarily due to surface adsorption to the mineral component and organic matter coatings (Bartoli et al. 2012; Boguta et al. 2022). Additionally, the emission of heavy metals like Cu, Zn, and Cd are also due to automobile exhaust in bigger cities (Bradl, 2005). These metals are also likely to be enriched in the river due to their atmospheric deposition. A wide range of areas in close proximity to major cities exhibit increased levels of As, Cu, Pb, Sn, and Zn in the sediment samples (Bradl, 2005).

The Bagmati River flows from the urbanized areas of the Kathmandu Valley which is the biggest city of Nepal. Anthropogenic activities such as mixing domestic sewage, dumping of untreated wastewater, and emissions from vehicles might be the contributors for heavy metals contamination in the river sediments. Kayastha (2015) also highlighted that untreated municipal wastewater, industrial effluents, and heavy traffic are significant factors contributing to heavy metal contamination in the sediment of the Bagmati River in urban areas. Panthi et al. (2017) noted an increase in pollution in the Bagmati River attributed to factors such as urban land use, population growth, domestic water consumption, improper solid waste management, and the discharge of untreated industrial wastewater. The positive loading of only pH in PC2 demonstrates that the increase in pH has no significant role in fluctuations of physicochemical parameters in the river water.

**Table 3: The principal component, associated heavy metals, percentage of variance explained by principal components**

| Metals | PC1 | PC2 |
|---|---|---|
| pH | -0.311 | **0.925** |
| EC | **0.870** | 0.185 |
| OM | **0.764** | -0.086 |
| Cu | **0.905** | 0.107 |
| Zn | **0.910** | 0.287 |
| Cd | **0.797** | -0.208 |
| Eigen Value | 3.717 | 1.034 |
| Variance | 61.954 | 17.231 |
| Cumulative | 61.954 | 79.185 |

## CONCLUSIONS

The pH of Bagmati River sediment was slightly alkaline with highly variable EC and moderate to high levels of OM. The texture of the sediment was mostly sandy and loamy sandy. Some stretches of river exhibited notable contamination with high levels of Cu, Zn, and Cd in the river sediments as based on the Canadian Interim Sediment Quality Guidelines for Protection of Aquatic Life. The Cu exhibits high contamination factor and geoaccumulation index. The $mC_d$ and PLI values of the sediments suggest that S9 (Tilganga) experienced the highest level of pollution from the studied metals. The overall

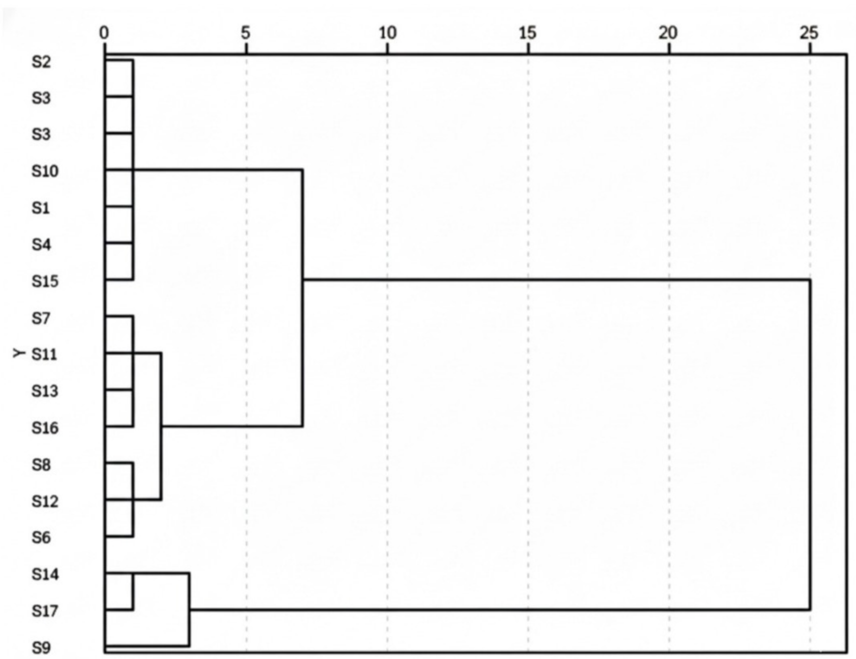


**Fig. 8: Dendrogram of sampling sites using Ward's method.**

ecological risk assessment for the study area indicated a low to moderate risk associated with Cu, Zn, and Cd, as suggested by the RI value. The significant positive correlations among Cu, Zn, and Cd indicate that a common source for these metals. In addition, PCA demonstrates that anthropogenic causes such as mixing of domestic sewage, untreated effluents, and industrial activities may be the source of Cu, Zn, and Cd contamination in the sediment of the river. The HCA reveals that the middle and downstream of the study area is more contaminated by heavy metals than the upstream. It is advised to conduct regular monitoring of sediment and water of the Bagmati River to identify the sources of heavy metal pollution and record changes in the level of contamination. This study focused on a selected group of heavy metals (Cu, Cd, Zn, and Pb) analyzing their presence only in the sediment during a single sampling period. This limitation suggests that future researchers should consider extensive spatial and temporal sampling, as well as other significant heavy metals to provide a comprehensive assessment of ecological risks.

## AUTHOR'S CONTRIBUTION

Shraddha Bhattarai: Data curation, Formal analysis, Funding acquisition, Methodology, Writing – original draft. Suman Man Shrestha: Conceptualization, Writing – original draft, Supervision, Writing – review and editing.

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## REFERENCES

Abrahim, G.M.S., and Parker, R.J., 2008, Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environ. Moni. Assess., v. 136, pp. 227–238.

Acharya, D., and Pant, B.R., 2021, Water quality of Bagmati River in Kathmandu Valley, Nepal. Saptagandaki J., v. 12(1), pp. 95–109. https://doi.org/10.3126/sj.v12i12.46156

Adhikari, M.P., Neupane, M.R., and Kafle, M., 2019, Physico-chemical parameterization and determination of effect of tributaries on enhancement of pollutants in Bagmati River. J. Nepal Chem. Soc., v. 40, pp. 36–3. https://doi.org/10.3126/jncs.v40i0.27276

Adhikari, M.P., Rawal, N.B., and Adhikari, N.B., 2021, Real-time fine-scale measurement of water quality parameters along the Bagmati River in the Kathmandu Valley. Nat. Environ. Poll. Technol., v. 20(3), pp. 1047–1057. https://doi.org/10.46488/NEPT.2021.v20i03.012

Afshan, S., Ali, S., Ameen, U.S., Farid, M., Bharwana, S.A., Hannan, F., and Ahmad, R., 2014, Effect of different heavy metal pollution on fish. Res. J. Chem. Environ. Sci., v. 2(1), pp. 74–79.

Ahmad, K., Muhammad, S., Ali, W., Jadoon, I.A.K., and Rasool, A., 2020, Occurrence, source identification and potential risk evaluation of heavy metals in sediments of the Hunza River and its tributaries, Gilgit-Baltistan. Environ. Technol. Inno., v. 18(4), 100700. https://doi.org/10.1016/j.eti.2020.100700

Ali, M.M., Rahman, S., Islam, M.S., Jahan Rakib, M.R., Hossen, S., Rahman, M.Z., Kormoker, T., Idris, A.M., and Phoungthong, K., 2022, Distribution of heavy metals in water and sediment of an urban river in a developing country: A probabilistic risk assessment. Int. J. Sediment Res., v. 37(2), pp. 173–187. https://doi.org/10.1016/j.ijsrc.2021.09.002

Baniya, B., Khadka, N., Ghimire, S.K., Baniya, H., Sharma, S., Dhital, Y.P., Bhatta, R., and Bhattarai, B., 2019, Water quality assessment along the segments of Bagmati River in Kathmandu Valley, Nepal. Nepal J. Environ. Sci., v. 7, pp. 1–10. https://doi.org/10.3126/njes.v7i0.34314

Bartoli, G., Papa, S., Sagnella, E., and Fioretto, A., 2012, Heavy metal content along the Calore River: Relationships with physical-chemical characteristics. J. Environ. Manag., v. 95, pp. S9–S14. https://doi.org/10.1016/j.jenvman.2011.02.013

Boguta, P., Skic, K., Baran, A., and Szara-Bąk, M., 2022, The influence of the physicochemical properties of sediment on the content and ecotoxicity of trace elements in bottom sediments. Chemosphere, v. 287. https://doi.org/10.1016/j.chemosphere.2021.132366

Bradl, H.B., 2005, Heavy metals in the environment. In: H.B. Bradl (Ed.), Sources and origins of heavy metals. Elsevier Academic Press, pp. 1–27.

CCME, 1999, Canadian Environmental Quality Guidelines, Canadian Council of Ministers of the Environment, Winnipeg.

Chapman, P.M. and Mann, G.S., 1999, Sediment quality values (SQVs) and ecological risk assessment (ERA), Mar. Poll. Bull., v. 38(5), pp. 339–344. https://doi.org/10.1016/S0025-326X(99)00033-8

Chen, L., Wei, Q., Xu, G., Wei, M., and Chen, H., 2022, Contamination and ecological risk assessment of heavy metals in surface sediments of Huangshui River, Northwest China. J. Chem., v. 2022, pp. 1–9. https://doi.org/10.1155/2022/4282992

Chen, S., Chen, B., and Fath, B.D., 2013, Ecological risk assessment on the system scale: A review of state-of-the-art models and future perspectives. Ecol. Model., v. 250, pp. 25–33. https://doi.org/10.1016/j.ecolmodel.2012.10.015

Dash, S., Borah, S.S., and Kalamdhad, A.S., 2021, Heavy metal pollution and potential ecological risk assessment for surficial sediments of Deepor Beel, India. Ecol. Indic., v. 122. https://doi.org/10.1016/j.ecolind.2020.107265

Fadlillah, L.N., Utami, S., Rachmawati, A.A., Jayanto, G.D., and Widyastuti, M., 2023, Ecological risk and source identifications of heavy metals contamination in the water and surface sediments from anthropogenic impacts of urban river, Indonesia. Heliyon, v. 9(4). https://doi.org/10.1016/j.heliyon.2023.e15485

Hakanson, L., 1980, An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res., v. 14(8), pp. 975–1001. https://doi.org/10.1016/0043-1354(80)90143-8

Islam, M.S., Proshad, R., and Ahmed, S., 2017, Ecological risk of heavy metals in sediment of an urban river in Bangladesh. Hum. Ecol. Risk Assess., v. 24(3), pp. 699–720. https://doi.org/10.1080/10807039.2017.1397499

Kahlon, S.K., Sharma, G., Julka, J.M., Kumar, A., Sharma, S., and Stadler, F.J., 2018, Impact of heavy metals and nanoparticles on aquatic biota. Environ. Chem. Lett., v. 16, pp. 919–946. https://doi.org/10.1007/s10311-018-0737-4

Kannel, P.R., Lee, S., Lee, Y.S., Kanel, S.R., and Pelletier, G.J., 2007, Application of automated QUAL2Kw for water quality modeling and management in the Bagmati River, Nepal. Ecol. Model., v. 202(3), pp. 503–517. https://doi.org/10.1016/j.ecolmodel.2006.12.033

Kayastha, S.P., 2015, Heavy metals fractionation in Bagmati River sediments, Nepal. J. Hydrol. Meteorol., v. 9(1), pp. 119–128. https://doi.org/10.3126/jhm.v9i1.15587

Kazlauskaite-Jadzevice, A., Volungevicius, J., Gregorauskiene, V., and Marcinkonis, S., 2014, The role of pH in heavy metal contamination of urban soil. J. Environ. Eng. Landsc. Manag., v. 22(4), pp. 311–318. https://doi.org/10.3846/16486897.2013.872117

Khadka, Y.J., Iqbal, M.Z., and De Nault, K.J., 2015, Urban pollution of Bagmati River Corridor within densely populated Kathmandu Valley in Nepal. Asian J. Water Environ. Poll., v. 12(4), pp. 43–59. https://doi.org/10.3233/AJW-150017

Lin, J.G., and Chen, S.Y., 1998, The relationship between adsorption of heavy metals and organic matter in river sediments. Environ. Int., v. 24(3), pp. 345–352. https://doi.org/10.1016/S0160-4120(98)00012-9

Mahat, A., Maharjan, K.K., Regmi, P.K., Ghimire, K., and Mohapatra, S.P., 2020, Assessment of water pollution in Bagmati River of Kathmandu Valley. Adv. Plant Sci., v. 33(1), pp. 89–93.

McKeague, J.A., 1978, Manual on soil sampling and methods of analysis. Canadian Society of Soil Science, Ottawa.

Mishra, B.K., Regmi, R.K., Masago, Y., Fukushi, K., Kumar, P., and Saraswat, C., 2017, Assessment of Bagmati River pollution in Kathmandu Valley: Scenario-based modeling and analysis for sustainable urban development. Sustain. Water Qual. Ecol., v. 9, pp. 67–77. https://doi.org/10.1016/j.swaqe.2017.06.001

Mordhorst, A., Zimmermann, I., Fleige, H., and Horn, R., 2022, Environmental risk of (heavy) metal release from urns into cemetery soils. Sci. Total Environ., v. 817, 152952. https://doi.org/10.1016/j.scitotenv.2022.152952

Müller, G., 1969, Index of geoaccumulation in the sediments of the Rhine River. Geojournal, v. 2, pp. 108–118.

Nour, H.E., El-Sorogy, A.S., El-Wahab, M.A., Nouh, E.S., Mohamaden, M., and Al-Kahtany, K., 2019, Contamination and ecological risk assessment of heavy metals pollution from the Shalateen coastal sediments, Red Sea, Egypt. Mar. Poll. Bull., v. 144, pp. 167–172. https://doi.org/10.1016/j.marpolbul.2019.04.056

Pal, K.B., Pant, R.R., Rimal, B., and Mishra, A.D., 2019, Comparative assessment of water quality in the Bagmati River Basin, Nepal. Zoo J., v. 5, pp. 68–78. https://doi.org/10.3126/zooj.v5i0.34919

Panthi, J., Li, F., Wang, H., Aryal, S., Dahal, P., Ghimire, S., and Kabenge, M., 2017, Evaluating climatic and non-climatic stresses for declining surface water quality in Bagmati River of Nepal. Environ. Moni. Assess., v. 189, pp. 292. https://doi.org/10.1007/s10661-017-6000-9

Paudyal, R., Kang, S., Sharma, C.M., Tripathee, L., and Sillanpaa, M., 2016, Variations of the physicochemical parameters and metal levels and their risk assessment in urbanized Bagmati River, Kathmandu, Nepal. J. Chem., v. 2016, 6025905. https://doi.org/10.1155/2016/6025905

Raj, S., Jee, P.K., and Panda, C.R., 2013, Textural and heavy metal distribution in sediments of Mahanadi estuary, East coast of India. Indian J. Geo-Mar. Sci., v. 42(3), pp. 370–374.

Regmi, R.K., Mishra, B.K., Masago, Y., Luo, P., Kojima, A.T., and Jalilov, S.M., 2017, Applying a water quality index model to assess the water quality of the major rivers in the Kathmandu Valley, Nepal. Environ. Moni. Assess., v. 189(8), 382. https://doi.org/10.1007/s10661-017-6090-4

Shah, P.K., and Chaturwedi, S.B., 2019, Physicochemical and bacteriological water analysis of Bagmati and Bishnumati River. Tribhuvan University J., v. 33(1), pp. 23–30. https://doi.org/10.3126/tuj.v33i1.28678

Sudhanandh, V.S., Udayakumar, P., Ouseph, P.P., Amaldev, S., and Babu, K.N., 2011, Dispersion and accumulation trend of heavy metals in coastal and estuarine sediments and its textural characteristics, a case study in India. J. Hum. Ecol., v. 36(2), pp. 85–90. https://doi.org/10.1080/09709274.2011.11906421

Talukder, R., Rabbi, M.H., Baharim, N.B., and Carnicelli, S., 2022, Source identification and ecological risk assessment of heavy metal pollution in sediments of Setiu wetland, Malaysia. Environ. Forensics, v. 23, pp. 241–254. https://doi.org/10.1080/15275922.2021.1892871

Tham, T.T., Lap, B.Q., Mai, N.T., Trung, N.T., Thao, P.P., and Lan Huong, N.T., 2021, Ecological risk assessment of heavy metals in sediments of Duyen Hai Seaport Area in Tra Vinh Province, Vietnam. Water Air Soil Poll., v. 232, 49. https://doi.org/10.1007/s11270-021-05014-5

Tomlinson, D.L., Wilson, J.G., Harris, C.R., and Jeffrey, D.W., 1980, Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgolander Meeresunters, v. 33, pp. 566–575. https://doi.org/10.1007/BF02414780

Tripathi, A., and Misra, D.R., 2012, A study of physico-chemical properties and heavy metals in contaminated soils of municipal waste dumpsites at Allahabad, India. Int. J. Environ. Sci, v. 2(4), pp. 2024–2033. https://doi.org/10.6088/ijes.00202030086

USDA, 2017, Soil Survey Manual, USDA Handbook, United States Department of Agriculture, Washington, D.C.

USEPA, 1986, Test methods for evaluating solid waste: Physical/chemical methods (SW-846), United States Environmental Protection Agency, Washington, D.C.

Vu, C.T., Lin, C., Nguyen, K.A., Shern, C.C., and Kuo, Y.M., 2018, Ecological risk assessment of heavy metals sampled in sediments and water of the Houjing River, Taiwan. Environ. Earth Sci., v. 77, pp. 1–11. https://doi.org/10.1007/s12665-018-7573-5

Wakida, F.T., Lara-Ruiz, D., Temores-Peña, J., Ventura-Rodriguez, J.G., Diaz, C., and Garcia-Flores, E., 2008, Heavy metals in sediments of the Tecate River, Mexico. Environ. Geo., v. 54(3), pp. 637–642. https://doi.org/10.1007/s00254-007-0831-6

Waziri, N.M., 2023, Assessment of levels of contamination and estimation of ecological risk by potentially toxic elements in Chanchaga River in Minna, Nigeria. Dutse J. Pure Appl. Sci, v. 9, pp. 62–72. https://doi.org/10.4314/dujopas.v9i3a.7

Yan, C., Li, Q., Zhang, X., and Li, G., 2010, Mobility and ecological risk assessment of heavy metals in surface sediments of Xiamen Bay and its adjacent areas, China. Environ. Earth Sci., v. 60(7), pp. 1469–1479. https://doi.org/10.1007/s12665-009-0282-3

Yang, Y., Jin, Q., Fang, J., Liu, F., Li, A., Tandon, P., and Shan, A., 2017, Spatial distribution, ecological risk assessment, and potential sources of heavy metal(loid)s in surface sediments from the Huai River within the Bengbu section, China. Environ. Sci. Poll. Res., v. 24(12), pp. 11360–11370. https://doi.org/10.1007/s11356-017-8732-z

Zeng, F., Ali, S., Zhang, H., Ouyang, Y., Qiu, B., Wu, F., and Zhang, G., 2011, The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Environ. Poll., v. 159(1), pp. 84–91. https://doi.org/10.1016/j.envpol.2010.09.019

Zhang, G., Bai, J., Xiao, R., Zhao, Q., Jia, J., Cui, B., and Liu, X., 2017, Heavy metal fractions and ecological risk assessment in sediments from urban, rural and reclamation-affected rivers of the Pearl River Estuary, China. Chemosphere, v. 184, pp. 278–288. https://doi.org/10.1016/j.chemosphere.2017.05.155

Zhang, L., and Liu, J., 2014, In situ relationships between spatial–temporal variations in potential ecological risk indexes for metals and the short-term effects on periphyton in a macrophyte-dominated lake: a comparison of structural and functional metrics. Ecotoxicology, v. 23, pp. 553–566. https://doi.org/10.1007/s10646-014-1175-0

Zhang, Z., Pei, N., Sun, Y., Li, J., Li, X., Yu, S., Xu, X., Hu, Y., and Mai, B., 2019, Halogenated organic pollutants in sediments and organisms from mangrove wetlands of the Jiulong River Estuary, South China. Environ. Res., v. 171, pp. 145–152. https://doi.org/10.1016/j.envres.2019.01.028