ASSESSMENTOF HEAVY METAL CONTAMINATION IN THE SEDIMENTS OF MAHANANDA RIVER IN THE SEEMANCHAL ZONE OF NORTHERN BIHAR, INDIA

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Abstract
The present study includes a systematic analysis of bed sediment contamination by heavy metals of the Mahananda River flowing through Seemanchal zone of Bihar, India. To assess the spatial distribution, degree of contamination and risk assessment of heavy metals, seven selected metals were examined from the freshly deposited river sediment. The heavy metal concentration in the sediments ranged from 49.51-82.78, 83.64-141.68, 121.34-198.67, 41.28-83.43, 245.67-423.64, 0.53-1.05 and 17.91-29.62 mg kg^{-1} for Cu, Zn, Cr, Ni, Mn, Cd and Pb respectively. Highest concentration of heavy metals was found in the sediment of river especially, midstream and downstream. According to degree of contamination and pollution load index assessment, heavy metals pollution was highest in the sediment of downstream and lowest in upstream of River. Geo-accumulation indices showed that sediment was uncontaminated to moderately contaminate and may adversely affect the fresh water ecology of the river. Metal enrichment factor (EF) for all sampling stations was recorded 2 - 8. The exceptionally high EF value was observed for Cd (6.32-7.68) at all sampling stations. The mean ecological risk factor ($E^i r$) values were found below 40 except Cd ($E^i r$ = 75.2) and average potential ecological risk index (PERI) value (99.35) of the combined heavy metals showed that the metals in the sediment of River in the Seemanchal zone caused low potential ecological risk overall. Based on the comparison of heavy metals concentration with the consensus-based sediment-quality guidelines Ni and Cr are likely to result to the deleterious effect on bottom-dwelling organisms. Our findings also suggest that 33.3% of sediment samples have mean probable concentration quotients (m-PEC-Q) values in between 0.1 - 1, indicating moderate toxicological risks for sediment dwelling organisms, with a toxicity incidence of between 15 - 29% in the study areas. Positive correlation was recorded among Cu, Zn, Pb, Ni, and Cr indicated common pollution sources or identical geochemical behaviour for these metals. Therefore proper management is required to control the direct dumping of wastewater and wastes in the river and continuous monitoring, and cleanup operation is suggested to minimize pollution.

Keyword: Mahananda River stretch, Bed-Sediment, Heavy metals, Assessment of sediment contamination, Risk Assessment of heavy metals**.**

1. INTRODUCTION

Heavy metal pollution of waste water and sediment is a significant environmental problem and has a negative impact on aquatic organisms, human health and agriculture (Islam *et al.*, 2015; Singh *et al.*, 2018; Decen *et al.*, 2018). Most of the Himalayan Rivers pass through various types of geographical areas which have their specific characteristic features. Rivers come in contact with different types of rocks in their pathway which are weathered by physical, chemical and biological processes. The weathered elements by the natural processes add directly in to the river system. Various types of chemicals also are added in the rivers by anthropogenic activities which contribute changing the physical, chemical, and biological properties of the river water. In the light of extreme human activity, natural sources of heavy metals are usually of a little importance (Xu *et al.*, 2016a; Patel *et al.*, 2018; Yan *et al.*, 2018). Anthropogenic activities such as industrial effluent, sewage sludge, domestic wastes (Guatam *et al.*, 2013; Mozumdar *et al.*, 2015; Arbind and Seema, 2016; Kumar *et al.*, 2017), atmospheric pollutants (Arbind and Seema , 2017) and agricultural runoff (Zhang *et al.*, 2014; Singh *et al.*, 2016, 2017) entering the water bodies are one of the prime sources of heavy metal toxicity, which deteriorates water quality and danger to human health and aquatic organisms (Xu *et al.*, 2016a; Xu *et al.*, 2016b).

There are basically three types of reservoirs for metal in the aquatic environment: water, sediment and biota (Saha *et al.*, 2001; Balsan *et al.*, 2013)**.** Sediment is loose sand, silt, clay and other particles that is deposited at the bottom of body of water or accumulated at other depositional sites (Andem *et al.*, 2015: Kuriata-Potasznik *et al.*, 2016). They are essential integral parts of water regime and can provide the substrate for the organism and through interaction with overlying waters play an important responsibility in the ecosystem (Al Obaidy *et al.*, 2014). The fate of heavy metals in an aquatic environment is affected by processes such as precipitation, sorption, and dissolution (Abdel-Ghani and Elchaghaby 2007). These processes are also affected by factors such as pH, temperature, dissolve oxygen and the disturbance of the water (Atkinson *et al.*, 2007; Simpson *et al.*, 2004, Petal *et al.*, 2018; Wang *et al.*, 2018). At higher pH, heavy metals precipitate and get adsorbed onto sediment surfaces. Metals are also released more easily into the water at lower pH and higher temperatures. When the dissolved oxygen concentration is low, i.e., less than 7 mg L^{-1}, heavy metals especially those bound to organic matter sediments are released into the overlying water and vice versa (Haiyan *et al.*, 2013). Physical disturbance of water releases metals more rapidly into water than biological disturbance (Atkinson *et al.*, 2007). The study of heavy metals in sediments can serve as a guide in predicting the extent of pollution of the overlying water under different environmental conditions. The heavy metals that are accumulated in the river sediment through adsorption depend upon the properties of adsorbed components and the nature of sediment (Robee *et al.*, 2011) and these contaminated sediments have the potential to cause direct effect on sediments dwelling organism and can indirectly adversely affect man and other animal at the higher tropic levels (Gupta *et al.*, 2014; Aazami *et al.*, 2018). Thus sediments act as both carrier and potential sources of contaminant in an aquatic environment and can serve as a pool that can retain or release contaminants to water column by various process of remobilisation (Ogbibu *et al.*, 2014). In the aquatic ecosystem, sediments have been widely used as environmental indicator and their chemical analysis can provide significant interaction or the assessment of anthropogenic activities (Shafie *et al.*, 2014; Singh *et al.*, 2015; Petal *et al.*, 2016; Emmanuel *et al.*, 2018).

The River Mahananada is a trans-boundary river that flows through Bangladesh and Indian States, West Bengal and Bihar. It plays a significant role in the health of people of Seemanchal zone of Bihar, India located on its bank. The people of Seemanchal zone are highly dependent on this river water to meet their demand for drinking and other domestic purpose on regular basis, but at present, it has become polluted at some places due to discharge of untreated or partial treated industrial and domestic wastes, and also agricultural runoff from its catchment areas.

Various researchers have reported the heavy metal contamination in river basin which eventually confirms the high rate of anthropogenic discharge in river basin which is polluting water as well as sediments (Jain *et al.*, 2008; Montuori *et al.*, 2013; Shafie *et al.*, 2014; Singh *et al.*, 2015; Patel *et al.*, 2016) but there are few published data on sediment of Mahananda River in India however, not available in the literature of sediment of Mahananda River in Seemanchal zone. Therefore, the main goal of the present study is to determine the current status of the heavy metals at three urban and rural areas namely Kishanganj, Purnia and Katihar which are located in middle stretch of Mahananda River bank in Seemanchal zone along with the potential ecological risk assessment for all elements.

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2. MARERIALS AND METHODS

2.1 Study area

The River Mahananda is one of the major northern tributries of the river Ganga, passing through Nepal, India and Bangladesh. It is bounded on the North by the Himalayas, the ridges separating it from the Teesta river system in the East, the Ganga on the South and the Kosi river system in the West. It originates 6 kms north of kurseong in the Darjeeling district of West Bengal in the Himalayan range, near to Chimli at the elevation of 2062 meters. It has a commanding role in regulating overall economy of the catchment area, such as Darjeeling, Uttar Dinajpur and Maldah districts of west Bengal and Kishanganj, Purnea and Katihar districts of Bihar in more than one way. The Mahananda River starts its 360 km long journey to the Ganga out of which 324 km are in India and 36 km are in Bangladesh. The total drainage area of the this river is 24,753 km^2, of which 5,293 km^2 are located in Nepal, 6,677 km^2 in west Bengal, 7,975 km^2 in Bihar and rest is located in Bangladesh, where it finally joins in the Ganga (Padma) near Godagarighat in Nawabganj district. In north Bihar Mahananda River bifurcates into two streams close to Bagdob (Bihar), among which right portion, known as Jhawa (Katihar) branch and traverses through Jhawa, Prannpur, Labha, Singhia and Gobindpur and falls in Ganga near to Chowakia Paharpur in the Katihar district.

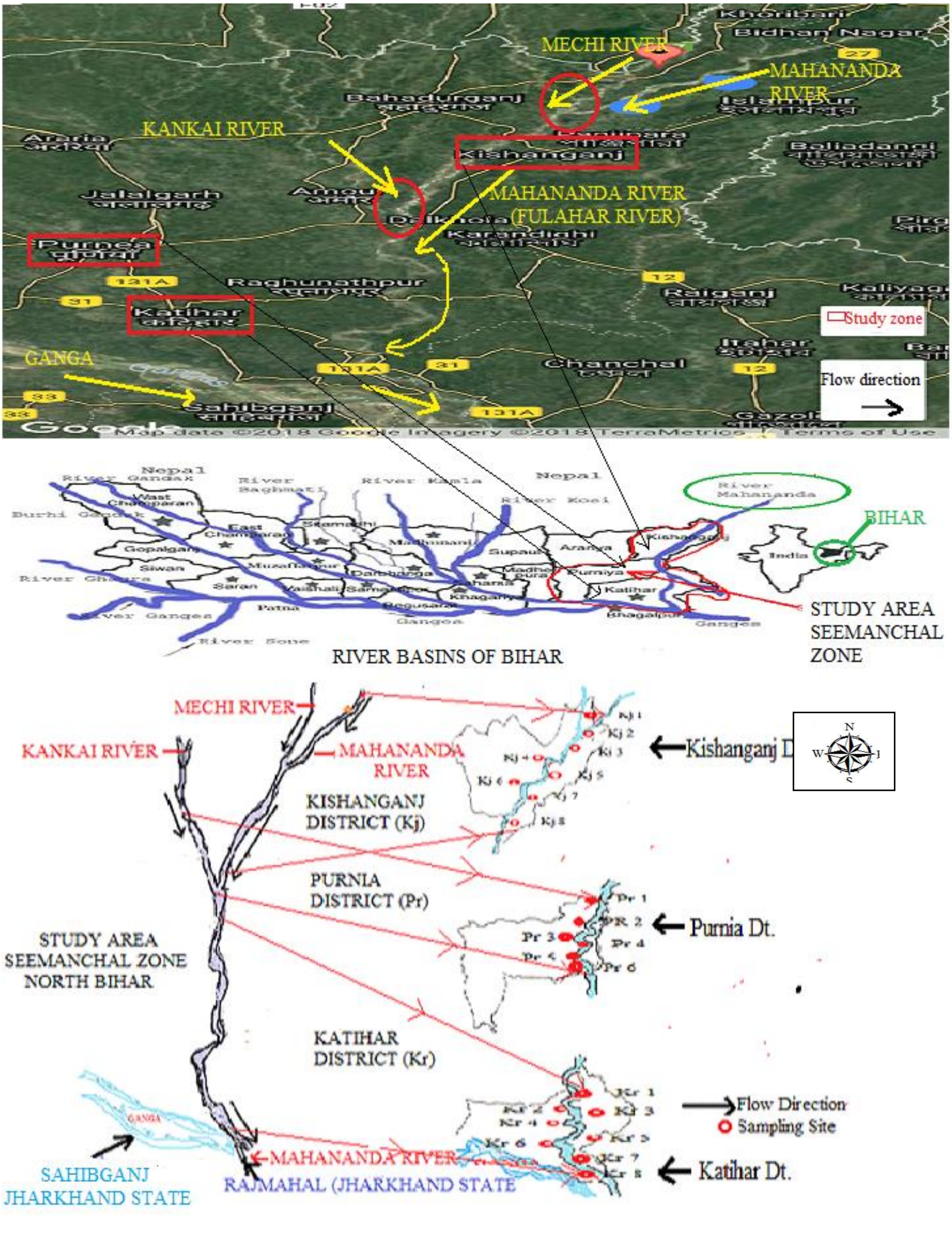


Figure 1 Location of study area

. The left branch popularly known as the Barsoi (Katihar) branch and forms a loop to enter West Bengal. Babakhola, Shivkhola, Manakhola, Mechi, Dowk, Kankai, Gamari, Sudhani etc., are some of its major tributaries. After entering the plains near Silliguri the River flows on almost flat land and after it crosses the Barhi-Guwahati NH-31 near Dhengraght, the ground slopes for the Jhawa branch are as low as10 cms km^{-1} whereas the Barsoi branch has slope of about 15 cms km^{-1}. Due to these flat slopes, the River Mahananda used to split its banks causing flood and water logging in the Seemanchal zone. The River Mechi and Kankai flow through Nepal and form the boundary between India and Nepal and then flow through the Indian state of Bihar to join the Mahananda in Kishanganj district (Fig. 1).

2.2 Description of sampling sites

Kishanganj: The River system after crossing Siliguri district of West Bengal enters into Kishanganj district of Bihar and passes through Thakurganj (Kj-1), Arrabari (Kj-2), Halamla (Kj-3), Palkoaikund (Kj-4), Balubari (Kj-5), Gobondpur (Kj-6), Chakandra

(Kj-7) and Kishanganj town (Kj-8) as shown in Fig. 2. Kishanganj district is part of northern Indian plains just before start of the hills of West Bengal. The district occupies an area of 1,884 km^2. According to the 2011 census Kishanganj district has a population of 1,690,948. Kishanganj district is located between 25 ^{0} 20' and 26 ^{0} 30' north latitudes, and 87 ^{0} 7' and 88 ^{0}19' east longitudes. The average elevation of Kishanganj city above the sea level is 55 m. The Rivers flowing through this district include Mahananda, Kankai, Mechi, Donk, Rauta, Sudhani and Ramzan are key sources of irrigation water meant for agriculture in Kishanganj District. Alluvial soil of Kishanganj district and nearby regions makes it best suitable for various crop farming. Soil texture also maintains sandy and loamy features which make its plains suitable for the agricultural activities. Few factories too have been established in this region in the recent decades. Thakurganj and Terhagach are two blocks of the district where ample forest reserves are found. Forest formations found in Kishanganj include herbal plants, fruit plants, teak, Sal and several others making forestry a mixed one. The water body receives a lot of wastes ranging from industrial, agricultural and domestic sources, which apart from adversely affecting the normal hydrochemistry of the river, also decreases its channel capacity at various points, and this has been largely responsible for flood disasters in the river.

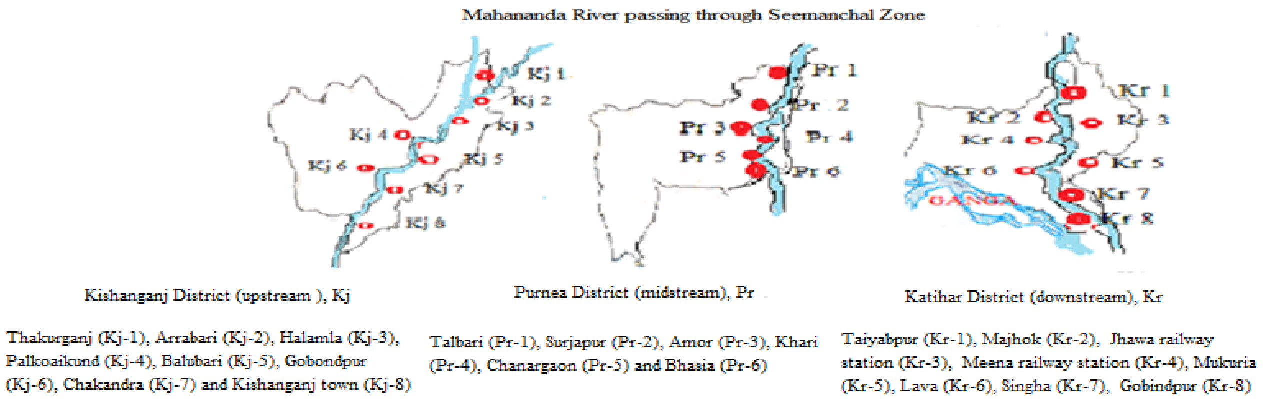


Figure 2 Study of sampling sites

Purnea: Kankai River is major tributary of Mahananda River, when enters in Purnea district of Seemanchal zone, passes through Talbari (Pr-1), Surjapur (Pr-2), Amor (Pr-3), Khari (Pr-4), Chanargaon (Pr-5) and Bhasia (Pr-6) as shown in Fig 2. Purnea district is situated in Northern part of Bihar; its geographical area is 3229 km^2 and lies between 25 ^{0} 13' 80" and 27 ^{0} 7' 59" north latitude and between 86 ^{0} 59' 6"and 87 ^{0} 52' 35" east longitude. There are four important rivers which traverse the city and also divide the district into four distinct zones. The rivers which traverse the city are Kosi in the west, Panar in the northeast, Mahananda in the east and Ganga in the south. The area which is located around the Kosi River shows sandy deposits while the area around Mahananda shows Loamy deposits. Since there is frequent flooding of the banks of the river, the region is well suited for Jute and Paddy cultivation. The region is also known for makhana cultivation which is gaining prominence in recent times. The district is one of the fastest growing districts in the state and this can be seen in the increasing infrastructural facilities in the city. River also receives effluents from many small industries, textile battery producing unit and also agricultural runoff from its catchment area,

Katihar: The right portion of River Mahananda at Bagdob known as Jhawa branch, when enters in Katihar district of Seemanchal zone, passes through Taiyabpur (Kr-1), Majhok (Kr-2), Jhawa railway station (Kr-3), Meena railway station (Kr-4), Mukuria (Kr-5), Lava (Kr-6), Singha (Kr-7), Gobindpur (Kr-8) to merging points of the river Ganga near to Chowakia Paharpur Panchayat, Amdabad block of Katihar district. Katihar district is situated in the plains of North Eastern part of Bihar State. It is located at 25.53 ° N 87.58 ° E. It has an average elevation of 20 m. The main rivers of the District are mighty Ganga, Kosi and Mahananda. This district shares boundary with two states i.e. Jharkhand at the southern side and West Bengal at the eastern side. The Bangladesh lies around 80 km east of Katihar town and Nepal lies around 100 km north of Katihar Town. The soil of Mahananda River basin is alluvial and is exceedingly fertile because of the large quantity of soil transport with water of flood. The River receives allochtonous input of organic matter from the surrounding vegetation derived through runoff from the surface of soil. Solid wastes are produced daily from domestic uses in Katihar city and about 65% of them are dumped in the river.

The Mahananda River, like any other major Rivers of Bihar, brings with it a high amount of detritus, as it debouches unto the plains, from the loosely packed, geologically nascent Himalayan range of mountains. The river is to have changed its course in past. Various small seasonal rivers with varying water and sediment loads discharge into River. Most of these rivers have become channels for small industrial and domestic waste discharge. The Mahananda catchment has an average rainfall of about 1.563 mm in its Bihar portion which rises to a maximum of about 6,000 mm in the higher catchment.

2.3 Sediment Sample collection

The sampling sites were chosen to arbitrarily take over the previously prepared sampling location map (Fig.2).Sediment samples were collected from 8 sites of River in each of Kishanganj (upstream) and katihar (downstream), and 6 sites in Purnea (midstream) areas of Seemanchal zone in the April 2017- March 2018 by applying method of US EPA, (2001). About 500 gm sediments were taken from 0-10 cm depth of the middle of the river or the bank of the running water channel from each site of river and immediately transferred into polyethylene bags, which were already washed with 10% HNO_3 solution and successively ranged with distilled water (Rabee *et al.,* 2011; Kumar *et al.,* 2012; Ogbeibu *et al.,* 2014). At each site, three samples were collected and were subsequently well mixed to get composite mixture. All sediment samples were transferred using ice box to the laboratory for further processing.

2.4 Preparation of sediment samples

Each sample was air dried and homogenized by grinding, using an agate mortar and pestle to pass through 100 mesh nylon sieve at room temperature. To estimate the heavy metal content, 2 gm of sediment sample collected from each site was digested separately with 25 mL of tri-acid mixture of HNO_3, H_2SO_4 and $HClO_4$ in the proportion of 5:1:1 respectively in Teflon measuring beaker at about 80 º C for 4-5h by applying method of Allen *et al.,* 1986, modified by Singh *et al.,* 2017. After this digested solution was filtered by using Whatman No.42 filter paper in pre-cleaned 100 mL measuring flask and volumes were made up to mark and then subjected to atomic absorption spectrophotometer for analysis of Cr, Cu, Ni, Zn, Mn, Cd and Pb.

2.5 Assessment of sediment contamination

The Contamination Factor, Pollution Load Index, Geo-accumulation index, and Enrichment Factor methods are commonly used to estimate the level of heavy-metal contamination in sediments.

2.5.1 Contamination Factor (C_F)

The C_F is an indicator of sediment contamination used in evaluating pollution in an aquatic environment by a given toxic substance (Kadhum *et al.,* 2016). To evaluate the level of heavy-metal contamination in sediments, C_F is calculated with the Eq.1 (Hakanson, 1980):

$$C_F = C_{\text{heavy metal}} / C_{\text{background value}} \quad (1)$$

Where, $C_{\text{heavy metal}}$ is metal concentration in polluted sediment and $C_{\text{background value}}$ is background value of metal. Local background value for these metals is not available; thus background concentration of metals in the average shale obtained from Turekin and Wedepohi, 1961, is used in the present study. For Cu, Zn, Cr, Ni, Mn, Cd and Pb average shale value (background value) was considered as the 45, 95, 90, 68.850, 0.3 and 20 mg kg^{-1} respectively. If C_F <1 refers to low contamination; 1≤ CF ≥ 3 means moderate contamination and C_F > 6 indicates high contamination (Hakanson, 1980; Kadhum *et al.,* 2016).

2.5.2 Pollution Load Index (PLI)

PLI provides valuable information and advice for policy and decision makers on the pollution level of an aquatic ecosystem (Thomilson *et al.,* 1980). The PLI of a single site is obtained as the *n* th root of *n* number of multiplied together contamination factor (C_F) values. The index is computed as follows (Thomilson *et al.,* 1980):

$$PLI = n\sqrt{\ } (C_{F1} \times C_{F2} \times C_{F3} \times \text{-------} \times C_{Fn}) \quad (2)$$

Where, n is the number of metals studied (7 in the study) and the C_F is the contamination factor calculated as above Eq.1. The PLI < 1 refers no pollution; PLI = 1 present that only baseline, whereas PLI >1 would indicate deterioration of site quality (Thomilson *et al.,* 1980; Mohiuddin *et al.,* 2010).

2.5.3 Geo-accumulation index (I-geo)

The I-geo has been widely applied to the assessment of soil and sediment contamination. I-geo values for heavy metals in sediment were determined by using Eq. 3 as introduced by Muller *et al.,* 1969 and described by Boszke *et al.,* 2004:

$$I\text{-}geo = \log_2 \frac{Ci}{1.5 \; x \; Bn} \quad (3)$$

Where C_i is measured concentration of metal in sediment and B_n is geochemical background value in average shale of element n. Factor 1.5 is used because of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences. I-geo was distinguished in to seven grades and classes by Mulller, 1981

I-geo ≤ 0 (grade 0), unpolluted; 0 < I-geo ≤ 1 (grade 1), slightly polluted; 1 < I-geo ≤ 2 (grade 2), moderately polluted ; 2 < I-geo ≤ 3(grade 3), moderately severely polluted; 3 < I-geo ≤ 4(grade 4), severely polluted; 4 < I-geo ≤ 5(grade 5), severely extremely polluted; I-geo > 5 (grade 6), extremely polluted.

2.5.4 Enrichment Factor (EF)

EF is considered as an effective tool to evaluate the magnitude of contaminants in the environment (Kadhum et al., 2016). The EF for each element was calculated to evaluate anthropogenic influences on heavy metals in sediments using the following Eq.4 (Zahra *et al.*, 2014; HU *et al.*, 2013):

$$EF = \frac{(Ci \,/\, CRef)\ Sediment}{(Ci \,/\, CRef)\ Background} \qquad (4)$$

Where C_i / C_{Ref}) $_{Sediment}$ is the ratio of the concentration of a particular metal (C_i) to the concentration of reference metal (C_{Ref}) in the sediment sample; (C_i / C_{Ref})$_{Background}$ is the ratio of the background concentration of a particular metal (C_i) to the reference background concentration of metal (C_{Ref}).The commonly used reference metals are Mn, Al and Fe (Liu et al., 2005) thus Mn was used as reference metal in this study because it was found most abound in the sediment and natural in the environment. The EF values were interpreted with the following categories, where EF < 1 indicates no enrichment, 1 ≤ EF < 3 is minor enrichment, 3≤ EF < 5 is moderate enrichment,5 < EF < 10 is moderate severe enrichment,10 ≤ EF < 25 is very severe enrichment and EF ≥ 25 is extremely severe enrichment (Zahra *et al.*,2014).

2.6 Risk Assessment of heavy metals

In the present study, two methods, consensus-based sediment-quality guidelines (SQGs) and potential ecological risk index (PERI) were used to assess the risk assessment of the heavy metals in bed sediments to benthic organisms and humans.

2.6.1 Sediment Quality Guidelines

The consensus-based sediment-quality guidelines (SQGs) were proposed by MacDonald *et al.*, 2000, which included a threshold effect concentration (TEC) and a probable effect concentration (PEC). TECs are the concentrations below which adverse effects are not expected on sediment-dwelling organisms, while PECs are concentrations above which adverse effects are expected to occur frequently (MacDonald *et al.*, 1996; Swartz, 1999; MacDonald *et al.*, 2000; Varol *et al.*, 2012; Lin *et al.*, 2013; Wang *et al.*, 2016). The toxicity of heavy metals present in bed sediment on aquatic-organism was evaluated by determining the mean probable concentration quotients (m-PEC-Q) in sediment samples. The m-PEC-Q values for heavy metal in sediment were calculated by using Eq.5 as described MacDonald *et al.*, 2000.

$$\text{m} - \text{PEC-Q} = \sum_{n-1}^{i}\left(\frac{Ci}{PECi}\right)/n \qquad (5)$$

Where C_i = content of metal in sediment sample 'i', PECi is the PEC for individual metal 'i' and 'n' is the number of study metals. Four ranges of the mean PEC quotient were developed by Long *et al.*, 2006 for ranking samples in terms of toxicity incidence. The m-PEC-Q < 0.1 indicates low (< 14% incidence of toxicity), 0.1 < m-PEC-Q < 1 indicates moderate (15-29 % incidence of toxicity), 1.0 < m-PEC-Q < 5.0 indicates considerable (33-58 % incidence of toxicity), m-PEC-Q > 5 indicates very high ecological risk (75-81 % incidence of toxicity) of heavy metal.

2.6.2 Potential ecological risk index (PERI)

The potential ecological risk index was originally developed by L. Håckanson, 1980, which is widely used in assessing ecological risk of heavy-metal pollution in sediments (Lu *et al.*, 2012). PERI is computed as follows:

$$PERI = \sum E^i_r \qquad (6)$$

$$E^i_r = Tir \times C^i_F$$

$$C^i_F = Ci / C^i_n$$

Where PERI is the total potential ecological risk index for multiple metals, E^i_r the ecological risk index for a single metal, and T^i_r is the toxic-response factor for a given metal, considering both toxicity and the sensitivity. C^i_F is the contamination factor, C^i is the metal concentration in the sediment and C^i_n is a reference value for metals. T^i_r = biological toxic factor of an individual metal (Cd = 30, Cr = 2, Cu = 5, Pb = 5, Ni = 6 and Zn = 1) taken from the literature (Håckanson, 1980). The PERI values were categorized in to the three classes. The PERI < 150 indicates low, 150 < PERI < 300 indicates moderate, 300 < PERI < 600 indicates considerable and PERI < 600 indicates very high potential risk for the sediment (Håckanson, 1980).

2.7 Statistical Analysis

Statistical analysis were performed by using lenovo ™ computer using the Microsoft EXCEL and Word 2007 format. Correlation coefficient is the study of relationship between two data sets, if two sets of data are strongly linked together and has a value (-1 to 1), '1' means a perfect positive correlation, 0' means no correlation, and '-1' is a perfect negative correlation. Standard deviation (SD) is measure of inconstancy, measuring the spread of the data and the relationship of the mean to rest of the data. The SD will be zero, if all the data points show equal values. The mean, standard deviation (σ_{n-1}), population deviation (σ_n),variance and correlation coefficient of the concentrations of heavy metals in sediments were calculated by using Casio calculator (made in China) *fx-991 MS*. A probability level of $p < 0.05$ was considered statistically

3. RESULTS AND DISCUSSION

Statistical parameters for heavy metal concentration (mg kg^{-1}) in the Mahananda River sediments in Kishanganj, Katihar and Purnea urban and rural areas of Seemanchal Zone, Bihar, India are presented in the Tables 1, 2 and 3. Distribution of individual metals concentration at each site is demonstrated in Fig. 3(a-g).

3.1 Distribution of Heavy metals in Sediment

Cu: The concentration of Cu was ranged between 49.51 and 82.78 mg kg^{-1} for all studied stations of Mahananda River in seemanchal zone. According to UNEP, 1993 permissible level of Cu in fresh water sediment is 40-50 mg kg^{-1} and TRV proposed by USEPA, 1999 is 16 mg kg^{-1}. The concentration of Cu noted in above was greater than UNEP, 1993 guideline except Kj-3 site (Fig.3a) of Kishanganj zone and it was three to five times higher than TRV. At Kishanganj zone the average value of Cu content was found 60.38 ± 8.61 mg kg^{-1} with maximum value as 74.38 mg kg^{-1} and minimum value as 49.51 mg kg^{-1} was found at Kj-5 and Kj-3 sites respectively. At katihar zone minimum value was found as 58.43 mg kg^{-1} at Kr-6 and maximum as 81.65 mg kg^{-1} at Kr-5 site, similarly at Purnea zone minimum value was found as 54.53 mg kg^{-1} at Pr-3 and maximum as 82.78 mg kg^{-1} at Pr-6 site with average value of 69.09 ± 11.24 mg kg^{-1}. The range of Cu observed in the present study was slightly higher to the sediment of Ganga at Ghazipur, Buxar, Balia (39-75 mg kg^{-1}) at Kanpur (38-68 mg kg^{-1}), at Allahabad (48-68 mg kg^{-1}) of India, and Tigtis river at Baghadad (40.0-54.0 mg kg^{-1}) of Iraq (Singh *et al.*, 2012, Bhatnagar *et al.*, 2013; Pandey *et al.*,2016; Al Obaidy *et al.*, 2014).

Cu is highly toxic than some other trace metals except Hg, hence its small quantity is most dangerous to large portion of the fishes, invertebrates and aquatic plants. Since aquatic plants absorb about three time more Cu than plants on dry lands, so that its small amount becomes very harmful to aquatic plants and its higher concentration can damage the plant roots by disturbing the cell membrane structure, and control root development and also keep in check the formation of many short auxiliary roots. Arbind and Seema, 2016 also reported that Cu mainly accumulated in roots while certain fraction of absorbed Cu transferred to shoot. The concentration of Cu in the shoots was significantly influenced by Cu concentration in soil sediment. This element is crucial for the proper growth of the plants because it is a component of various enzymes and proteins (Losaka *et al.*, 2004). Cu is widely used in electrical wiring, roofing, and production of alloys, pigments, cooking utensils, and piping (Pandey *et al.*, 2007). Further, contamination of the environment with Cu is being linked with the application of agrochemicals (Adekola *et al.*, 2007).

Cr: The Cr content in the sediment samples was found to vary between 121.34 -198.69 mg kg^{-1} at all sampling sites. The observed values were found to be below the permissible limit of 500 mg kg^{-1} as guided by USPHA, 1997, whereas they were many folds higher than the toxicity reference value (TRV) of 26 mg kg^{-1} as proposed by USEPA, 1999 which indicates that the sediment of the River Mahananda is toxic for aquatic life at all sampling sites. The average value of Cr was measured as 160.12 ± 25.77 mg kg^{-1} at Kishanganj area and was minimum as 121.43 mg kg^{-1} at Kj- 8, whereas maximum as 198.67 mg kg^{-1} at Kj-1 site (Fig.3c). At Katihar minimum value was observed as 160.32 mg kg^{-1} at Kr-5 and maximum as 183.26 mg kg^{-1} at Kr-1 with mean value 174.38 ± 9.85 mg kg^{-1}. Similarly at Purnia area minimum value for Cr was recorded as 132.32 mg kg^{-1} at Pr-5 and maximum as 191.58 mg kg^{-1} at Pr-3 site. The results revealed that the level of Cr in the sediments of this study was close to the sediment of Ganga at Ghazipur, Buxar, Balia (130-230 mg kg^{-1}) at Kanpur (110-178 mg kg^{-1}), of India, and Tigtis River at Baghdad (156-174.5 mg kg^{-1}) of Iraq (Singh *et al.*, 2012; Bhatnagar *et al.*, 2013; Al Obaidy *et al.*, 2014).

Cr is an abound element in the earth crust; It occurs in oxidation states ranging from Cr^{2+} to Cr^{6+}. Only Cr^{3+} and Cr^{6+} however are of biological importance. The toxicity of Cr depends upon the species under consideration. The Cr^{3+} is more or less nontoxic while Cr^{6+} is highly toxic. In aquatic environment Cr^{6+} will be insoluble form and eventually converted to Cr^{3+} by reduction with hydrogen sulphide, iron sulphide, ammonium and nitrate ion. Cr^{6+} and Cr^{3+} have been accumulated in many aquatic species, especially in fishes. In acidic medium (pH 3.5), the main aqueous species of Cr (III) are Cr^{3+}, $Cr(OH)^{2+}$, $Cr(OH)_3$ and $Cr(OH)_4^-$. Precipitated Cr^{3+} hydroxides are persisting in the sediments under aerobic conditions; under low pH and anoxic conditions, while Cr^{3+} oxidizes to Cr^{6+} through mixing and aeration (Ecological Analysis Inc.1981). The important sources of Cr in natural aquatic system are wastes from chrome plating, leather tanning, steel pigment, industries, and use of chrome as a mordant in dyeing wood presentation. High level of Cr at sampling points may be due to municipal effluents, laundry, chemical, paints, leather, and road runoff due to tire wear, corrosion of bushings, break wires etc.

Ni: Ni content was recorded between 41.28 and 83.43 mg kg^{-1} for all considering locations. The results showed that the mean concentration of Ni in the sediment of the Mahananda River in Seemanchal zone was 53.87± 8.01 mg kg^{-1} at Kishanganj area, 63.75 ± 6.87 mg kg^{-1} at Katihar zone and 72.23 ± 8.61 mg kg^{-1} at Purnia area. The level of Ni exceeded the permissible limit 50 mg kg^{-1} as guided by USPHS at all stations of Katihar and Purnia and 62.5 % sites at Kishanganj zone whereas it was three to five folds higher than the TRV value 16 mg kg^{-1} as proposed by USEPA ,1999. The level of Ni noted in this study significantly was lower than the sediment of Yamuna River (40-538 mg kg^{-1}) at India, of Buriganga (79.5-278.4 mg kg^{-1}) and of Meghna River (76-116 mg kg^{-1}) at Bangladesh (Singh et al., 2001; Mohiudin et al., 2015; Hassen et al., 2015).

Ni is usually present in the organically bound form in soil, which under acidic and neutral conditions increases its mobility and bioavailability (Losaka et al., 2004). In aquatic system Ni forms complexes with soluble organic and inorganic materials. It adsorbs directly on the clay particles and has capacity to co-precipitate with hydroxides of Fe and Mn. It is mainly transported in the form of a precipitated coating on particles and in association with organic matter. It may also be bio-accumulated through aquatic organisms like phytoplanktons, seaweeds, and algae. Adsorption process may be reversed leading to release of Ni from the sediment (Ahmd *et al.,* 2010). The identified major anthropogenic sources of Ni are nickel wood, fuel combustion, agricultural wastes, and domestic sludge (Purushothaman et al., 2007).

Zn: The average concentration of Zn in the sediment of River Mahananda in Seemanchal zone was found as 104.8 ±10.2 mg kg^{-1} at Kishanganj, 117.35 ± 10.08 mg kg^{-1} at Katihar and 115.46 ± 21.91 mg kg^{-1} at Purnia urban and rural area. The permissible level of Zn in river sediment is 100 mg kg^{-1}as guided by USPHS and TRV value is 110 mg kg^{-1} as proposed by USEPA. However the concentration of Zn was either close or slightly above the permissible limit at most of sites whereas exceeded the TRV value as 25%, 50%, and 75% sites of Kishanganj, Purniaa and of Katihar respectively. The range of concentration of Zn in the present study (83.64-141.68 mg kg^{-1}) was good agreement with 72-140 and 110-147.2 mg kg^{-1} in the sediment of Ganga (at Ghazipur, Buxar, Balia) and Yamuna River respectively (Singh *et al.*, 2012; Singh *et al.*, 2001).

In aquatic system before accumulation in the bottom sediment, it combines with suspended materials. In solvent medium its binary compound like sulphate and chloride have much more inclined to move through the earth than complex bound state as in natural matter or present in insoluble precipitate. Studies suggested that Zn has high mobility (Yang *et al.*, 2012; Mohiuddin *et al.*, 2012; Morillo *et al.*, 2004) and the presence of the element in dissolved species potentially increases its bioavailability in an aquatic environment (O'Sullivan et al.,.2012). Zn is easily adsorbed and scavenged by the hydroxide and oxides (Mito *et al.*, 2004). The elevated concentration of Zn in the sediments could be attributed to vehicular emissions and commercial and industrial discharges (Sekabira *et al.*, 2010). Zn plays an important role in protein (Nizir *et al.*, 2009). Zn toxicity is minimal in humans but higher concentration can be toxic to the organism and also bring root chlorosis and check the development of plants (Singh *et al.*, 2017).

Cd: The Cd concentration in the sediment ranged from 0.53 to 1.05 mg kg^{-1} at all sampling sites. The highest value of Cd was found at Kj-8 site of Kishangnj and lowest at Pr-2 site of Purnia zone (Fig.3f). The concentration of Cd in the present study was found less than the permissible value of 1.0 mg kg^{-1}set by USPHS except only one site (Kj-8) of Kishanganj, however found to be either close or slightly above the TRV (0.6 mg kg^{-1}) at 81.8% sites of studied areas. The average concentration of Cd (0.72 mg kg^{-1}) in the sediment of present study was good agreement with 0.64, 0.8, 0.61and 0.82 mg kg^{-1}in the sediment of Ganga, Buriganga, Bangshi and Buriganga River respectively (Singh *et al.*, 2012; Saha and Hossain, 2010; Rahaman *et al.*, 2014; Saha and Hossain, 2011), however lower than 1.9 and 2.93 mg $kg^{-1}$of Eupharates River at Iraq(Salah *et al.*, 2012) and Jialu River at China (Fu *et al.*, 2014).

Cadmium is more mobile in the aquatic environment than most of other metals and it is also bio-accumulative and persistent in the river body. It is found in the surface and ground water as either Cd^{2+} hydrated ion or as an ionic complex with other organic or inorganic substances and may be harmful to aquatic flora and fauna. Cd is added to the surface water through paints, pigments, glass finish, and galvanized pipes and deposited on road surfaces from the studded tires. It is less toxic to plants than Cu, however similar in toxicity to Pb and Cr. It is equally toxic to invertebrates and fishes (Singh *et al.*, 2016).

Mn: Concentration of Mn was recorded between245.67-423.64 mg kg^{-1}. About 42% of river sediment samples were above permissible limit (300 mg kg^{-1} set by EPA, 2001) of Mn to communicate moderately toxic to aquatic organisms.
It was observed (Fig.3e) that Mn levels along the river course with highest value in upstream sample Kj-3 (416.43 mg kg^{-1}), followed by downstream sample Kr-3 (421.12 mg kg^{-1}) and midstream sample Pr-3 (423.64 mg kg^{-1}).The contamination with mn could result from atmospheric deposition and release from organic matter.

Pb: The mean level of Pb content in the sediment of the River Mahananda in present study was observed as 22.95 ± 4.34, 23.95 ± 3.62 and 25.41± 3.66 mg kg^{-1} at Kishanganj, Purnea and Katihar urban and rural area of Seemanchal zone respectively and maximum value 29.41 mg $kg^{-1}$was recorded at Kr -6 site of Katihar and minimum17.9 mg kg^{-1}at Kj-6 site of Kishanganj zone. Over all the level of Pb was found below the permissible limit (35.8 mg kg^{-1}) and TRV (31 mg kg^{-1}) set by USEPA, 1999.

Table 1
Statistical parameters for heavy metal concentration (mg kg^{-1}) in the River sediments at Kishanganj dist. (n= 8)

Sampling Site	Cu	Zn	Cr	Ni	Mn	Cd	Pb
Minimum	49.51	91.25	121.34	41.28	245.67	0.72	17.91
Maximum	74.38	121.31	198.67	62.27	416.43	1.05	29.62
Max/Min	1.5	1.33	1.64	1.51	1.69	1.46	1.65
$\sum n$	483.07	830.36	1280.96	430.99	2552.6	6.91	183.64
Mean	60.38	104.8	160.12	53.87	309.08	0.864	22.95
Median	64.81	107.91	176.43	54.87	270.44	0.835	22
Standard Dev. (σ_{n-1})	8.61	10.2	25.77	8.01	54.85	0.118	4.34

Variance	74.13	104.04	664.09	64.16	3008.5	0.014	18.83
Population Dev. (σ n)	8.05	9.54	24.1	7.49	51.31	0.108	4.06

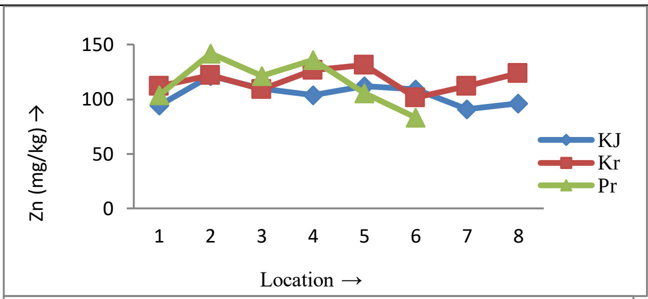
Table 2

Statistical parameters for heavy metal concentration (mg kg^{-1}) in the River sediments at Purnea dist. of (n= 6)

Sampling Site	Cu	Zn	Cr	Ni	Mn	Cd	Pb
Minimum	54.53	83.64	132.32	61.98	255.71	0.53	19.59
Maximum	82.78	141.68	191.58	83.43	423.64	0.81	28.86
Max/Min	1.52	1.69	1.45	1.35	1.66	1.53	1.47
∑n	417.53	692.78	976.78	433.41	1821.4	4.09	143.72
Mean	69.09	115.46	162.79	72.23	323.6	0.68	23.95
Median	56.55	128.9	187.12	67.56	347.5	0.77	20.6
Standard Dev. (σ n-1)	11.24	21.91	23.61	8.61	63.63	0.109	3.62
Variance	126.33	480.04	557.4	74.13	4048.8	0.012	13.109
Population Dev. (σ n)	10.26	20.0	21.55	7.86	58.08	0.099	3.31

Table 3 Statistical parameters for heavy metal concentration (mg kg^{-1}) in the River sediments at Katihar dist. (n= 8)

Sampling Site	Cu	Zn	Cr	Ni	Mn	Cd	Pb
Minimum	58.43	101..46	160.32	53.94	251.82	0.54	18.47
Maximum	81.65	126.45	183.46	73.52	421.82	0.83	29.41
Max/Min	1.4	1.25	1.14	1.36	1.67	1.54	1.59
∑n	554.57	938.8	1395.01	510.01	2556.45	5.7	195.3
Mean	69.32	117.35	174.38	63.75	309.5	0.712	25.41
Median	78.76	128.9	161.36	58.16	264.08	0.56	23.12
Standard Dev. (σ n-1)	9.49	10.08	9.85	6.87	56.42	0.103	3.66
Variance	90.06	101.61	97.022	47.19	3183.2	0.01	13.39
Population Dev. (σ n)	8.88	9.43	9.21	6.42	52.78	0.096	3.43



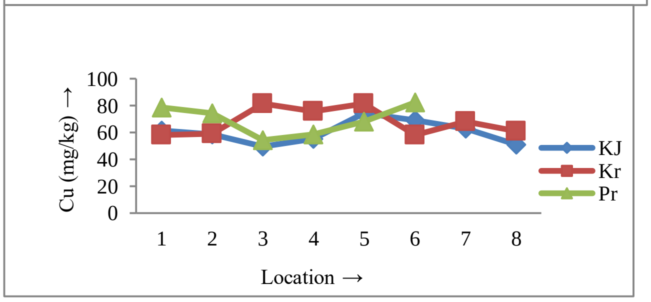
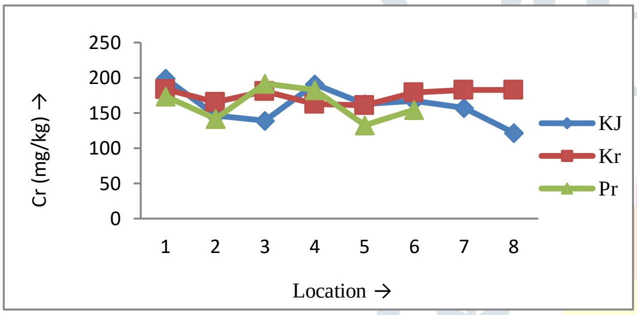


Figure a

Figure b



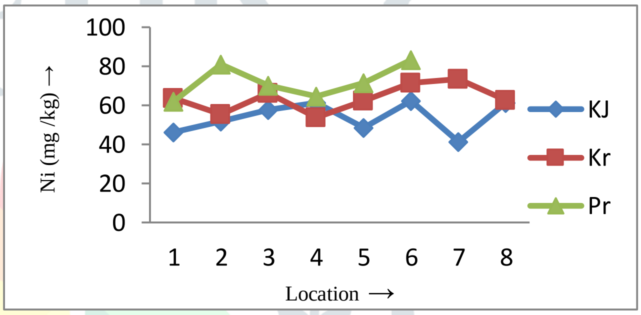


Figure c

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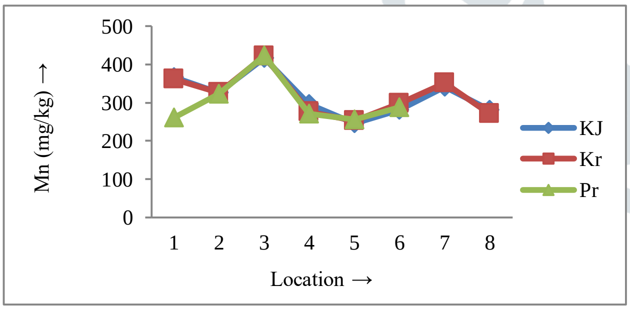


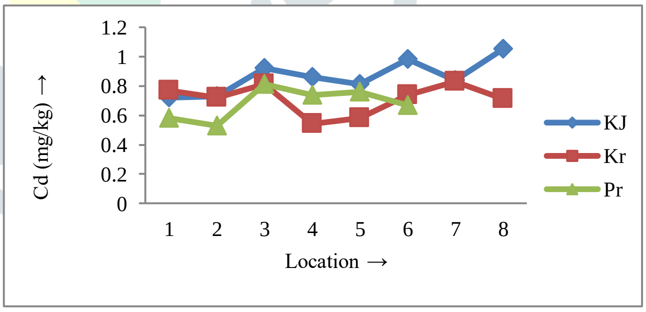
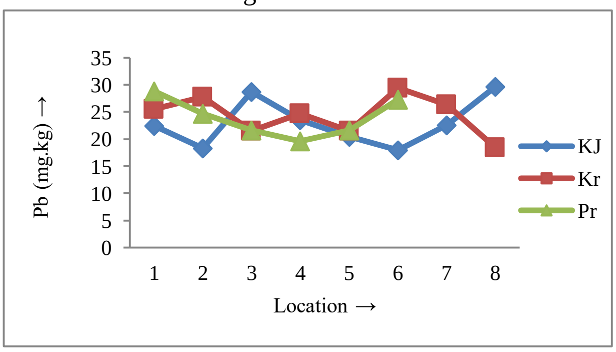


Figure e

Figure f



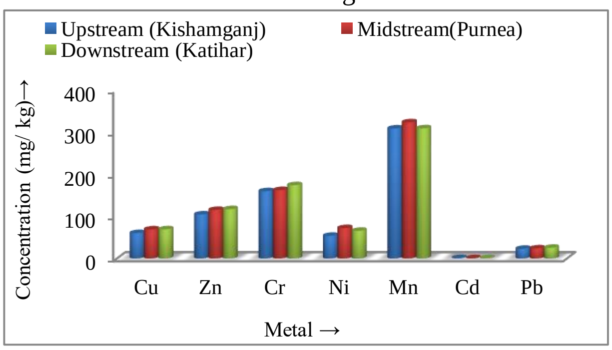


Figure g

Figure h Sediment toxicity

Figure3 (a- g) Distribution of individual metal at each site and Figure 2 h Sediment toxicity in the River sediments

The range obtained in this study was much lower than the value of 69.54-75.6 mg kg^{-1}obtained by Al Obaidyea *et al.*, 2014 in sediments at Tigtis River in Baghdad and of 44.85 mg kg^{-1}obtained by Hassen *et al.*, 2015 at Meghna River at Bangladesh, however very close to 15-27 mg kg^{-1} reported by Singh *et al.*, 2012 in sediment of middle stretch of River Ganga. The high value of Pb at Katihar zone (downstream) may be due to presence of small sale battery, discharge of improperly treated waste effluent sledge and use of lead containing Fertilizer and Pesticide at this site.

Lead is toxic element and can be harmful to animals and plants. In earth crust it is found in an average concentration of 0. 1 mg kg^{-1}, and also associated with sulphide ore of, Cu, Zn and Pb (Cu-Pb-Zn sulphide ore) which is obtained as by-product during processing of these ore and is discharged in the surface water through paints, solders, pipes, building material, gasoline, etc. The elevated level of Pb in the water system poses threat to fisheries resources. Pb^{2+} can interfere with Ca^{2+} and consequently bones are affected. At higher levels of Pb (more than 0.8 ppm) in the blood can damage the mitochondria of kidney and finally brain damage. It also damages the liver and gastrointestinal.

Sediment toxicity was maximum for Cu, Zn, Cr and Pb at downstream for Ni and Mn at midstream, whereas for Cd at upstream of River in Seemanchal zone (Fig. 3.h). On comparison with upstream and downstream zone, midstream zone consists of mainly agricultural farms along with intensive urbanised activity that generates large amount of wastewater, which directly discharge into river basin. The high concentration of metal in downstream is due to river velocity and it might take time for metals to be absorbed onto sediment or accumulated compare to upstream and midstream zone. The concentration of heavy metals in sediments decreased in the following order Mn > Cr > Zn > Cu > Ni > Pb > Cd (Fig. 3.h).

3.2 Assessment of the level of Contamination

The results as shown in Fig. 4 Cd, Cr, Cu, Pb and Zn showed moderate contamination factor and Mn and Ni exhibited low C_F for all investigated stations of Mahananda River in Seemanchal zone. The highest C_F for Cd (2.88) was found in an upstream (Kishanganj) site. The high C_F value of Cu (1.55) and Ni (1.06) were found in the midstream (Purnea) whereas the highest C_F values for Cr (1.94), Pb (1.22), Zn (1.24) and Mn (0.376) were found in the downstream (Katihar) site. The average C_F values for Cu, Zn, Cd, and Pb indicating that River was moderately contaminated with respect to these metals. In contrast the average values of C_F for Ni and Mn were below one which suggested lithogenic sources .The results also revealed that average C_F values for heavy metals decreased with following order Cd > Cr > Cu > Pb = Zn > Ni > Mn. The degree of contamination(C_D) as shown in Fig. 5 also suggested that sediment of river falls in class 2, which indicates that sediments of studied zone were moderate level of contamination and follows the order Katihar (downstream) > Purnea (midstream) > Kishanganj(upstream).

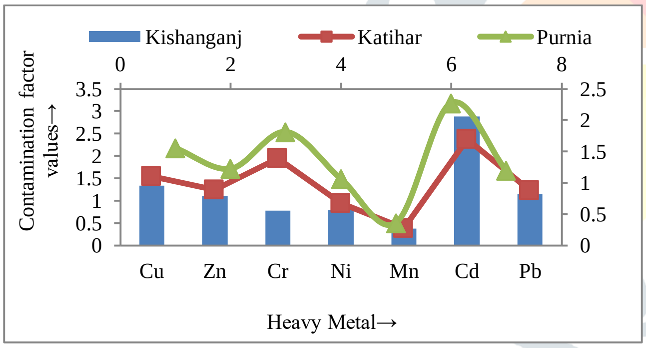


Figure 4 C_F of heavy metals in the River sediment

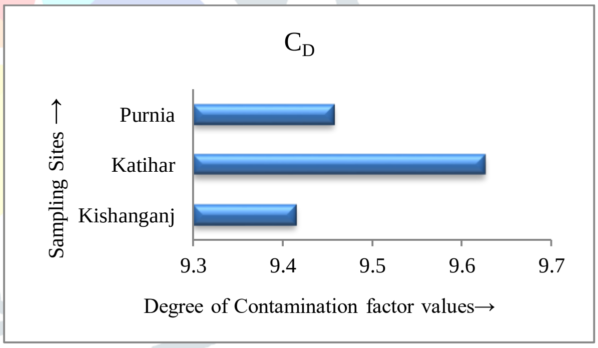
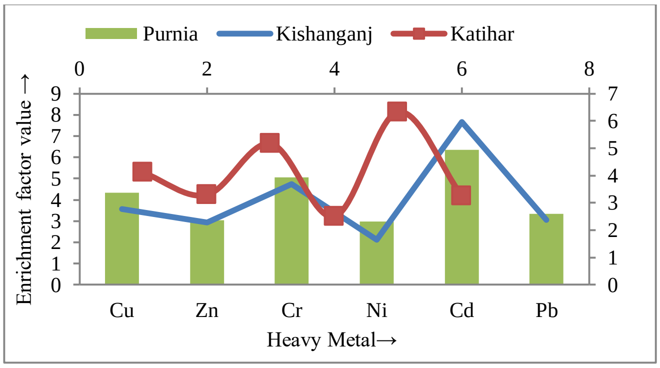


Figure5 C_D of heavy metals in the River sediment

The mean EF values for Cd (6.79) were > 6 while the other metals were in the range of 2-5. All of the EF values for Cd in the sediments of the Mahananda River were significantly higher than 6 and in the order of EF =7.67 (kishanganj area) > EF = 6.35(Purnea area) > EF = 6.32 (Katihar area). These values indicate moderate severe enrichment of Cd in the sediments of river at all three districts of seemanchal zone. The EF values for Cd were especially high in the upstream (kishanganj area) and low in the downstream (Katihar area) sediments of the River. In addition EF values for Cu, Cr, Zn, and Pb metals were in the range of 3-5 indicating moderate enrichment, and highest values were observed in the downstream (Katihar area) and lowest values were observed in the upstream (kishanganj area), while Ni had highest EF values in the midstream (Purnea area) and lowest in the upstream (kishanganj area) in the range of 1-3, showed minor enrichment as shown in Fig. 6.



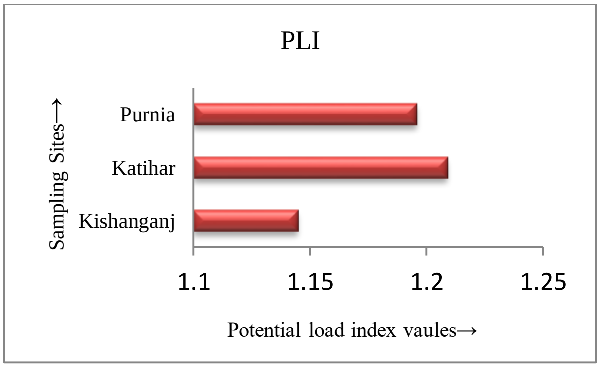


Figure 6 EF of heavy metal in the River sediment

Figure7 PLI of heavy metal in the River sediment

The PLI values varied from 1.145 to 1.209 (Fig. 7) suggested that deterioration of sediment quality at all three studied areas of Seemanchal zone. The PLI values also indicated that trend of heavy metals contamination in the sediments of River Mahananda was Katihar (downstream) > Purnea (midstream) > Kishanganj (upstream). Thus Pollution load index (PLI) provided valuable information and advice for policy and decision makers on the pollution level and progressive deterioration of an aquatic ecosystem.

I-geo based on average shale value recommended by Turekianand Wedepohl, 1961 are presented in Table 4. The results revealed that I-geo varied from -0.1617 to 0.044 for Cu, -0.4434 to -0.2802 for Zn, 0.2462 to 0.3693 for Cr, -0.9211 to -0.4979 for Ni, -2.07 to -1.996 for Mn, 0.9412 to 1.25 for Cd and -0.3846 to -0.2975 for Pb. I-geo values for Cu, Zn, Ni, Mn and Pb in all studied points fell under grade 0, which suggests that sediments of these points were unpolluted with reference of these metals. The I-geo values for Cr fell under grade 1 suggests the sediments were slightly polluted and the I-geo values for Cd fell under grade 2 suggests the sediments were moderately polluted. The results also revealed that sediments of Mahananda River in Katihar zone were highly polluted compare to Kishanganj and Purnea zone with reference to Cr and Cd.

Table 4

I-geo and PLI of the studied heavy metal in the Sediment of the Mahananda River in the Seemanchal zone

Location	Cu	Zn	Cr	Ni	Mn	Cd	Pb	PLI
Kishanganj	-0.1617	-0.4434	0.2462	-0.9211	-2	0.9412	-0.3249	1.145
Katihar	0.0384	-0.2802	0.3693	-0.6781	-1.996	1.25	-0.3846	1.209
Purnia	0.044	-0.3036	0.2701	-0.4979	-2.07	1.181	-0.2975	1.196
Min	-0.1617	-0.4434	0.2462	-0.9211	-2.07	0.9412	-0.3846	1.145
Max	0.044	-0.2802	0.3693	-0.4979	-1.996	1.25	-0.2975	1.209
I-geo value	≤ 0	< 0	0-01	< 0	< 0	01- 02	< 0	------
I-geo class	0	0	1	0	0	2	0	-----

3.3 Risk Assessment of Heavy Metal in Sediment

Ecological risk factor ($E^i r$) of the individual heavy metal and potential ecological index (PERI) of the combined heavy metals in the sediments of Mahananda River in the Seemanchal zone are presented in the Fig.8. The mean $E^i r$ values of Cu, Cr, Zn, Mn, Ni and Pb were below than 40 except Cd ($E^i r$ = 75.2) suggesting a low ecological risk from these metals. Cd had highest $E^i r$ values in the sediment of River in the Kishanganj area (86.4) i.e., followed by Katihar ($E^i r$ =71.1) and Purnea (68.1). $E^i r$ values were particularly higher in upstream and lower in midstream of the River in the Seemannchal zone. The average potential ecological risk index (PERI) values indicated that the metals in the sediment caused low potential ecological risk (PERI=99.35) overall.

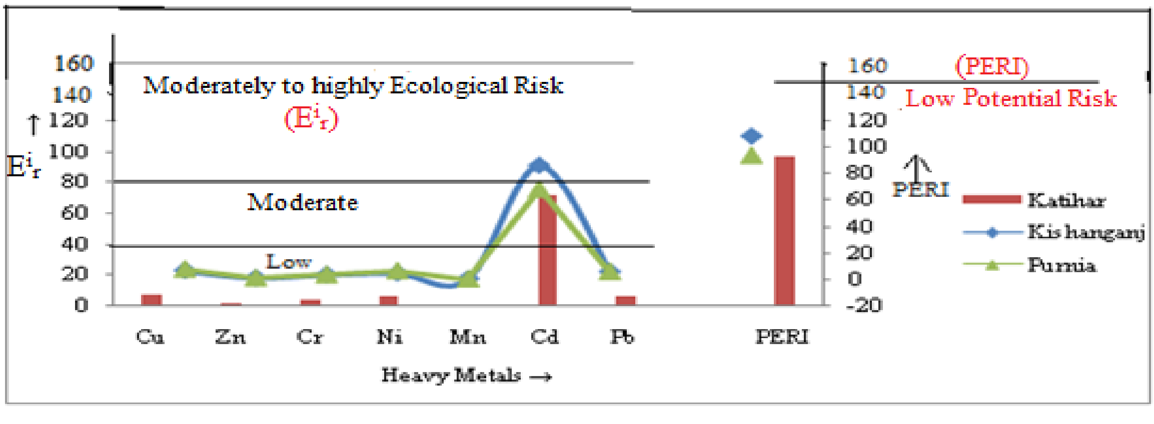


Figure 8 $E^i r$ and PERI of studied heavy metals in the sediment of the River Mahananda

SQG method revealed that the metal concentration were lower than the TEC for Zn, Cd and Pb at 63.63%, 95.95% and 100%, sites respectively, and the concentration of Ni and Pb exceeded the PEC value at 90.90% and 100% of samples, respectively, while percentage of samples with Cd, Ni, and Cu were between the TEC and PEC values in 4.54 %, 9.1 %, 36.36 % and 100 % respectively (Table 5). The results also suggest the concentration of Ni and Cr are likely to result to the deleterious effect on bottom-dwelling organisms that were expected to occur frequently (Varol *et al.*, 2012; Rodrigue *et al.*, 2016).

The toxicity, derived from m- PEC-Q quotients, those results from the mixture of the six heavy metals at each sampling site of Mahananda River in all three districts of Seemanchal zone, the mean PEC quotients for samples in the Katihar region (range 0.021–0.225) were slightly higher than those in the Kishanganj region (range 0.025–0.206) and slightly lower than the Purina region (range 0.027–0.297)

Table 5

Comparison between sediment quality guidelines with heavy metals concentration of all sites in the River

Sediment quality guidelines (SQGs)	Cu	Zn	Cr	Ni	Cd	Pb
TEC	31.6	121	43.4	22.7	0.99	35.8
PEC	149	459	111	48.6	4.98	128
% of samples < TEC	< 0	< 63.63	< 0	< 0	< 95.95	< 100
% of samples between TEC and PEC	100	36.36	0	9.10	4.54	0
% of samples > PEC	>0	>0	> 100	> 90.90	> 0	> 0

Our finding as shown in Table 6 also suggest that 66.7% of sediment samples have m-PEC-Q values < 0.1, indicating low toxicological risks whereas 33.3% of sediment samples have m-PEC-Q values 0.1 < m-PEC-Q < 1, indicating moderate toxicological risks for sediment dwelling organisms, with a toxicity incidence of between 15 and 29% in the study areas **(**R.C.Swartz (1999)**.**

Table 6

Predictive ability of mean probable concentration quotients in sediment sample of the river in Seemanchal zone

m-PEC-Q	Ecological risk of heavy metal	Percentage (%)
m-PEC-Q < 0.1	Low	66.7
0.1 < m-PEC-Q< 1	Moderate	33.3
1.0 < m-PEC-Q < 5.0	Considerable	-----------
m-PEC-Q >5	Very high	----------

3.4 Source Identification for Heavy Metal -Pollutants

Correlation coefficient of the studied metals is presented in table in Table 7. Cu, Zn, Pb, Ni, and Cr were significantly correlated with each other such as Cu-Zn: r = 0.986, Cu-Pb: r = 0943, Cu-Ni: r = 0.898, Cu-Cr: r = 0.621, Zn-Pb: r = 0.985, Zn-Ni; r = 0.815, Zn-Cr: r = 0.743, Pb-Ni: r = 0.702, Pb-Cr: r= 0.846 except Mn and Cd which were not related with either Cu, Zn, Pb, Ni, or Cr however both were correlated with each other (Cd-Mn: r =0.616), The correlation among heavy metals may indicate the same migration pattern of these element (Ke et al.,2017) The lack of any significant correlation signifies that the heavy metals may originate from different sources and be controlled by multiple factors.

Table 7

Correlation of analysed metals in Mahananda River Sediments

Variables	Cu	Zn	Cr	Ni	Mn	Cd	Pb
Cu	1						
Zn	**0.986**	1					
Cr	**0.621**	**0.743**	1				
Ni	**0.898**	**0.815**	0.214	1			
Mn	-0.502	-0.454	0.366	-0.831	1		
Cd	-0.99	-0.954	-0.508	-0.95	**0.616**	1	
Pb	**0.943**	**0.985**	**0.846**	**0.702**	-0.186	-0.888	1

4. CONCLUSION

On the basis of experimental finding, it was concluded that toxicity level of Cu, Cr, Ni and Cd exceeded whereas Zn level was below only at Kishanganj zone and level of Pb was below at all study points than TRV. C_F and C_D indices demonstrate the river sediment was moderately contaminated, PLI > 1 suggested that deterioration of sediment quality at all studied areas. I-geo also suggested that sediments of River in Katihar zone were highly polluted compare to Kishanganj and Purina zone with reference to Cr and Cd. The mean EF values for Cd were > 6 while the other metals were in the range of 2-5 indicated that river sediment was moderate to severe enrichment of studied metals. Positive correlation among Cu, Zn, Cr, Ni, and Pb indicated common sources or additional geochemical behaviour for these metals. Since there were no large scales industries and availability of some small scale industrials in the studied area the source of contamination were not only industrial wastewater but may originate from natural processes, agricultural activities and sewage water. The average PERI values < 150 indicated that lower potential ecological risk overall. The SQCs also suggested that the concentration of Ni and Cr are likely to result ina the deleterious effect on bottom-dwelling organisms. The m-PEC-Q values suggests, 33.3% of sediment samples were predicated to be toxic to sediment dwelling organisms with toxicity incidence of 15- 29% in the study areas. This work provides basic information to Government of India and urban environmental agencies of the country for designing corrective strategy to reduce local pollution and contamination and to keep the river clean from various types of pollutants.

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