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Ecological Risk Assessment of Heavy Metals concentration in Sediment of the Shitalakhya River

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Abstract— The study investigates the pollution status of sediment of the Shitalakhya River, Bangladesh. The sediment sample have been collected from five sampling sites of Shitalakshya river and those are analyzed to determine the concentrations of Lead (Pb), Nickel (Ni), Chromium (Cr), Copper (Cu). Samples are digested by aqua regia and analysis is performed by Atomic Absorption Spectrophotometry. Average concentration of Pb, Ni, Cr and Cu have been found 13.29, 22.98, 32.68 and 18.46 mg/kg in sediments respectively. Based on USEPA sediment quality guideline, the sediment samples are not polluted by Pb, however, slightly polluted by Cr, Cu and Ni. Different pollution indices, such as, metal pollution index and Degree of contamination index have also been analysed to identify the pollution status according to various index. Also, the principal component and cluster analysis have been performed. The Risk index suggests that the sediments have low potential risk. Only one principle component was found and all metals have strong correlation to sediment sample contaminants. The Cluster analysis suggests that sediments of Kachpur Bridge (S-2), Shadur Ghat (S-3) and Nabiganj (S-3) are similar and South Rupshi (S-1) and Nabiganj (S-2) are similar based on tested heavy metal contamination.

Keywords— Sediment of Shitalkhya river, heavy metal contamination, Metal pollution index, Degree of contamination index, Ecological risk assessment

I. INTRODUCTION

Intensive anthropogenic activities, such as, industrial, agricultural and domestic activities, rapid urbanization, river-side land development result in huge amount of hazardous chemicals. Such chemicals release toxic heavy metals indiscriminately in the rivers. This pose a serious threat to the bioavailability and ecology of the riverine system across the world in recent decades. Due to the abundance, persistence and toxicity of various heavy metals in river, those are accumulated in flora and fauna of rivers, such as, fishes, aquatic plants, invertebrates, organisms. Later, the heavy metals transfer to the human body through the food chain pathways, some of them are carcinogenic and affect human health adversely [1-3].

Heavy metal defined as metallic element which has relative high density and toxic at low concentration, such as, Lead (Pb), Copper (Cu), Zinc (Zn), Chromium (Cr), Nickel (Ni) and Cadmium (Cd) [4]. Heavy metals generated from industrial, agricultural waste and untreated sewage are not only affecting water quality by releasing into water but also those are deposited to the bottom of riverbed and attached to the fine grains of the sediment [5]. In fact, water, sediment and biota of river combined act as a reservoir to contain various heavy metals, for example, Pb, Cd, Cr, Cu, Ni, Zn and so on. Concentration of heavy metals in sediment is a function of various physical and chemical factors, such as pH, temperature, concentration of solute, compositions, and components of suspended sediment [6]. Rahman et al. [7] studied severe effects of heavy metal effluent on sediment, water and fish samples. Especially the effluents of textile industries and tanneries have high concentration of toxic heavy metals [8]. Besides, oil spillage from water vessels, runoff of fertilizers and domestic waste add to the pollution and heavy metals concentration. Pollutants consist with toxic heavy metals can alter crucial physio-chemical characteristics, such as, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total dissolved solid (TDS), pH and temperature—which are vital for the aquatic life in a river system [6].

The Shitalakhya is a major urban river flowing through the industrialized districts of Gazipur, Dhaka and Narayanganj in Bangladesh and it receives huge amount of pollutant discharges and different heavy metals from various industries on daily basis, which are located along the riverbank. Pharmaceutical, textile, chemical, cement, fertilizer and ship repairing docks are some of them. In most of the cases, untreated effluents of those industries produce large amount of polluted water, which are discharged directly into the river illegally. Islam and Azam [9] found that Shitalakhya river water was highly polluted during post monsoon season. Chowdhury et al. [10] adopted water quality index (WQI) approach to rate overall water quality of the Shitalakhya river. They marked electric conductivity, turbidity, total suspended solids (TSS) were in the worst situation in the river water. TDS, BOD, COD and dissolve oxygen (DO) content in the Shitalakhya river water are below standard limit and unsuitable for drinking and agricultural purpose [11]. A study on the fish specimens of the Shitalakhya river revealed that the river water is becoming inhabitable for different species of fishes day-by-day [12]. Prior studies, such as, Rahman [13] investigated on heavy metal pollutions of sediment and water samples of Buriganga, Sitalakhya and Turag around Dhaka City during 2011. Our research on heavy metal pollutions of sediment and water in the Shitalakya River based on recent sampling data will help to understand present scenarios.

This study investigated the pollution in sediment samples of the Shitalakhya river in the years 2018-2019. Especially, measuring the heavy metal (Pb, Cu, Ni, Zn, Cr and Cd) concentrations in the sediment at various locations and compare with respect to the USEPA sediment quality guideline. This study is going to be the first systematic study to explore the heavy metal pollution in the Shitalakhya river. The study would be able to provide information on sediment pollution status and ecological risk of the Shitalakhya river. Proposed research will help the decision makers to take necessary steps to reduce pollution and manage dredged materials.

II. METHODOLOGY

A. Study area

The study area is Shitalakshya river which is one of the major rivers around the capital of Bangladesh and it is branch of Brahmaputra river. The river starts flowing from Toke, Gazipur. The GPS co-ordinates of selected five points along Shitalakshya river is shown in Table 1. The samples of sediments were collected in the last week of November 2018 to January 2019.

Table 1: GPS data of sample collection in Shitalakshya river.

Sample No	Location	Latitude	Longitude
S-1	South Rupshi	23˚43'55"N	90˚30'31"E
S-2	Kachpur Bridge	23˚42'16"N	90˚31'04"E
S-3	Sadhur Ghat	23˚40'17"N	90˚31'55"E
S-4	Nabiganj	23˚37'58"N	90˚31'6"E
S-5	Nitaiganj	23˚36'24"N	90˚30'20"E

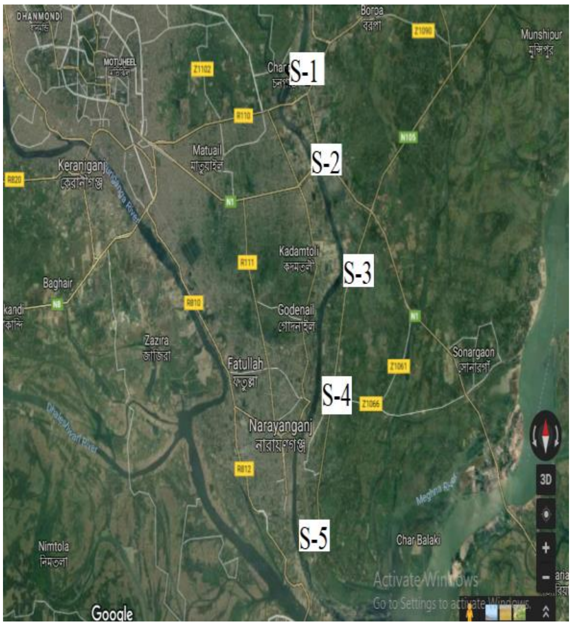

Figure 1: Sample collection location along Shitalakshya

B. Digestion technique and AAS

Digestion is one of the most important steps for determining concentration by Atomic absorption spectrophotometer (AAS). This were used to dissolve the metal into solution. The collected sample were placed in acid washed container and placed in oven for 24 hr at 105˚C. After fully dried the sediment were separated by large sieve and remove stone, pebbles. Then sediments were crushed by acid washed pestle and again separated by sieve of No. 50. Then 5gm of sieved sediment were collect and transferred to an acid-washed volumetric flask with adding 100ml of distilled water. Then 2.5ml concentrated nitric acid and 7.5ml concentrated hydrochloric acid (aqua regia) were added into volumetric flask. The sample then heated at 200˚C for 1hr for digestion. After the samples had all cooled to room temperature; they were stirred for 5 minutes and filtered (0.45 µm) through a glass funnel containing Whatttman No.1 filter paper. The reaction vessels and watch glass cover were rinsed with distilled water. The solution was stored in a glass bottle for the analysis of heavy metal concentration. Then AAS were calibration by 0.2, 0.5, 2, 5 PPM stock solutions. Then analysis were performed by AAS attached with a graphite furnace to determination of metal concentrations within each sample. Atomic absorption spectrophotometer (AA-7000, Shimadzu Corporation, Japan) measured the heavy metal concentrations in the sediment samples.

C. Pollution assessment techniques

Heavy metals, such as, Pb, Cd, Cr, Cu, Ni and Zn can accumulate in fine grained sediment easily and subsequently, carried to the river downstream [6]. These toxic pollutants bearing heavy metals mix with upstream water, suffer the downstream inhabitants severely. In our study, metal pollution index will be calculated to evaluate metal contamination indices in sediment such as, Degree of Contamination (*CD*) and Contamination Factor (C_f).

D. Metal Pollution Index

Metal pollution index is the geometric mean of the concentration of metal for locations. It describes the overall degree of metal pollution. MPI is calculated according to Usero *et al.* [14].

$$\text{MPI} = (C_1 \times C_2 \times C_3 \times \ldots\ldots\ldots.. \times C_n)^{\frac{1}{n}} \quad (2)$$

Where, C_n is the concentration of metal n expressed in mg/kg of dry weight.

E. Ecological Risk Indices

Ecological risk indices is the practical environmental assessment proposed by Hakanson [15]. It is widely used for recognizing the aquatic pollution.

F. Potential Ecological Risk Index (PERI)

PERI index is calculated as the following equations:

$$C_f^i = \frac{C_D^i}{C_R^i},\ C_H = \sum_{i=1}^{m} C_f^i,$$

$$E_f^i = T_f^i \times C_f^i \text{ and } RI = \sum_{i=1}^{m} E_f^i \quad (3)$$

Where, C^i_f = pollution coefficient of individual metal; C^i_D = measured concentration of heavy metal; C^i_R = background concentration of heavy metal. C^i_R values for Cr, Pb, Cu and Ni are 97, 20, 32 and 49 respectively [16]. C_H = polluted coefficient of various metals and E_f^i = potential ecological risk factor of single metal. T_f^i = biological toxicity factor of different metals and values for Cr, Pb, Cu and Ni are 2, 5, 5 and 5 respectively. RI = potential ecological risk index of various metals. E_f^i is the potential ecological risk factor values categorized as I, II, III, IV and V corresponding to <30 (low), 30-60 (middle), 60-120 (appreciable), 120-240 (high) and >240 (very high) respectively. Potential ecological risk index RI values categorized A, B, C and D corresponding to <110 (low), 110-220 (middle), 220-440 (appreciable) and >440 (high) respectively [16].

G. Contamination Factor and Degree of Contamination

Contamination factor and degree of contamination is used to predict the contamination status of the sediment and water. Contamination factor is estimated according to Tomlinson *et al.* [17].

$$C_F = \frac{C_{metal}}{C_{background}} \quad (4)$$

World surface rock average proposed by Martin and Meybeck [16] is considered as background concentration in this study. C_F less than 1 stands for low contamination factor; C_F within 1 to 3 is moderate contamination factor; C_F within 3 to 6 means considerable contamination factor; C_F greater than 6 is very high contamination factor.

$$\text{PLI} = (C_{F1} \times C_{F2} \times C_{F3} \times \ldots\ldots\ldots\ldots\ldots\ldots\ C_{Fn})^{(1/n)} \quad (5)$$

If PLI<1 shows no pollution and PLI>1 shows polluted sediment.

The degree of contamination (C_d) is the sum of all contamination factors. C_d less than 6 represents low degree of contamination, C_d within 6 to 12 represents moderate degree of contamination, C_d within 12 to 24 represents considerable degree of contamination and C_d greater than 24 represents very high degree of contamination.

III. RESULTS AND DISCUSSION

Table 2 shows the heavy metals concentration of Shitalakshya river sediment samples. The metal concentration in sediment has trend of: Chromium (Cr)>Nickel (Ni)>Copper (Cu)>Lead (Pb). Lead concentration at location S-1, S-2, S-3, S-4, S-5 are 20.118, 6.748, 8.908, 6.852, 23.82 mg/kg respectively. The average value was 13.29mg/kg. The concentration is maximum at Nitaigang (S-5) and minimum at Kachpur Bridge (S-2). The concentration is above 20 mg/kg at South Rupshi and Nitaigang.

Table 2: Heavy metals concentration (mg/kg dry weight) of Shitalakshya river sediment sample.

Site	Lead (Pb)	Nickel (Ni)	Chromium (Cr)	Copper (Cu)
S-1	20.12	48.23	55.40	40.91
S-2	6.75	6.36	20.44	1.93
S-3	8.91	11.27	20.5	2.88
S-4	6.85	10.22	20.66	5.71
S-5	23.82	38.82	46.41	40.87
Mean	13.29	22.98	32.68	18.46
Max	23.82	48.23	55.40	40.91
Min	6.75	6.36	20.44	1.93
SD	8.08	19.13	16.94	20.52

Sediment quality guidelines by USEPA, Consensus Based New York and Interim criteria [18] described that Pb concentration less than 40 mg/kg is unpolluted, 40-60 mg/kg is slightly polluted , greater than 60 mg/kg heavily polluted, Cu concentration less than 25 mg/kg is unpolluted, 25-50 mg/kg is slightly polluted and greater than 50 mg/kg is heavily polluted, Cr concentration less than 25 mg/kg is unpolluted, 25-75 mg/kg is slightly polluted and greater than 75 mg/kg is heavily polluted and Ni concentration less than 21 mg/kg is unpolluted, 21-52 mg/kg is slightly polluted, greater than 52 mg/kg are heavily polluted.

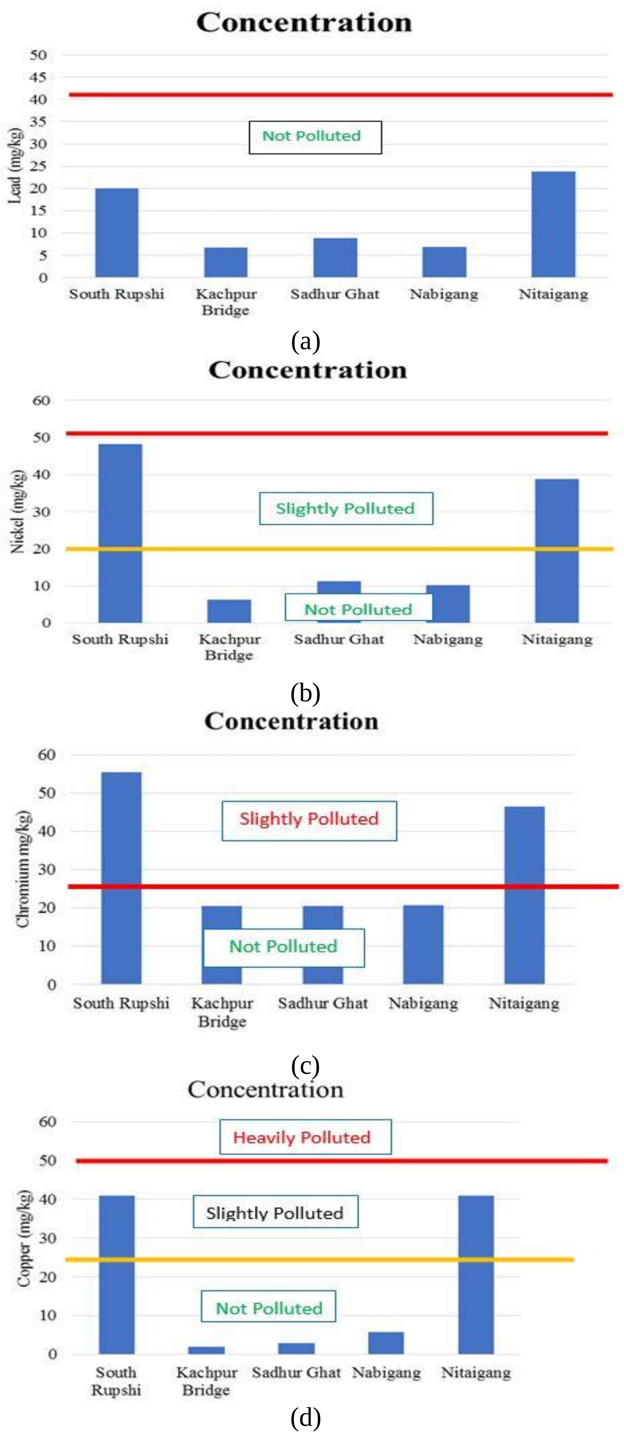

Figure 2: Concentration of (a) Pb, (b) Ni, (c) Cr and (d) Cu at sediments of different locations in Shitalakshya river

Nickel concentration at location S-1, S-2, S-3, S-4, S-5 are 48.23, 6.36, 11.27, 10.22, 38.82 mg/kg respectively. The average value was 22.98 mg/kg. The concentration is maximum at South Rupshi (S-1) and minimum at Kachpur Bridge (S-2). Chromium concentration at location S-1, S-2, S-3, S-4, S-5 are 55.40, 20.44, 20.50, 20.66, 46.41 mg/kg respectively with on average 32.68 mg/kg. The concentration is maximum at South Rupshi (S-1) and minimum at Kachpur Bridge(S-2) as similar with Nickel concentration. Copper concentration at location S-1, S-2, S-3, S-4, S-5 are 40.91, 1.93, 2.88, 5.71, 40.87 mg/kg respectively with on average 18.46 mg/kg. The concentration is maximum at South Rupshi (S-1) and minimum at Kachpur Bridge(S-2) as similar with Nickel and Chromium concentration. Concentration of most of the metal was maximum in South Rupshi (S-1). The upstream of South Rupshi has various industries such as weaving factory, pharmaceuticals industries, edible oil factory and an economic zone (City Economic zone) is situated there. So, the pollution was higher there. The standard deviation is higher for most of the metal, it means that the concentration of metal is not uniform in all five locations.

A. Metal Pollution Index

As various pollutants present in a location, combined effect of heavy metals on the aquatic life is expressed by metal pollution index (MPI). The critical MPI value is 100. MPI value of S-1, S-2, S-3, S-4 and S-5 sites are 18.55, 4.55, 5.68, 6.07 and 17.73 respectively. MPI suggested that pollution at location S-2, S-3, S-4 is uniform and correlated, but at location S-1 and S-5 are differ and highly polluted from other.

B. Potential Ecological Risk Index

The ecological risk index was calculated by Hakanson method for the quality status of the sediments. Pre-industrial background values provided by Martin and Meybeck [16] was used as background value.

Table 3 Ecological risk index for selected heavy metals of sediments of Sitalakshya river.

Site	Lead (Pb) E_f	Nickel (Ni) E_f	Chromium (Cr) E_f	Copper (Cu) E_f	RI	Grade Hakanson [15]
S-1	5.03	4.92	1.14	6.39	17.49	Low
S-2	1.69	0.65	0.42	0.30	3.06	Low
S-3	2.23	1.15	0.42	0.45	4.25	Low
S-4	1.71	1.04	0.43	0.89	4.07	Low
S-5	5.96	3.96	0.96	6.39	17.26	Low

Potential ecological risk index ranges from 3.06 to 17.49. The average value of the risk index (RI) is 9.22. The index shows that the Shitalakshya river has low potential ecological risk. The index value will be increasing, if more metal is tested.

C. Contamination Factor and Degree of Contamination

The contamination factor, pollution load index and degree of contamination are calculated according to Tomlinson *et al*. [18].

Table 4: Contamination and pollution status of Shitalakshya river sediment

Sites	Contamination factor				PLI	Degree of contamination
	Pb	Ni	Cr	Cu		
S-1	1.006	0.984	0.571	1.279	0.937	3.840
S-2	0.337	0.130	0.211	0.060	0.223	0.738
S-3	0.445	0.230	0.211	0.090	0.287	0.977
S-4	0.343	0.209	0.213	0.178	0.307	0.943
S-5	1.191	0.792	0.478	1.277	0.896	3.739

PLI less than 1 shows no pollution. PLI greater than 1 shows polluted sediment. Location S-2, S-3, S-4, S-5 are low contaminated and location S-1 is moderately contaminated with Lead. All location is low contaminated with Nickel and Chromium. Location S-2, S-3, S-4, S-5 are low contaminated and location S-1 is moderately contaminated with Copper. Pollution load index shows that all locations are unpolluted, and degree of contamination shows that all location are low degree of contamination.

D. Correlation Coefficient Matrix

The correlation coefficient varies from −1 to 1. There are significant correlations among the all variable. All the variable has correlation coefficient above 0.93. This indicate that the contaminants variables were from similar source input.

Table 5: Correlation matrix between heavy metal in sediment sample.

	Ni	Cu	Cr	Pb
Ni	1.000			
Cu	0.981	1.000		
Cr	0.996	0.980	1.000	
Pb	0.940	0.977	0.933	1.000

E. Principal Component

Only one principle component was found. So, component plot in rotated space is not possible. Table 7 shows the principle component. This indicate Cu, Ni, Cr and Pb has strong correlation to sediment sample contaminants.

Table 6: Principle component

	Component 1
Cu	0.997
Ni	0.991
Cr	0.989
Pb	0.974

F. Cluster Analysis

Dendrogram of five sampling locations were obtained by using hierarchical cluster analysis by average groups linkage method to find out the similarities and dissimilarities among the locations.

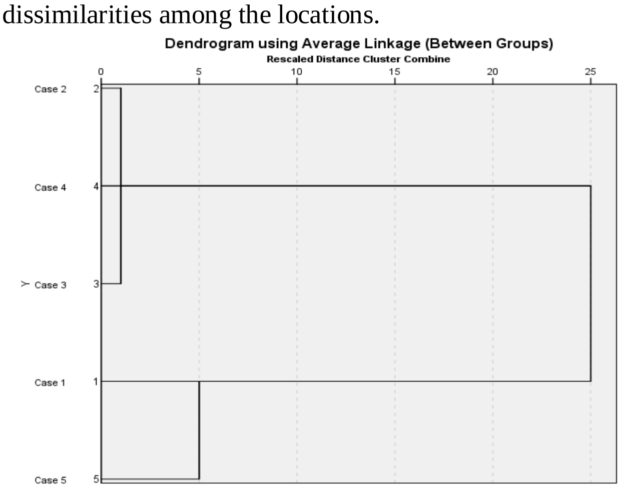

Figure 3: Dendrogram from cluster analysis of sediment contamination.

Figure 3 shows two group. That is the group-1 (sample locations S-2, S-3, S-4) are closely correlated i.e. sediments of these three locations are similar. Also, group-2 (sample locations S-1 and S-5) are similar.

Boxplot shows that median value of each metal in every location are near the minimum concentration. There is huge difference between lowest quartile and highest quartile, this indicate that the concentration of each metal in various locations has wide range of variations.

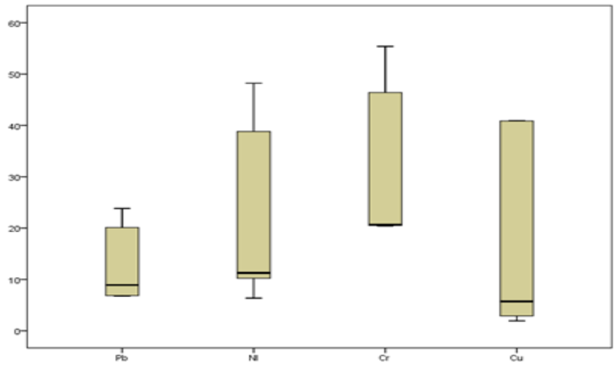

Figure 4: Boxplot representation of metal concentration in sediments of various locations

IV. CONCLUSION

The concentration of heavy metal in sediment samples are higher at South Rupshi (S-1) and Nitaiganj (S-2). According to USEPA sediment quality guideline Pb concentrations are not exceed pollution levels in the sites, however slightly polluted by Cu, Cr and Ni in the South Rupshi (S-1) and Nitaiganj (S-2) sites. Shitalakshya river has low potential ecological risk due to heavy metal concentration according to PERI. South Rupshi (S-1) site is moderately contaminated by Pb and Cu. Moreover, the Shitalakshya river sediment has low degree of contamination. The pollution source of Pb, Cu, Ni and Cr are same correlation coefficient> 0.93. The sediment samples of Kachpur Bridge (S-2), SadhurGhat (S-3) and Nabigang (S-4) have similar heavy metal pollution. Also, the sediment samples of South Rupshi (S-1) and Nitaiganj (S-2) are equally polluted.

The future study can be extended for the testing concentration of other heavy metals, along with parameters of pollution, such as, BOD, organic content and pH. The seasonal variation of heavy metal concentration, when river flow reaches at its lowest level can be investigated. Furthermore, the analysis process in the study can be used for the ecological risk assessment due to heavy metal for other rivers and canals. The concentration of heavy metal in mussel, fish, plant grow at small canal and water hyacinth can be investigated.

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