Pollution Evaluation And Health Risk Assessment of Heavy Metals In The Surface Water of A Remote Island Nijhum Dweep, Northern Bay of Bengal

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Abstract

The current study aimed to evaluate the distribution and status of heavy metal contamination of surface water in the Nijhum Dweep, northern Bay of Bengal. Ten surface water samples were collected to determine the heavy metals and the associated human health risk. The mean concentrations of the selected heavy metals were ranked in descending order of Fe (3.412 mg/L) > Mn (0.3911 mg/L) > Pb (0.3 mg/L) > Co (0.2918 mg/L) > Zn (0.230 mg/L) > Ni (0.1943 mg/L) > Cu (0.167 mg/L) > Cd (0.11 mg/L) > Cr (0.077 mg/L). All the metals except Cd, Pb, and Ni were found uncontaminated, and these three metals influenced the values of heavy metal pollution indices. Heavy metal evaluation index (HEI), heavy metal pollution index (HPI), and Nemerow pollution index (NI) revealed that the surface water of the study area is low to moderately contaminated by these selected heavy metals. Hazard quotient (HQ) and hazard index (HI) for adults and children showed no non-carcinogenic risk of heavy metals from dermal exposure pathways except station number 4 at the south of the Nijhum Dweep due to high Mn concentration. No possible carcinogenic risk was found from the analyzed metals. Several local sources of heavy metals were found during the field investigation, such as domestic effluents, small-scale metallurgical activities, oil spills from ships, and fishing trawlers. Again, industrial effluents and agrochemicals from upstream regions also contribute to heavy metal pollutions in downstream coastal regions of Bangladesh. Even though the surface water pollution level is low in the study area, the authority should take proper management and monitoring strategy for sustainability.

Introduction

Water is a priceless essential natural resource for the sustainable development and the socio-economic growth of any country (Pobi et al. 2019). Surface water is a fundamental component in the industry, households, fisheries, aquaculture and agricultural activity, transportation, and habitat for many aquatic organisms. Despite its significance, surface water is a worse managed resource than other natural resources, facing a severe impedance due to a wide array of anthropogenic activities (Reza and Singh 2010, Islam et al. 2013). Water quality in rivers and oceans is influenced by integrating natural and anthropogenic inputs and processes (Rzetala 2015).

Heavy metals are one of the most investigated surface water pollutants, and the accumulation of trace metals in aquatic ecosystems has become a great concern throughout the world in recent years (Wang et al. 2010). Due to having toxicity, persistence, and bioaccumulation characteristics, heavy metals pose a serious threat to human health, living organisms, and natural ecosystems (Islam et al. 2015; Ahmed et al. 2016). Elevated concentrations of heavy metals in surface water reduce sensitive native aquatic species density through reproductive impairment and increased diseases (Luo et al. 2014). In addition, contaminated water with high levels of heavy metals can consequence in cancer or damage the kidney and the central nervous system (WHO, 1996). Some common toxic environmentally pertinent heavy metals and metalloids are Cr, Ni, Cu, Zn, Cd, Pb, Hg, and As. Weathering of metal-bearing rocks and volcanic eruptions are the geological or natural sources of heavy metals in the environment.

On the other hand, enormous industrial and agricultural activities are the primary anthropogenic sources of heavy metals in the environment (Siddique and Aktar 2012a,b). The discharge of untreated or partially treated industrial effluents, agrochemicals, and domestic sewage into the rivers leading to an increase in heavy metal concentrations and deteriorating the surface water quality (Juang et al. 2009; Sekabira et al. 2010). Metals from anthropogenic sources reach the sea via rivers and outfalls, atmospheric fallout, dumping, marine mining and drilling, and oil spilling from ships (Siddique et al. 2012).

Bangladesh is a riverine country with a sizeable coastline of 580 km covering ~ 73% of the Bengal Basin (BB), which is equivalent to ~ 9.2% of the total Ganges-Brahmaputra-Meghna (GBM) drainage basin (Rasid and Paul 1987). The river Ganges and Yamuna have been primary recipients of suspended materials contaminated with heavy metals from India entering Bangladesh as Padma and Jamuna. Bangladesh is comprised of around 230 small and large rivers. The Meghna River, which is approximately 950 km long, is one of the country's most vital rivers, descends towards the Bay of Bengal (Hossain et al. 2019). Almost every river flowing through the country is more or less polluted with heavy metals due to anthropogenic activities, primarily industrial and domestic effluents (Kibria et al. 2016, Hasan et al. 2019). Every year, 152×10^6 tons of dissolved chemicals from upstream point and non-point sources reach the Bay of Bengal through the Ganges, Brahmaputra, and Meghna Rivers (Datta et al. 2008). Many studies have been conducted on the distribution and occurrence of heavy metals in estuarine and coastal sediments of different rivers in

Bangladesh. These studies have focused on the bioaccumulation, spatial and temporal variation, and potential sources of varying trace metals in the sediment from the Feni River estuary (Islam et al., 2018), Poshur River and Shela River (Islam et al. 2017), Buriganga River (Tanim et al. 2016), Karnaphuli River estuary (Kibria et al. 2016), Bakkhali River (Siddique et al. 2012) and Korotoa River (Islam et al. 2015) have been investigated.

The lower Meghna River estuary is a very important location for fishery resources and acts as a breeding and nursery ground for many freshwater and marine fish species (Siddique et al. 2021a). In addition, a vast amount of fish is supplied to the local and national markets from the Meghna River estuary and also plays a vital role in the livelihood of the local inhabitants. However, several studies have been conducted on the distribution and concentration of trace metals in the upper Meghna River water and sediments (Datta & Subramanian 1998; Hossain, 2019), related investigations in the coastal areas of the lower Meghna river estuary are very scarce (Siddique et al. 2021b).

Nijhum Dweep is a small island under Hatiya Upazila, in the lower Meghna River estuary of the northern Bay of Bengal, where 25000 people are living. During the field investigation, several pollution sources like oil spilling from fishing trawlers and water vehicles, agricultural activity, small-scale metallurgical activities have been identified in the Nijhum Dweep area. Unfortunately, no scientific study concerning heavy metal pollution in the surface water using different pollution indices of the Nijhum Dweep has been conducted. Therefore, rigorous investigations are needed to assess the toxicity level of heavy metals in the surface water of the Nijhum Dweep and to identify the possible human health risk of using this surface water. Therefore, the present study aimed to determine the spatial distribution of heavy metals in the surface water and their potential human health risk at the Nijhum Dweep.

Materials And Method

Description of the study area

The study location was Nijhum Dweep Island of Hatiya Upazila under the Noakhali district of Bangladesh. The study area has occupied an area of 14,050 acres and is located between 22.0231° N to 22.1034° N latitude and 90.9752° E to 91.0477° E longitudes (Fig. 01). Nijhum Dweep is the island of Bangladesh that confluences the Meghna River estuary of the Bay of Bengal and separated from Hatiya in the North by the Moktaria Channel. From satellite image analysis, the Moktaria channel width was around 700-1200 m. The Bay of Bengal encloses the Nijhum Dweep Island to the South and West and the Meghna River to the East. The total population of Nijhum Dweep was recorded around 25,000 in 2016. The main occupations of local inhabitants are cultivation, fishing, and livestock farming. The island is about 2.2 meters high from sea level (Saha et al. 2014) and, physiographically, lies in the active delta (Rashid 1977).

Numerous sedimentations formed this island and the surrounding landmass through the major rivers (Ganges, Brahmaputra, and Meghna) of Bangladesh (Goodbred and Kuehl 2000). Every year, more than 0.7×10^9 tons of sediments and associated elements are transported to the Bay of Bengal by the Ganges, Brahmaputra, and Meghna (GBM) Rivers (Dietrich et al. 2020). Semidiurnal micro to the meso-tidal environment exists in this study area (Barua 1990). The annual average maximum and minimum temperature in Nijhum Dweep are around 30 °C and 21.6 °C, respectively (BMD 2009). Most of the annual rainfall occurs from May to October in Nijhum Dweep, with average precipitation ranges from about 2000–3600 mm/year (Sarkar and Choudhury 2003). A unique combination of brackish, marine, and freshwater, the estuarine environment has endowed the Nijhum Dweep as a highly productive ecosystem for fisheries resources.

Sample collection and preservation

A total of 10 surface water samples were collected in February 2020. Sampling locations were recorded using a handheld GPS receiver. One liter of surface water sample was collected in polypropylene plastic bottles from each site. After collection, the water sample was acidified with nitric acid (pH = 2) to reduce the precipitation and adsorption to the container wall and reduce the bacterial activities. The samples were stored at 4°C and transferred to the Bangladesh Council of Scientific and Industrial Research (BCSIR) laboratory, Chattogram immediately for further analysis.

Analytical techniques

Initially, the metal standard solution was prepared from analytical grade chemicals and reagents with distilled water to calibrate the instruments following the standard procedure of APHA 1995. Analyses of metals were performed on the same day to avoid possible deterioration of the standard with time. A reagent blank was prepared in the same manner to avoid contamination. Approximately 100 mL water from each of the water samples was taken in a beaker. Then the samples were digested by adding 5 mL concentrated HNO_3. Ultra-pure HNO_3 was used for sample digestion because of its oxidizing nature. Then the samples were boiled at 130 °C on a hot plate till the volume came to about 50 mL and light color.

The heavy metal concentration of the collected water samples was determined by atomic absorption spectroscopy (AAS, Model-ICE 3300, Thermo Scientific, UK) using standard procedures of APHA 1995. Atomic absorption spectroscopy is one of the most user-friendly tools for determining metals and metalloids because of its sufficient sensitivity and relatively interference-free results. Standard solutions were used to prepare the calibration curve. The calibration curves with R^2>0.995 were accepted for concentration calculation. The calibration curves were obtained for concentration versus absorbance. All the measurements were assessed using internal quality approaches, and for each experiment, a run included blank and duplicate analysis were done to eliminate any batch-specific error.

Pollution evaluation indices

Heavy metal evaluation index (HEI)

The HEI helps to assess the general quality of the water concerning heavy metals, and HEI was calculated as (Edet and Offiong 2002):

$$\mathrm{HEI}=\sum_{i=1}^{n} \mathrm{Hc}/\mathrm{Hmac}$$

Here, Hc is the calculated value of the i^{th} parameter, and Hmac is the maximum admissible concentration (MAC) of the i^{th} parameter. The MAC for Zn, Fe, Cu, Mn, Cr, Cd, Pb, and Ni are 3, 2, 2, 0.4, 0.05, 0.003, 0.01, and 0.07 mg/L, respectively (WHO 2017). Therefore, the level of the heavy metal evaluation index was classified into three divisions based on the calculated values, like low HEI ≤ 10, medium HEI (10–20), and high HEI > 20 (Proshad et al. 2020; Edet and Offiong 2002).

Heavy metal pollution index (HPI)

The heavy metal pollution index is a convenient method for determining water quality concerning heavy metals (Sheykhi and Moore, 2012). The HPI is a mean weighted arithmetic tool to assess water quality index utilizing Edet and Offiong's (2002) method.

$$\mathrm{HPI}=\frac{\sum_{i=1}^{n} QiWi}{\sum_{i=1}^{n} Wi}$$

Where Qi is the sub-index of the i^{th} parameter, Wi is the unit weight of the i^{th} parameter, and n is the number of parameters considered. Unit weight (Wi) was taken as a value inversely proportional to the corresponding parameter's recommended standard (Si). Therefore, the sub-index (Qi) of the parameter was determined by

$$\mathrm{Qi}=\sum_{i=1}^{n} \frac{\{Mi(-)Ii\}}{(Si-Ii)} \times 100$$

Here, Mi is the determined heavy metal value of the i^{th} parameter, Ii is the ideal heavy metal value of the i^{th} parameter, and Si is the standard heavy metal value of the i^{th} parameter (BIS, 2012). The critical pollution index value of HPI for drinking water is 100, according to Prasad and Bose (2001). Again, an adjusted three-class scale has been used in the current investigation, and the classes are; low level < 15, medium level 15–30, and high level >30 for HPI values (Khan et al. 2020).

Nemerow pollution index

The Nemerow pollution index (NI) is a comprehensive, simple, and straightforward mathematical method to determine how different heavy metals pollute the sampling site (Zhong et al. 2015). The NI combines the single factor pollution index, the extreme value, and the highest and lowest pollution degree. The NI was calculated using the following formula:

$$\mathrm{NI} = \sqrt{\left(\frac{[(1/n)\sum(Ci/Si)]^2 + [Max\,(\frac{Ci}{Si})]^2}{2}\right)}$$

Here, n expresses the number of indices, Ci is the measured concentration of heavy metal i, and Si is the evaluation standard value of heavy metal i. In this study, NI values were compared with the groundwater pollution NI scale, and the NI was divided by 6 degrees of pollution; no pollution ≤0.5, clean 0.5–0.7, warm 0.7–1.0, polluted 1.0–2.0, medium pollution 2.0–3.0, and severe pollution > 3.0 (Bodrud-Doza et al. 2019).

Health risk assessment

Heavy metals from surface water enter the human body via oral exposure or dermal contact. Through empirical models, non-carcinogenic or carcinogenic health impacts of heavy metals can be predicted due to oral intake or dermal contact. As the surface water around the Nijhum Dweep area is not drinkable due to salinity problems and people do not drink that water, health risk only for the dermal exposure pathway was estimated. Chronic daily intake (CDI) helps assess the impact of heavy metals on human health for dermal exposure pathway and was calculated using the equations: (USEPA, 1989; Zheng et al., 2017, Saha and Paul 2019).

$$\mathrm{CDI_{Dermal}} = \frac{C \times SA \times Kp \times ET \times EF \times ED}{BW \times AT}$$

Hazard quotient (HQ) assesses health risk due to its non-carcinogenic effect based on CDI (Muhammad et al. 2011). The HQ was calculated by:

$$\mathrm{HQ} = \frac{CDI}{RfD}$$

Hazard index (HI) is the summation of individual HQs (Boateng et al. 2015; Rupakheti et al. 2017) and can be expressed as:

$$\mathrm{HI} = \sum HQ$$

According to USEPA (1989), the HI > 1 indicates the non-carcinogenic health risk due to exposure to a combination of toxic elements, whereas HI < 1 means no adverse health risk. Thus, HI>1 is referred to as an unacceptable value. Dermal contact of heavy metal contaminated water can generate cancer in the human body over a specific time or a lifetime. The potential carcinogenic risk (CR) for human health can be calculated for any individual toxic metal using the following equation (Rahman et al. 2018):

$$\mathrm{CRdermal} = \mathrm{CDI_{Dermal}} \times \mathrm{CSF}$$

Here, CSF stands for cancer slope factor, which is variable for different metals. An accepted value of ≤1.0E-06 is determined for cancer risk and assumed that approximately 1 per 10,00,000 would generate cancer due to exposure to a carcinogenic metal

(Adamu et al. 2015).

Statistical analysis

All data were analyzed using PAST software version 4.03 and Microsoft Excel version 2010. The mean concentrations, standard deviation, and Pearson correlation coefficient (two-tailed) of the selected heavy metals in the sediment were analyzed.

Results And Discussion

Heavy metal concentrations in surface water

The distribution of heavy metals expressed a wide range of variabilities in the studied sites (Table 2). The average concentration of Cr, Cu, Cd, Fe, Mn, Ni, Pb, Co, and Zn were 0.077, 0.167, 0.11, 3.412, 0.391, 0.194, 0.3, 0.292, and 0.231, respectively. The mean concentrations of the determined heavy metals were ranked in descending order of Fe > Mn > Pb > Co > Zn > Ni > Cu > Cd > Cr. The mean concentrations of Fe, Cr, Cd, Pb, and Ni were comparatively higher than the WHO (2017) standard and BIS (2012) limits. Co has no standard limits yet set by WHO or BIS.

Zn, Fe, Cu, and Mn were detected in almost all sampling locations, but Cr, Co, Cd, Pb, and Ni were sparingly detected in the sampling locations. The discharge of agrochemical runoff, untreated household waste, battery manufacturing, the oil spill from the boat, welding, and electroplating operations emerges as possible contamination of surface water with heavy metals (Singh et al. 2005). Again, a huge amount of chemicals from upstream neighboring countries are transported to the coastal regions of Bangladesh via Ganges, Brahmaputra, and Meghna Rivers (Datta et al. 2008). The concentration of (Zn) ranged between 0.075 and 0.614 mg/L, which falls within the permissible levels of BIS (2012). The Cd concentration varied between 0.09 and 0.15 mg/L, where 30% of the study sites exceeded BIS's permissible levels (2012). The distribution pattern of Cd showed that station St-1 (0.09 mg/L), St-8 (0.09 mg/L), and station St-9 (0.15 mg/L) had the highest concentration of Cd compared to other sampling sites. Domestic and industrial effluents, runoff of agrochemicals, and small-scale metallurgical activities with the fishing trawlers, ships, and ferries are the possible sources of Cd in the water of the Bay of Bengal as determined in previous studies (Hasan et al. 2016; Khan et al. 2017). Four sampling sites (St-01, St-04, St-07, and St-09) expressed a very high degree of Pb values varying between 0.27 and 0.37 mg/L. Pb contamination sources in surface water could be due to excessive use of pesticides (agrochemicals), automobile emissions, and paints.

The mean concentrations of Cr, Zn were much lower in the study area compared to studies conducted in other estuaries and riverbanks of Bangladesh. The mean concentrations of Cd, Pb, Fe, Ni were found much higher in the present investigation than in the other reported studies (Table 03). A study in the upstream river estuary identified agricultural and other anthropogenic activities as the potential sources of heavy metals in the surface water (Islam et al. 2018). In the present study, some sampling stations were near the fishing and transporting trawler terminal, from where heavy metals can be released as oil spilling and metallurgical activities of trawlers. The mean concentration of Cu (0.167 mg/L) from this study was lower than the Bangshi River (1.053 mg/L; Rahman et al. 2014) and Buriganga Riverbank (0.239 mg/L; Bhuiyan et al. 2015), but higher than in the water reported from other riverbanks and estuaries (Table 3). The mean concentration of Mn was three times elevated (1.44 mg/L) in the water of the Old Brahmaputra River compared to the present study. Again, the mean concentration of Pb was (0.3 mg/L) three times higher in the present study than in the water from the Old Brahmaputra River (Bhuyan et al. 2019).

Heavy metal evaluation index (HEI)

The heavy metal evaluation index (HEI) estimates the water quality, focusing on heavy metals in the surface water samples. HEI was calculated for Ni, Cr, Cu, Fe, Mn, Zn, Pb, and Cd and presented in the scatter plot (Fig. 02). The average HEI value was 27.49, while the value range was 2.175 to 96.598. The HEI values of the present study divided in terms of contamination levels as low, medium, and high. According to the HEI classification of Edet and Offiong (2002), at five sampling stations were within the limit of low class (HEI < 10), and at the rest of the sampling stations, the HEI values were within the boundary of high level (HEI>20). The high values of HEI were mainly due to Cd, Ni, and Pb concentrations in the analyzed samples. Other metals were found safe according to HEI calculations.

Heavy metal pollution index (HPI) & Nemerow pollution index (NI):

The HPI model is a handy tool for evaluating the overall pollution level of surface water with heavy metals. The mean value of HPI was 760.538 and ranged between 5.497 and 3462.89. According to Edet and Offiong (2002), 40% of the samples were within the limit of low-class (HPI <15), 10% were within the range of medium-class (HPI 15-30), and the rest of the samples (50%) were within the high-class rank (HPI >30). Again, comparing the critical value of 100 proposed by Prasad and Bose (2001), 40% of the samples exceeded the critical limit due to the higher concentration of Cd in those sampling stations (St-1, St-8, St-9). In general, the surface water was not polluted or contaminated by other metals except Cd. Localized Cd in surface water increased the overall HPI values of these sampling stations.

The Nemerrow pollution (NI) index of heavy metals in the studied surface water was prepared using WHO (2017) and BIS (2012) standards. The mean value of NI was 12.0476, and the range was 0.176 to 36.15 (Table 3). Sampling stations where Cd was found in the surface water increased the values of NI than the locations where Cd was not found.

Health risk assessment (HRA)

The non-carcinogenic risk of heavy metals from the surface water due to dermal contact was analyzed for adults and children. The HQ for individual metals were revealed that no metal in the surface water of Nijhum Dweep poses any carcinogenic risk to adults and children. Only the concentration of Mn in the sampling site 04 was found risky for adults, where the HQ value of Mn was found 1.13. Again, the HQ values for all metals in each sampling site were summed to determine hazard index (HI), which indicates the overall metal risk on humans. The HI values of ten sampling locations for both adults and children show no carcinogenic risk of heavy metals on humans (HI <1), except sampling site 4. It happened due to Mn's high HQ value, which increased the overall HI values >1 for adults (Fig. 04). The HI values for adults were more than the children in all sampling locations, indicating that adults are more vulnerable than children. As no metal was found responsible for non-carcinogenic risk on adults and children, there is no possibility of carcinogenic risk from the dermal contact of those metals.

Relationship of analyzed heavy metals

In the present study, a Pearson correlation was performed among the analyzed metals (Fig. 5). Significant positive relations ($p < 0.05$) were found between Fe–Mn; Fe–Pb; Cu–Cr; Cu–Co; Cu–Ni; Co–Cd; Co–Pb; Ni–Pb, and Ni-Co suggests their similarity in behavior or sources in surface water of the study area. No significant relationship was found among Zn and other metals. The relationship among heavy metals indicates their mode of origin and migration process (Wang et al. 2012). If there is no correlation among elements, it suggests that a single factor does not control the metals, and their source is different (Kükrer et al. 2014).

Conclusions

The present study revealed that the mean concentration of the heavy metals in the surface water of the Nijhum Dweep is at uncontaminated levels except for Cd and, to a minor extent, Pb and Ni. Although Cd, Pb, and Ni were not detected in all sampling locations, these metals were most influential in calculating metal pollution indices. This is maybe due to their high concentration values or their much lower standard limits. Metal pollution indices (HEI, HPI, and NI) revealed that the surface water of the Nijhum Dweep area is moderately polluted in some locations and unpolluted in some places, mostly where Cd was not found. Health risk assessment for adults and children due to dermal exposure pathways of surface water for individual metals was analyzed and seen no metal was posing any non-carcinogenic health risk except station number 4 where Mn possessed a little bit of health risk for adults only. Even the HI values for all sampling sites were found safe for both adults and children. Again, the HI value was found >1 in sampling station 4 due to Mn concentration. The increased amount of Cd may be due to domestic effluents, small-scale metallurgical activities, and oil spills from ships and fishing trawlers. Again, the unplanned urban areas and rapid growth of industries in upstream regions increase heavy metal pollution in the downstream areas. Proper planning, adequate policies, and rules should be implemented to control the corrosion of surface water in Bangladesh and restore the ecosystem.

Declarations

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Authors' contributions

Conceptualization: Mahfuzur Rahman, Mohammad Abdul Momin Siddique, Subrota Kumar Saha; *Sample collection*: Sabrina Akhter Rima, Jerin Saima, Mohammad Sabbir Hossain, Tamisra Nath Tanni; *Laboratory analysis:* Muhammad Abu Bakar, Sabrina Akhter Rima, Jerin Saima; *Original draft writing*: Sabrina Akhter Rima, Mohammad Sabbir Hossain, Tamisra Nath Tanni; *Review and editing*: Mahfuzur Rahman, Mohammad Abdul Momin Siddique, Subrota Kumar Saha

Data availability

The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval and consent to participate

Not applicable since this study did not report on or involve the use of any animal or human data or tissue.

Consent to publish Not applicable

This manuscript did not contain data from any person.

Competing interests

The authors declare no competing interests.

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Tables

Table 01: Values of the variables for the estimation of dermal human health risk exposure to surface water

Parameters	Unit	Dermal values	References
CDI (Chronic daily intake)	mg/kg/day	-	USEPA 1989; Zheng et al. 2017
C (Conc. of trace metals in water)	mg/L	-	-
EF (Exposure frequency)	days/yr	240 for fishing	USEPA 2011
ED (Exposure duration)	year	30 years for adults, and 6 years for children in fishing	USEPA 2011
SA (Exposure skin area)	m^2	1.9, and 0.68 for adults and children, respectively	USEPA 2011
ET (Exposure time)	hr/day	4 and 0.5 for adults and children respectively in case of fishing	USEPA 2011
Kp (Permeability coefficient)	-	0.002 (Cr), 0.001 (Cu), (Cd), (Fe), (Mn) 0.0001 (Pb), 0.0002 (Ni), 0.0006 (Zn)	USEPA 2009; USEPA 2011
Bw (Body weight)	kg	65 and 16 for adults and children, respectively	USEPA 2011
AT (Averaging time for non-carcinogens)	days	365 X ED	-
RfD (Reference dose)	(mg/kg/day)	0.003 (Cr), 0.04 (Cu), 0.0005 (Cd), 0.0035 (Pb), 0.02 (Ni), 0.045 (Fe), 0.0008 (Mn), 0.06 (Zn)	USEPA 2009, Bodrud-Doza et al. 2019

Table 02: The statistical summary of heavy metal concentrations in mg/L at Nijhum Dweep, northern Bay of Bengl

Sample Number	Zn	Fe	Cu	Mn	Cr	Co	Cd	Pb	Ni
St-01	0.075	3.49	0.17	0.59	0.084	0.280	0.09	0.29	BDL
St-02	0.513	1.54	0.17	BDL	0.058	0.175	BDL	BDL	0.044
St-03	0.079	3.08	BDL	0.28	BDL	BDL	BDL	BDL	BDL
St-04	0.156	7.35	0.16	1.18	0.089	BDL	BDL	0.27	BDL
St-05	0.134	2.06	0.15	0.41	BDL	BDL	BDL	BDL	BDL
St-06	0.614	2.15	0.14	0.53	BDL	BDL	BDL	BDL	BDL
St-07	0.264	4.40	0.19	0.17	0.068	0.359	BDL	0.27	0.178
St-08	0.087	3.14	0.12	0.12	BDL	0.183	0.09	BDL	BDL
St-09	0.108	4.06	0.25	0.14	0.095	0.560	0.15	0.37	0.361
St-10	0.278	2.85	0.16	0.1	0.068	0.194	BDL	BDL	BDL
Mean	0.231	3.412	0.167	0.391	0.077	0.292	0.11	0.30	0.194
SD	0.190	1.644	0.036	0.347	0.014	0.149	0.0346	0.0476	0.159
WHO limit (2017)	3	2	2	0.4	0.05	NA	0.003	0.01	0.07
BIS limit (2012) Desirable	5	0.3	0.05	0.1	0.05	NA	0.003	0.01	0.02
BIS limit (2012) Permissible	15	No relaxation	1.5	0.3	No relaxation	NA	No relaxation	No relaxation	No relaxation

BDL: Below detection limit; NA: Not available, WHO: World Health Organization, BIS: Bureau of Indian Standards

Table 03: Comparison of heavy metal concentrations (mg/L) in the surface water of Nijhum Dweep with different locations of Bangladesh

Study area	Cr	Pb	Cu	Zn	Mn	Cd	Fe	Co	Ni	References
Nijhum Dweep	0.077	0.3	0.167	0.2308	0.391	0.11	3.412	0.292	0.194	*Present study*
Rupsa River	0.0072	0.00709	0.00536	NA	NA	0.000975	NA	NA	0.00385	Proshad et al. 2020
Ganges River	0.0007	0.0026	0.0068	0.089	0.00015	0.0001	0.08	NA	0.005	Haque et al. 2020
Old Brahmaputra River	0.01	0.11	0.12	0.01	1.44	0.001	NA	0.2	0.44	Bhuyan et al. 2019
Buriganga River	0.114	0.119	0.239	0.332	0.157	0.059	0.612	0.199	0.15	Bhuiyan et al. 2015
Korotoa River	0.073	0.027	0.061	NA	NA	0.008	NA	NA	0.032	Islam et al. 2015
Bangshi River	0.093	0.108	1.053	3.318	0.088	0.007	NA	NA	0.035	Rahman et al. 2014
Karnofully River	0.25	0.14	0.05	0.28	0.12	0.01	2.06	NA	NA	Islam et al. 2013
Shitalakhya River	NA	0.001	0.005	0.02	0.05	0.01	NA	NA	NA	Mokaddes et al. 2013
Turag River	NA	0.002	0.004	0.02	0.06	0.01	NA	NA	NA	Mokaddes et al. 2013
Khiru River	NA	0.02	0.004	0.006	0.17	0.13	NA	NA	NA	Rashid et al. 2012
Dhaleshwari River	0.44	0.05	0.15	NA	NA	0.006	NA	NA	0.007	Ahmed et al. 2009
Karnaphuli Estuary	0.421 - 0.925	0.405 - 1.195	0.372 – 0.973	0.472 – 1.186	0.498 – 1.372	0.090 – 0.217	NA	NA	0.356 – 0.865	Datta et al. 2008

NA: Not available

Figures

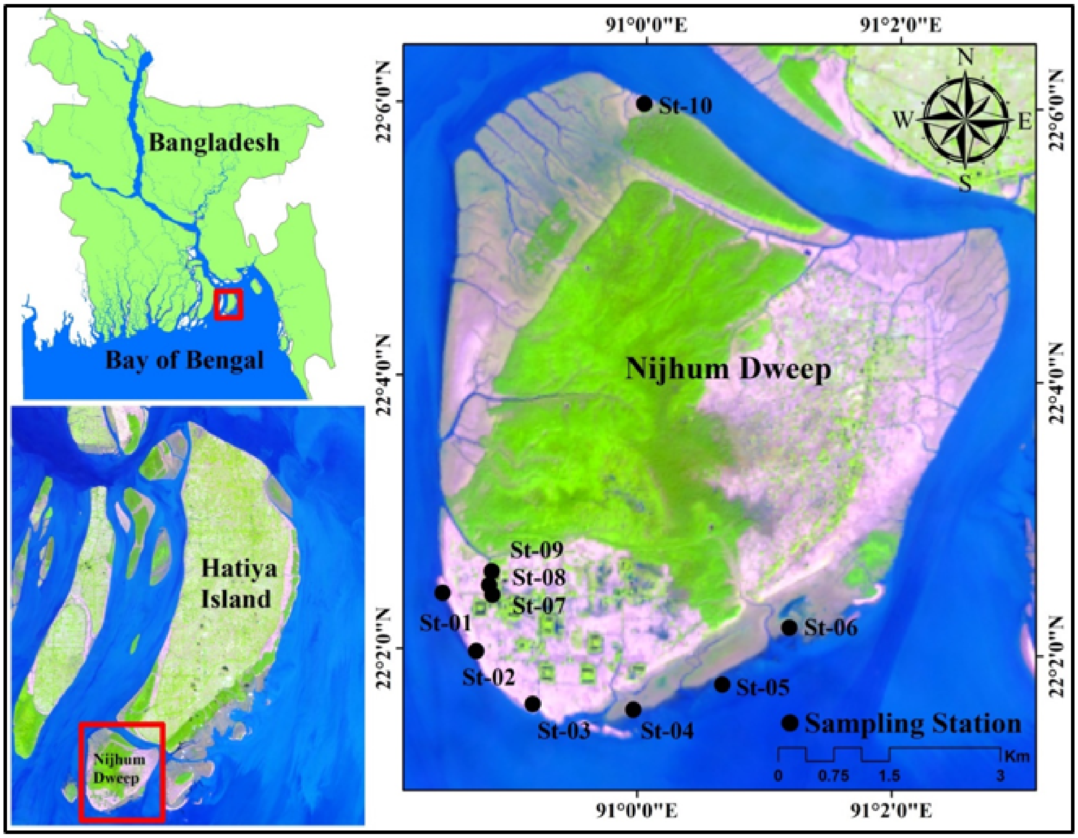

Figure 1

Location map of the study area. RGB 6 5 4 band combination indicates vegetation (green), bare land (pinky white color), and water body (blue) surrounding the Nijhum Dweep island.

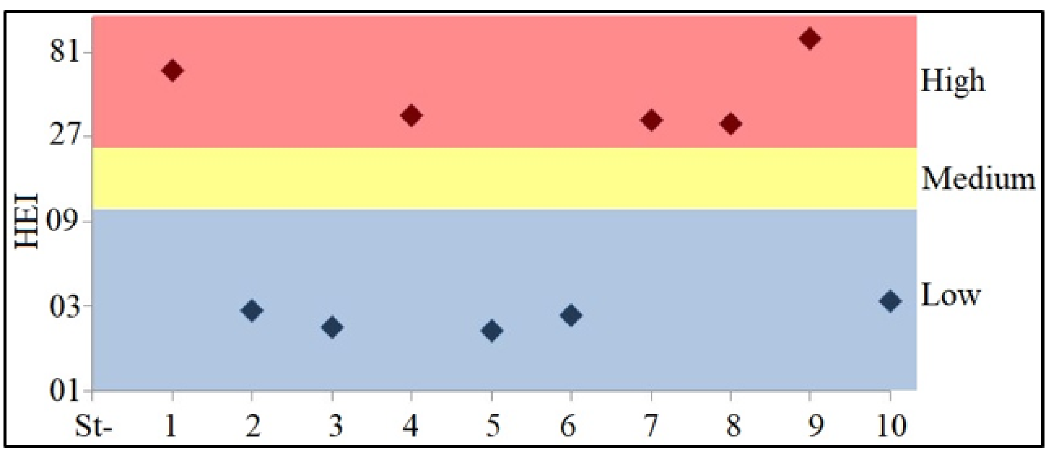

Figure 2

Heavy metal evaluation index (HEI) of the selected heavy metals from the Nijhum Dweep, northern Bay of Bengal, Bangladesh

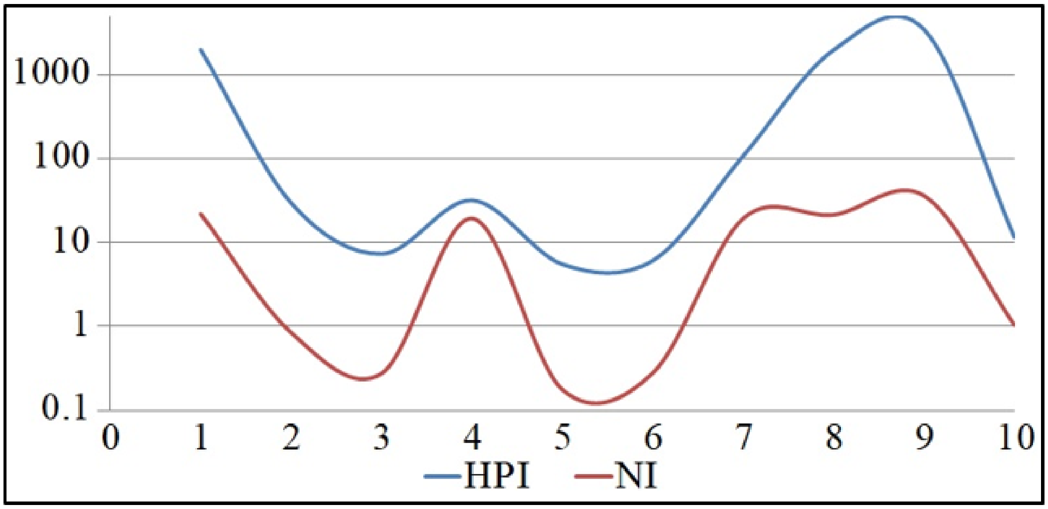

Figure 3

Heavy metal pollution index (HPI) and Nemerow pollution index (NI) of the selected heavy metals from the Nijhum Dweep, northern Bay of Bengal

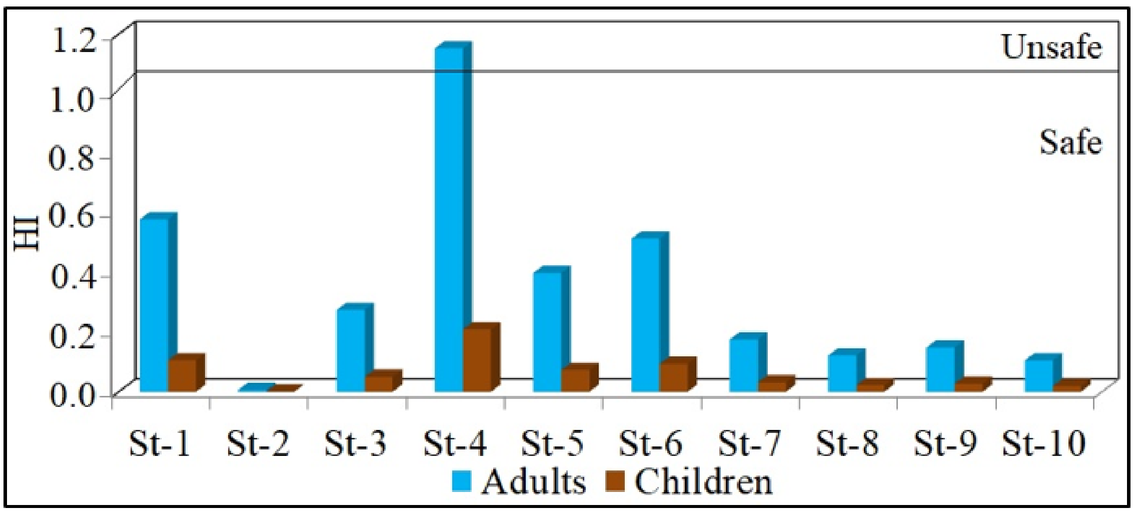

Figure 4

Hazard index (HI) values for adults and children of the ten collected surface water samples from the Nijhum Dweep

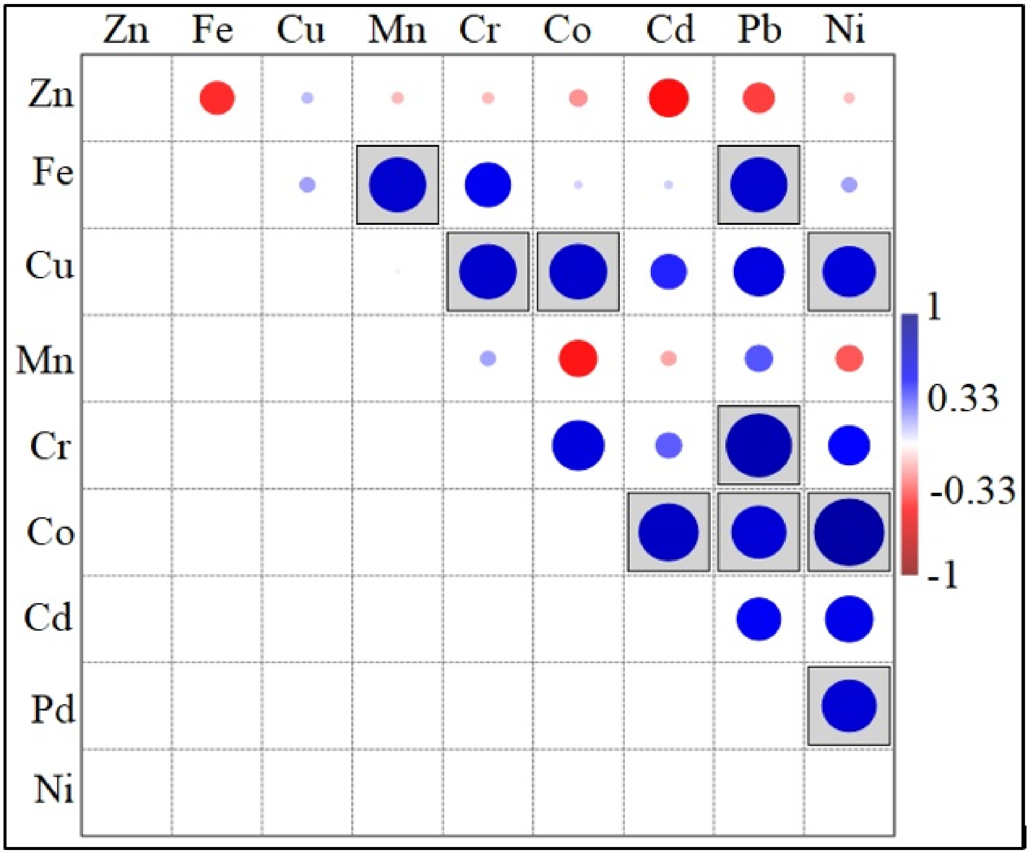

Figure 5

Pearson correlation coefficients (r) among the analyzed heavy metals (two-tailed). Data in the boxes show significant correlations ($p < 0.05$) between the elements.