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Assessment of Surface Water Quality Around a Shipyard Area in Chattogram, Bangladesh

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Abstract: Many people who live close to coastlines rely on marine resources for their livelihood. Shipyard activities near coastal Bangladesh threaten water quality, and the marine ecosystem. This study examined the water quality near shipyard sites in Chattogram, Bangladesh. There was a range of values for DO, TDS, pH, EC, BOD, and temperature from 2.2 to 3.0, > 1000 mg/L, 5.82 to 6.33, 20.4 to 23.4 mS/cm, 63 to 105 mg/L, and 29 to 33, respectively. The BOD, TDS, and EC readings were higher than the WHO-recommended level. The concentration of heavy metal ions observed in the present study appeared in the following order: Fe>Pb> Cr> Mn> Zn> Cu> Ni>Cd. Additionally, all sampling locations' HEI (heavy metal evaluation index) and HPI (heavy metal pollution index) values showed increased contamination level. Large-scale shipyard operations were the primary source of pollution, as demonstrated by principal component analysis and Pearson correlation. The dendrogram showed two clusters of six sampling points, indicating the presence of EC, Fe, Mn, TDS, Cd, and Zn from the same source of the study area. All results from the analysis demonstrated an increased level of pollution. So, there is an urgent need to reduce pollution through proper guidelines.

Keywords: *Heavy metals, shipyard area, surface water, pollution, water quality indices*

Introduction: Pollutants, mostly heavy metals (HMs), are found in the environment by human activities [1,2,3,4]. An increasing global environmental concern is the pollution of soil and marine habitats by heavy metals (HM) [5,6]. Most HMs are non-biodegradable and remain in the marine biota and food chain for extended periods, endangering the environment and public health [7,8]. Certain heavy metals can be highly harmful when they grow up in natural systems because they can be carcinogenic even in minimal doses [3,9]. 32% of Bangladesh's total land area, or 47,201 km^2, is in the coastal zone, where 37 to 38 million people reside [10]. Aquatic habitats, such as mangrove forests, wetlands, and tidal flats, contained the coastal zone. The coastal areas are important since, they are ecologically diverse and provide a number of substantial environmental goods and services to people to survive. Bangladesh's coastal areas, which are about 710 km long and have a high biodiversity that includes some indigenous species, are also quite susceptible to development. The sustained life of coastal fishing communities is largely dependent on the coastal ecology. These resources have been the basis of numerous business ventures. The majority of these beaches are in Chattogram. Unfortunately, the Bangladeshi coast is highly vulnerable to anthropogenic and non-anthropogenic impacts and is prone to severe natural disasters, such as cyclones, storm surges, and floods [11]. In addition to erosion, water logging, soil salinity and various other forms of pollution [12]. In association with manmade pollution [13], the coastal and marine environment is under threat. The shipyard industry was not established suddenly. It has steadily developed in Bangladesh, going through several stages of growth on a global scale. Bangladesh is now ranked third in the world for this industry. The Bangladeshi shipyard is home to the biggest ships in the world. Shipyards typically take place on beaches along any nation's coastline. Any discharge from shipyard operations, such as oil, grease, lubrication, etc., that ends up spilling or being thrown into the coast [14]. Shipyard companies employ about 40,000 people directly in professional capacities, and an additional 200,000 people work in other trades associated with Bangladesh's ship scrapping industry [15,16]. Bangladesh's shipyard sector is primarily accountable for marine pollution due to its contaminated pollutants and health hazard elements. Meanwhile, rising pollution levels, particularly those containing toxic metals, seriously harm fish and invertebrate species and have a direct detrimental effect on human health via the food chain [12]. Heavy metals, petroleum hydrocarbons, and other chemicals were the primary pollutants originating from shipyards operations. Because of their toxicity and durability, heavy metals and petroleum hydrocarbons were the most significant of all the pollutants [3,17]. Through the wide changes in physicochemical qualities, the fast rates of sedimentation, the influence of wave motion, the fluctuating redox conditions, and the availability of organic matter, metals are remobilized, discharged, or retained in coastal ecosystems in a number of ways [18]. Heavy metal concentrations in aquatic habitats and marine life have garnered significant interest due to the detrimental effects that these metals have on humans [19,20]. Yet, no effective integrated system has been taken to reduce the pollution in surface water caused by the activities associated with shipyards. Asbestos and various heavy metals, are released into marine water bodies during the ship recycling process. These heavy metals contaminate marine environments and water bodies [21].

The shipyard under study is located in Chattogram, Bangladesh, has built a wide range of vessels for customers worldwide and currently holds an 89% share of the country's shipyard market. Tug boats, container ships, ro-ro ferries, pontoons, barges, fishing trawlers, dredgers, oil tankers, and other oceangoing vessels are examples of these aquatic, multipurpose cargo and passenger

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boats. Since, this shipyard is the biggest in the country, it is imperative to examine the physio-chemical characteristics and assess the pollution level in the surface water surrounding it. Unfortunately, in comparison to previous studies in Bangladesh, shipyard activities and their impact on the coastal zone in this study area received very little attention. But this area plays a significant role in the national economy. Since, several studies on surface water have focused on the assessment of pollution [17,22,23] and there are no records of research on this area. Therefore, by considering the knowledge gap and importance of assessment of surface water quality of this shipyard area this study was carried out. The objective of this research was to ascertain the surface water quality parameters and heavy metal pollution in the surrounding area of a shipyard located in Chattogram, Bangladesh.

Materials & Method:

Study area location: The water samples from the shipyard were collected from a shipyard area in Chattogram district, sitting on the eastern bank of the Karnaphuli River in Chattogram district. The study area is 54 min (20.9 km) away from Chattogram City. The locations of the sampling points having latitudes and longitudes were point 1 (22.322519^{0}N and 91.862265^{0}E), point 2 (22.324549^{0}N and 91.86517^{0}E), point 3 (22.325129^{0}N and 91.864828^{0}E), point 4 (22.321002^{0}N and 91.866892), point 5 (22.327722^{0}N and 91.86920^{0}E), and point 6 (22.329440^{0}N and 91.869210^{0}E), respectively. The location of sampling point 1 is very close to the shipyard area, moreover few industries are located nearby the shipyard area and also Shikolbaha power station is very near distance to the sampling area. The shipyard area is around 400 meters in total length. A sampling site location map is shown in Fig. 1.

Sampling of water: To evaluate the water quality, a 1000 ml sample of water was collected using plastic bottles from each sampling point. The bottles were carefully washed, disinfected, and treated with 5% HNO_3 for a whole night before sampling. After being cleaned with deionized water, the bottles were dried. After the samples were taken, the vials were carefully screwed shut and marked with the corresponding identifying number. At the collection locations, all water sample parameters (DO, pH, temperature, TDS, and EC) were recorded. BOD was determined at the water research laboratory in the Institute of Environmental Science (IES), Rajshahi University, and heavy metals were analyzed in the Central Laboratory, Rajshahi University, Rajshahi.

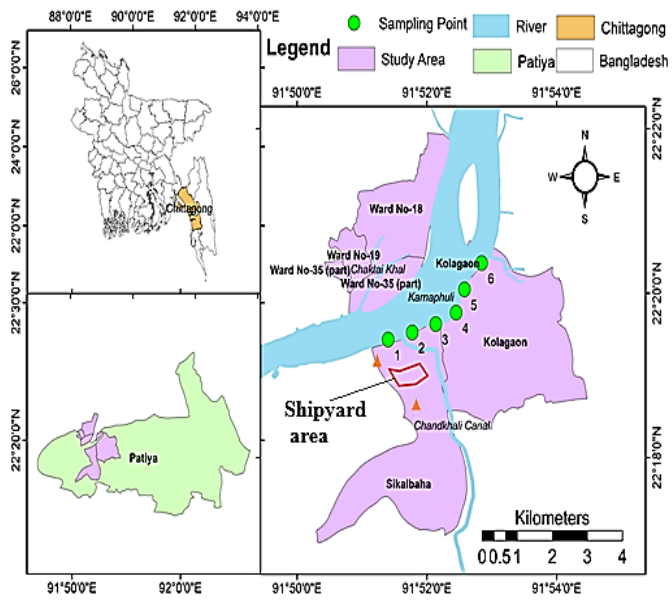

Fig. 1: Location map of the sampling site.

Sample Analysis: (YSI Pro 1030 and Lutron PDO-519) a digital multimeter were utilized to measure the DO, pH, temperature, TDS, and EC. Following the APHA (2005) standard protocols, additional physicochemical parameters were examined, including biochemical oxygen demand (BOD_5). In the Central Science Laboratory of the University of Rajshahi, Bangladesh, the concentrations of metals and metalloids were determined using a flame atomic absorption spectrometer (AAS) (SHIMADZU, AA-6800) in accordance with authorized analytical procedures [24].

Heavy metal pollution index (HPI) analysis: The total contamination status of six sample locations was ascertained by utilizing Equations (1-3) and the heavy metal pollution index (*HPI*). The *HPI*, which is inversely related to water quality and evaluates whether a water sample is acceptable for human consumption, is the summative influence of all the heavy metals in the sample. It indicates the sample's overall quality [6,24]. The following formulas were used to determine the *HPI* values

$$HPI = \frac{\sum_{i=1}^{i=n} W_i * Q_i}{\sum_{i=1}^{i=n} W_i} \quad (1)$$

where, n is the number of parameters that are taken into consideration, the unit weight of the *ith* parameter is W_i, and its sub-index is Q_i. The *ith* parameter's unit weight (W_i) and sub-index (Q_i) are given by the following formulae;

$$W_i = \frac{S_i}{Q_i} \quad (2)$$

$$Q_i = \frac{(M_i - I_i)}{(S_i - I_i)} * 100 \quad (3)$$

where, M_i, I_i, and S_i are the monitored heavy metals, ideal and standard values of the i th parameter, respectively. The maximum allowable concentration (MAC) of the selected parameter is inversely correlated with the unit weightage (W_i). Water with an *HPI* value of less than 100 is considered safe to drink, whereas water with a value higher than 100 is considered unsafe [24].

Heavy metal evaluation index (HEI) analysis: The heavy metal evaluation index (*HEI*) is a technique for determining the quality of water, concentrating on heavy metals in drinking water. This index is calculated by Eq. (4), represents the total heavy metal amount in the water [4].

$$HEI = \sum_{i=1}^{n} \frac{H_C}{H_{mac}} \quad (4)$$

Here, the monitored values for the i th parameter are H_c, and the maximum permissible concentration is H_{mac}. When the concentration of heavy metals exceeds the S_i value, the water quality is considered to be poor [5]. The WHO rules were followed in all of the *HEI's* computations. The suggested *HEI* guidelines are as follows: When the *HEI* is less than 10, pollution is classified as low, when it is between 10 and 20, and when it is more than 20, as high pollution [4]. The maximum acceptable concentration (MAC) values were established using the WHO (1998, 2004, 2011) guideline [25].

Statistical analysis: Principal component analysis (PCA) and Pearson's correlation matrix were used to examine the correlations between the variables. PCA is a powerful tool for assigning sources [13]. This analysis excluded factors having an eigenvalue larger than one. Statistical analysis was done using MS-Excel 2016.

Results and Discussion:

Physicochemical Parameters:

DO: Fish and other aquatic life depend on dissolved oxygen (DO), which is also an essential factor in contamination and river and ocean eutrophication. Fig. 2 shows the variation of DO values in different sampling locations. The present study's average DO value was determined to be 2.85 mg/L. The highest value of 3.0 mg/L was found at points 2, 3, 5, and 6, respectively, and at point 1, the lowest value of 2.2 mg/L was determined. The impact on aquatic life increases when DO levels in the water fall below 4 mg/L [26]. When DO falls below 4 mg/L, aquatic life is placed under substantial stress, leading to behavioral changes, reduced growth and reproduction rates, and even death for sensitive species. Prolonged exposure to low DO can fundamentally alter an aquatic ecosystem, reducing its health and resilience. The DO values at each sampling location were below the standard limit of 5 mg/L that is specified by WHO (2011) and ECR (2023) [25]. These value of DO is quite low and can lead to stress or even death for oxygen-dependent aquatic species like fish. Sampling point 1 has the lowest DO value because its distance is closer to the shipyard area and the oxygen consumption by microorganisms is faster than the replenishment rate, leading to lower DO values compared to other sampling point locations. Due to large amounts of various contaminants released from the shipyard area and discharges from surrounding industries. DO values get decreased in all the sampling point locations especially sampling point 1. Excessive pollutants (oils, grease, organic pollutants from ship repairing) released from shipyard area results high organic load suggested depletion of dissolved oxygen (DO) level [27].

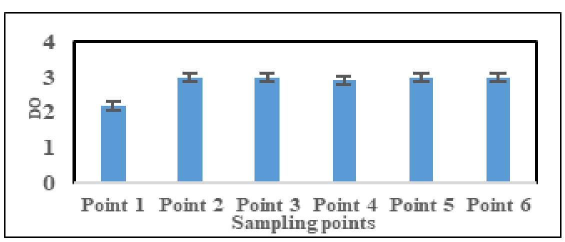

Fig. 2: DO values at different sampling locations.

Temperature: Temperature has a major impact on the physical, chemical, and biological processes that take place in water bodies. The respiration rate of aquatic organisms decreases with increasing water temperature, leading to an increase in the rate of decomposition due to oxygen consumption [28]. In Fig. 3, sampling point 1 shows the highest value of 33 ℃, while sampling point 6 shows the lowest value of 29 ℃. The average temperature in the current investigation was 27.1 ℃ [27]. The ECR (2023) standard value of 30.5 ℃. Sampling point 1 which is in closer distance to the shipyard area shows higher temperature than other sampling points which has direct influence in the biological activity and dissolved oxygen level. Moreover, Shikolbaha electric power station is very near distance to the sampling area. It is known that global warming directly affected the dissolved oxygen concentration in aqueous system. The solubility of any gases in aqueous system is inversely proportional to temperature [29]. So, an increase in temperatures can decrease microbial decomposition rates, causing to higher BOD and lower DO level [1].

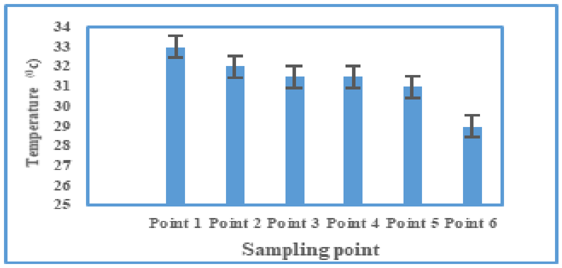

Fig. 3: Temperature values at different sampling locations.

BOD: The BOD value is frequently used as a substitute for the amount of organic water contamination [9]. The average BOD level in the current study was 83 mg/L (Fig. 4). Point 1 had the highest result, 105 mg/L, and Point 6 had the lowest, 63 mg/L. The BOD values at all sampling points exceeded the standard limit of 50 mg/L set by WHO (2011) and ECR (2023), indicating elevated pollution levels. It was observed from Fig. 4. that sampling location 1 which is nearer to the shipyard area showed the highest BOD value than the other sampling locations and the lowest BOD value was observed in sampling point 6 which is far distant from the shipyard area. Shipyard operations, such as ship maintenance and repair, have a major impact on the nearby waters' Biochemical Oxygen Demand (BOD). Routine operations like ship cleaning, machinery repair, and petroleum processing discharge oils, grease, and other organic contaminants into the seawater. Chemicals found in these organic wastes provide microbial populations with a carbon source, promoting microbial metabolism and oxygen uptake in the water. Because microbes consume dissolved oxygen (DO) during the breakdown of these organic contaminants, their presence raises BOD. These sources of elevated BOD can deplete DO, resulting in anoxic conditions that damage local biodiversity and affect aquatic ecosystems. Oil and grease accumulation, in particular, generates coatings on the surfaces that restrict oxygen exchange, accelerating depletion of DO level [30]. The reason of higher BOD value in sampling point 1 is caused by the untreated waste released from shipyard area and the surrounding industrial discharges (organic dyes, sizing agents, organic wastes, and pesticides) increases the oxygen demand for the decomposition of organic matter. Subsequently, the lowest DO value was observed in sampling point 1. Because, most of the available oxygen were being used by the microorganism to decompose organic pollutants released from shipyard area [26]. Aquatic biota faced stressed and in some cases died with a higher BOD value [31]. So, the surface water surrounding the shipyard area are in thread.

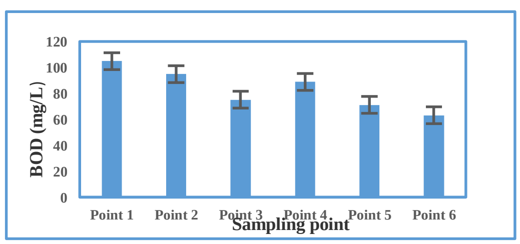

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Fig. 4: Values of BOD at different sampling locations.

pH: The pH value ranges from 5.82 to 6.33 shown in Fig. 5. Sampling point 1 had the highest pH of 6.33, while sampling point 2 had the lowest pH of 5.82. The study's pH results fell below the standard range of 6.8 and 8.5 mg/L specified by the Bangladeshi standards body (ECR, 2023). The observed low pH value is an indication of pollution by carbonation process and aquatic life may be at risk at low pH (pH 4). A low pH value in surface water can change physiological processes by decreasing the activity and effectiveness of enzymes [32]. Here, the surface waters in all the sampling point locations shows acidic nature which is caused by the discharge of wastes from shipyard area and surrounding industry. The slightly acidic conditions of surface water, may increase the solubility of heavy metals like lead and cadmium, making them more bioavailable and toxic to aquatic organisms [33].

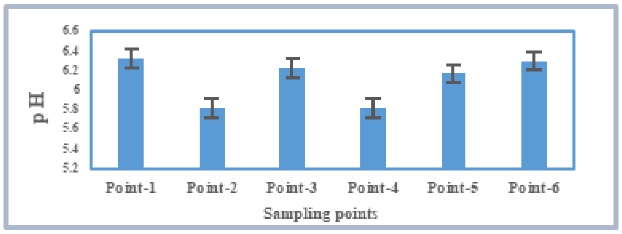

Fig. 5: pH values at different sampling locations.

Electrical Conductivity (EC): Electrical conductivity (EC) is an essential measure for identifying the qualities of surface water [34]. Fig. 6 shows, the average EC value in the current study was 21.96 mS/cm. Sampling point 1 recorded the highest value of 23.4 mS/cm, while sampling point 4 recorded the lowest value of 20.4 mS/cm. Every value above the WHO (2011) acceptable limit of 3 mS/cm for surface water. In a shipyard, the water becomes extremely polluted and hazardous to human health when EC levels are high [35]. Due to the closer distance, the location of sampling point 1 has a higher value of EC. Since, large amounts of contaminants (load of ionic component) released from the shipyard activities, the EC value of surface water increased.

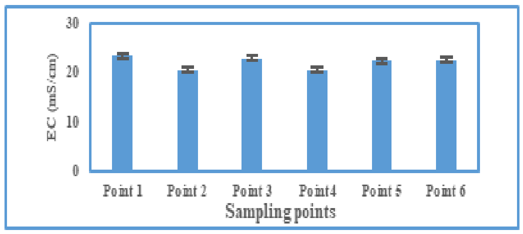

Fig. 6: Values of EC at different sampling locations.

TDS: The most important chemical component of an aqueous solution is TDS. TDS basically signifies the presence of several minerals in the water, such as metallic ions, alkalis, ammonia, nitrite, nitrate, certain acids, sulfate, and phosphate, in addition to other dissolved and colloidal solids [36]. The presence of waste-derived salts may be indicated by the higher TDS [37]. TDS levels were more than 10,000 mg/l in the samples that were taken from each site, which is more than the 2000 mg/L that the ECR (2023) and WHO (2011). The TDS values of all sampling points exceed the standard limit suggested the presence of ammonia, nitrite, nitrate, phosphate, alkalis, some acids, sulphate, metallic ions dissolve in all sampling locations [31]. Similar trend in TDS values are reported within the shipyard area than outside area [31,35]. Seawater in the shipyard zone has decreased physiochemical characteristics because of TDS being released and discharged from scraped sections of ships and constantly mixing with the water [14].

Heavy Metal concentrations in surface water of shipyard area: Many ship components, such as electrical machinery, paints, coatings, and anodes, comprise heavy metals. These parts are routinely burned or disposed of on the beaches where shipyard activities occurred, which has a negative effect on the environment and public health (Hossain and Islam, 2006). In the study area, the heavy metal concentrations were found in the following sequence: Fe>Pb>Cr>Mn>Zn>Cu>Ni>Cd. The study results showed that the concentration of Fe varied between 20.8 and 30.2 mg/L, sampling point 1 had the highest value, and sampling point 5 had the lowest value (**Table 1**). Since the location of sampling point 1 was closer to the shipyard area, the average concentrations in the sampling points are twenty to thirty times higher than the permissible limit, which may be derived from different metallic scraps from shipyard activities [23]. Mn values ranged from 0.0471 to 0.1661 mg/L, beyond the permitted limit [23]. Point 1 has the largest concentration of Mn since its location was nearer to the shipyard area. The sampling location 6 (which is located distant from the shipyard area) showed the lowest concentration. Pb concentration ranged in levels from 0.0501 to 0.0941 mg/L. Sampling point 1 gave the highest concentration of Pb, whereas sampling point 6 showed the lowest value. The Cd concentration ranged from 0.0013 to 0.0082 mg/L (**Table 1**). Point 1 had the highest value of Cd, whereas point 6 showed the lowest amount. The concentration of Cu was less than the standard limit at each sampling location. Because of numerous pollutants discharged in the shipyard region, the maximum of the heavy metal concentrations in this study were greater than permitted, which is also an indication of pollution to the surrounding surface water as well as the aquatic ecosystem [26]. From **Table 2**, it was observed that most of the heavy metal ion especially (Fe, Pb and Mn) concentrations exceeded the permissible limit. Since sampling point 1 located very close distance to the shipyard area, all heavy metal concentration found higher in this point. Various shipyard activities like metalworking, painting, welding, coatings and run off released numerous heavy metals like chromium, lead, and nickel. These released heavy metals through direct discharge, surface run off or leaching mixed with surface water nearby the shipyard area and potentially caused long term contamination, also affecting in irrigation and drinking water sources for human consumption and aquatic life.

Table 1. Six sampling points water samples heavy metal concentration.

	SL No	Heavy Metal Concentrations (mg/L)							
		Fe	Zn	Ni	Cd	Cr	Mn	Pb	Cu
Sampling Points	Point 1	30.2	0.0940	0.0301	0.0082	0.0591	0.1661	0.0941	0.0511
	Point 2	23.5	0.0752	0.0089	0.0062	0.0523	0.1151	0.0761	0.0422
	Point 3	24.2	0.0670	0.0030	0.0073	0.0376	0.1264	0.0661	0.0414
	Point 4	22.4	0.0699	0.0119	0.0063	0.0531	0.1230	0.0622	0.0276
	Point 5	20.8	0.0721	0.0079	0.0059	0.0228	0.1258	0.0541	0.0162
	Point 6	22.5	0.0482	0.0109	0.0013	0.0007	0.0471	0.0501	0.0138
	Surface water permissible limit (WHO, 2011)	0.3	05	0.02	0.005	0.05	0.05	0.05	1

Besides heavy metals, the shipyard area may be affected by solid waste and debris, which causes the clogging systems, altering habitats, and also degrading water quality. Various chemicals from paints and coatings do wash off into the water and cause toxic effects on marine organisms, potentially affecting water quality for human use. **Table 2** shows the comparison of heavy metal concentrations in surface water samples near the shipyard area in and around the country.

Table 2. Comparison of results of heavy metal concentrations in surface water samples from shipyard areas in Bangladesh and other shipyard area literature data in and around the country

Literature data	Heavy metal concentration (mg/L)							References
	Fe	Zn	Ni	Cd	Cr	Mn	Pb	
Persian Gulf, Iran	-	0.0315	0.214	0.00027	0.071	-	0.03652	[44]
Garhwal Himalaya, India	-	4.164	-	0.0008	0.00026	0.139	0.0112	[45]
Well water in the Chinese Loess Plateau, China	0.067	0.04676	0.01305	0.00002	0.01738	0.05822	0.00045	[46]
Ship-breaking area, Bangladesh	11.38	0.0702	0.0182	0.00662	0.0608	0.253	0.00994	[23]
Shipyard area, Bangladesh	23.93	0.110	0.0121	0.0058	0.0376	0.1172	0.067	This study

Heavy metal pollution index (*HPI*) analysis: The heavy metal pollution index (*HPI*) has five standard rankings, such as, excellent (0–25), good (26–50), poor (51–75), extremely poor (76–100), and inappropriate (>100) [38]. Every sampling point surpassed the critical limit, with the exception of sampling point 6, whose location is distant from the shipyard area gave *HPI* values are below the threshold level. Because the sampling stations are closer to the shipyard region, the majority of them have high *HPI* values (Fig. 7), indicating a significant amount of heavy metal pollution [39]. The *HPI* at all sites except sampling point 6 exceeds the permissible limit, primarily due to elevated levels of lead and cadmium. This suggests significant industrial contamination, likely from nearby manufacturing plants. Such high *HPI* values pose a serious risk to both aquatic life and human health, especially when water is used for drinking or irrigation. Since the location of sampling point is very closer to the shipyard area accumulated larger amount of Fe, Pb and Cr provided highest *HPI* value than the other sampling locations. Due to the far distant from the shipyard area sampling point 6 showed lowest *HPI* value [40].

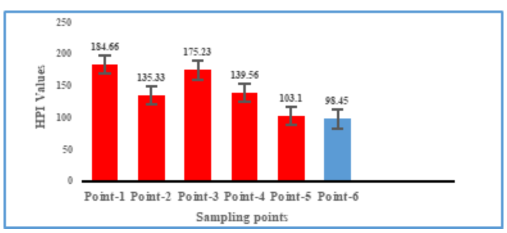

Fig. 7: HPI analysis of different sampling location.

Heavy metal evaluation index (*HEI*) analysis: Fig. 8 shows the *HEI* values of all the sampling point locations. All sampling points except sampling point 6, whose *HEI* values are below the threshold limit of 100, exceeded the critical limit. The greater pollution group (*HEI* > 20) included all of the sampling stations showed higher *HEI* values [41]. The *HEI* measures the cumulative effect of heavy metals on water quality. The *HEI* value at sampling location 1 is high, primarily driven by the concentrations of Fe, Mn, Pb, and Cr. These metals likely originate from nearby shipyard activities and industrial effluent discharge. The high *HEI* values also indicated that the surface water of shipyard area is heavily polluted by heavy metals and unsuitable for irrigation purposes and human consumption also thread to aquatic life [39].

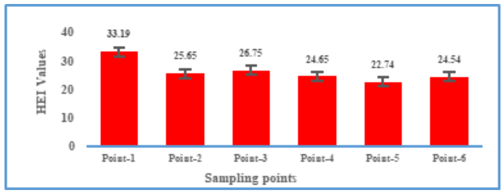

Fig. 8: HEI analysis of different sampling locations.

Statistical analysis: Principal Component Analysis (PCA) and Pearson correlation matrix analysis were used to examine heavy metal pollution and correlations between variables.

Pearson correlation analysis: The significant thresholds for the Pearson's correlation analysis, which was used to examine the relationships and correlations between heavy metals, were established at $p < 0.05$ and $p < 0.01$. Table 3 shows the Pearson correlation analysis among the water quality parameters. Parameters that correlated strongly positively with one another included Cr and Fe (0.747); Mn and Fe (0.742); and EC and Mn (0.753). However, there is a moderately positive correlation between EC and Cd (0.632), Mn and Zn (0.664); DO and Ni (0.528). The analysis from Table 3 noticed a statistically significant correlation among Pb, Fe, Cr, Mn and Zn. The strong correlations among variables suggested common sources of pollution (pollutants released from shipyard) [39]. The main sources of Pb, Cr and Ni pollution in the shipyard area are generated from waste paint chips. In Bangladesh it is usual to use electric grinder to remove paint coatings and rusts from scrap metal surfaces, are the sources of heavy metal pollution in the shipyard area

Table 3. Pearson correlation analysis among the water quality parameters.

	pH	DO	BOD	TDS	EC	Fe	Zn	Ni	Cd	Cr	Mn	Pb	Cu
pH	1												
DO	- 0.111	1											
BOD	**0.654**	-0.797	1										
TDS	0.322	-0.701	**0.664**	1									
EC	0.550	-0.486	-0.081	0.342	1								
Fe	0.080	-0.924	0.694	0.460	0.504	1							
Zn	0.143	-0.107	-0.022	0.362	0.583	0.120	1						
Ni	**0.644**	**0.528**	0.011	0.023	-0.713	-0.682	0.050	1					
Cd	-0.092	-0.092	-0.171	-0.049	**0.632**	0.342	0.758	-0.402	1				
Cr	-0.141	-0.596	0.420	-0.143	0.163	**0.747**	-0.387	-0.701	0.056	1			
Mn	0.092	**-0.809**	0.540	**0.748**	**0.753**	**0.742**	**0.664**	-0.395	0.497	0.198	1		
Pb	0.045	-0.325	0.406	0.449	-0.287	0.087	-0.646	0.050	-0.808	0.074	-0.112	1	
Cu	-0.013	-0.606	0.476	-0.036	0.115	0.080	-0.379	-0.691	0.131	0.091	0.200	0.158	1

** The correlation is significant at the two-tailed 0.01 level
* The correlation is significant at the two-tailed 0.05 level

Principal component analysis (PCA): Principal component analysis was used conventionally to determine the source of heavy metals and other physico-chemical characteristics [42]. To comprehend the physicochemical parameters in Fig. 9(a) the number of PCs maintained was ascertained using the scree plot. The similarity and difference between sampling locations can also be expressed using cluster analysis [43]. The R-mode cluster analysis (CA) yields two clusters for the parameter analysis. The elements in Cluster 1 included EC, Fe, Mn, TDS, Cd, and Zn, indicating that they might have come from the same anthropogenic source (various polluting agents dumped from the shipyard area) [30]. Cluster 1 also included BOD, pH, Pb, Cr, and Cu, suggesting anthropogenic sources of pollution [5]. Cluster 2 contained only DO and Ni, indicating a huge amount of metallic waste caused decreased the dissolved oxygen [4].

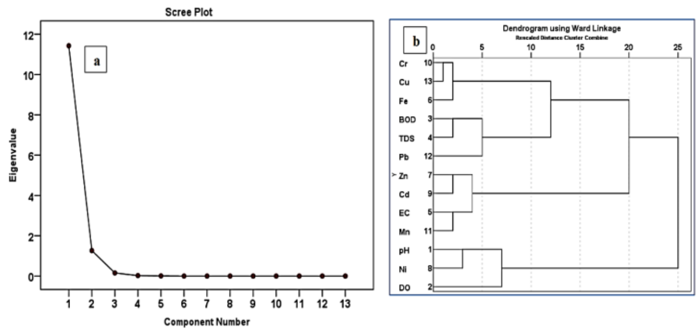

Fig. 9: (a) PCA analysis by scree plot of eigenvalues (b) Dendrogram diagram showing the hierarchical clusters analyzed for sample location.

Conclusions: In Bangladesh, the shipyard sector is extremely lucrative. Comparing the surface water quality of the shipyard area to other coastal locations without a shipyard industry, it was found to be unsatisfactory. There was a range of values for DO, TDS, pH, EC, BOD, and temperature from 2.2 to 3.0, > 1000 mg/L, 5.82 to 6.33, 20.4 to 23.4 mS/cm, 63 to 105 mg/L, and 29 to 33℃, respectively. The BOD, TDS, and EC readings were higher than the WHO-recommended level. The concentration of heavy metal ions observed in the present study appeared in the following order: Fe>Pb> Cr> Mn> Zn> Cu> Ni>Cd. The presence of a higher amount of Fe at all six sampling points clearly demonstrated the pollution status caused by numerous activities (metalworking, welding, painting and coating) in the shipyard area. Also, the amount of Cr and Pb is alarming and poses a hazard to aquatic life. Additionally, all sampling locations' *HEI* (heavy metal evaluation index) and *HPI* (heavy metal pollution index) values showed increased contamination level. Large-scale shipyard operations were the primary source of pollution, as demonstrated by Principal Component Analysis (PCA) and Pearson correlation matrix analysis. The dendrogram showed two clusters of six sampling points, indicating the presence of EC, Fe, Mn, TDS, Cd, and Zn from the same source (shipyard area) of the study area. Shipyard activities causes harm to the coastal surface water quality though this is a growing sector which offers huge opportunity in blue economy. Thus, it is crucial to ensure reduction in pollution through the implementation of efficient measures to prevent risks to the environment and public health in the vicinity of shipyard sites. Further studies may be conducted broadly in the future to determine shipyard activity's impact on air quality and health hazards.

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