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Is road-side fishpond water in Bangladesh safe for human use? An assessment using water quality indices

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ABSTRACT

Pond water is used in everyday life by many people in Bangladesh, however, without sufficient and reliable information regarding water quality and pollution status. For this reason, geospatial analysis and mapping of water quality indices such as metal (*MI*), contamination (C_d), and physicochemical water quality index (*WQI*) were assessed to improve the understanding of potential pollution sources. Samples were collected from twenty randomly selected ponds situated in Jashore Sadar Upazila, Bangladesh. Nineteen (19) water quality parameters were measured, including pH, temperature, EC, TDS, total suspended solids (TSS), chloride, alkalinity, total hardness, salinity, Fe, Mn, Pb, Cr, Cd, Co, Zn, Ag, Ni, and Cu. The average concentration of Fe, Mn, Pb, Cd, and Ag was much higher than recommended standards. The *WQI* ranged from 1.59-5.27, C_d from -0.19-18.28, and *MI* from 7.81-26.28. The spatial distribution of *MI* indicates that the south-western and south-eastern region of the study area are stands out with a very high pollution pressure. The spatial distribution of C_d, follows the same trend as for *MI*. A multitude of different types of pollution sources contributes to the high pollution load such as, municipal wastewater, leachate from landfills, small industry wastewater and stormwater, and agricultural runoff. The studied pond water is highly polluted and not suitable for household use and fish consumption.

1. Introduction

Bangladesh is a developing country with vast water resources (Uduma and Uduma, 2014). Small ponds are traditionally used as source of water and they have a vital role in providing both household water and fish for consumption (Abdullah et al., 2010). About 15% of total household income and 25-50% of total fish consumption depend on pond contribution and fish production is an important part of the national economy (Castine et al., 2017). Thus, they play an important role in alleviating poverty in Bangladesh. Pond habitats can easily be managed for an optimum environment yielding high level of fish production (El-Shafei, 2016).

Pollution of the natural environment, however, is a widespread problem (Hossain et al., 2016). Good water quality is important both for fish production and ecosystem services (Verma and Khan, 2015). Pond water pollution refers to toxic substances suspended in the water body. Metal toxicity displays itself in a variety of disorders and occurs due to oxidative strain induced by free radical formation depending on immersed dosage, path, and period of exposure such as acute or chronic (IUCN, 1998). Heavy metals may accumulate and spread through the food chain especially where fish is an important protein source (Afshan et al., 2014; Dwivedi, 2017; Tchounwou et al., 2012). Health effects include skin rashes, diarrhea, dysentery, respiratory illnesses, anemia, and complications in childbirth (Ahmed, et al., 2015; Halder and Islam, 2015; Haseena et al., 2017; Pressley, 1991; Song et al., 2008). Besides health effects of heavy metals, many kinds of diseases like typhoid, cholera, encephalitis, poliomyelitis, hepatitis, skin infection, and gastrointestinal are transmitted through wastewater to pond water due to contents of bacteria, virus, and parasites (Jaishankar et al., 2014).

Many studies have been performed on pollution status by heavy metals and their health effects on groundwater and river water but there is no available research on pond water in this area (Ahmed et al., 2019; Khan et al., 2019; Sardar et al., 2017; Shaibur et al., 2021, Shaibur et al., 2012). For this reason, creating basic information about the current pollution status of pond water is vital for people's health and

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managing necessary mitigation. In view of this, the objective of the study was to use water quality and toxicological indices such as metal (*MI*), contamination (C_d), and physicochemical water quality indices (*WQI*) to improve the understanding of potential pollution sources for representative ponds in the study area. Thus, geospatial analyses of pond water pollutant distribution were performed to assess the distribution of physicochemical and toxicological parameters. Water quality, contamination, and metal indices are important quantitative methods to define the quality of water (Hossain et al., 2020; Ponnusamy et al., 2020; Withanachchi et al., 2018).

2. Materials and methods

2.1. Study area

Jashore Sadar is a sub-district of Jashore district in the division of Khulna, Bangladesh (Ansari, 2012). Its administrative center is the Jashore City. According to the 2011 Bangladesh census, it has about 94,500 households with a 742,000 population and a total area of 435.2 km^2, 22°48′ and 23°22′ north latitude and 88°51′ and 89°34′ east longitude. The population density of this area is about 1700/km^2 (Bangladesh Population Census, 2011; Chisholm, 1911). The climate in Jashore is tropical with a rainy summer. The annual mean rainfall is about 1786 mm. The driest month is January with an average of about 9 mm of precipitation in January. Most precipitation falls in July, with an average of 346 mm. The average annual temperature in Jashore is 25.5°C. May is the warmest month with an average of 29.5°C. January, coldest month, has an average temperature of 18.4°C (Climate-data.org, 2019).

According to (Sarder et al., 2017; Shaibur et al., 2019), most of the people in Jashore district rely on underground water for drinking purposes. The rest of the people mostly depend on surface water such as ponds, rivers, and canals. About 16% of people depend on surface water (canal, river, and pond) for their daily household purpose. The remaining 84% people used groundwater for their daily purpose. Pond, river, and canal were the main sources of surface water in Jashore Municipality. Among 16% (out of 100 %), about 7% people used canal water, 5% river water, and 4% pond water for their daily activities.

Residents of the Jashore Sadar area have access to groundwater, river water, and pond water. Most needs for drinking water are supplied by groundwater. However, in cases when groundwater is not sufficient, inhabitants use pond water for activities including bathing, washing, irrigation, and crop production. However, fish is the main source of animal protein for most people in Bangladesh and ponds play a vital role in the production of fish. Thus, most ponds in the present study are used for fish production and an essential source of water and food in the area. Twenty major and representative ponds in Jashore City were randomly selected for the current study (Figure 1). Most ponds in the study area are manmade. The area of the ponds varies between about 0.05-5.2 ha **(Table 1)**, with a maximum depth of about 2.5-4.5 m during summer. During the dry season the depth usually decreases to 1.5-2.5 m. Most of the ponds are surrounded by residential buildings including business infra-structure such as offices, small-scale industry, bazars, markets, car workshops, roads, and railway lines. In some cases, bus, truck, and car terminals are situated beside the ponds producing waste from vehicles washing waste and repairing. Many ponds are situated beside trunk roads and railway lines. Many car workshops are situated along the roads that discharge car wash wastewater, petrol, and oil spills together with stormwater runoff from the road surfaces, especially during the rainy season.

3. Sample collection and analyses

Samples were collected from the 20 ponds using plastic bottles cleaned by rinsing with 8M HNO_3, followed by repeated washing with distilled water. Water samples were taken from the middle parts of the ponds and if necessary, by boat at 10-20 cm depth from the surface during the rainy season. Three water samples were randomly collected from each pond surface and then thoroughly mixed into a 1.0-1.5 L sample transferred to a clean plastic bottle. This was done to guarantee representative samples from each pond. Sample collection and preservation were done for AAS analysis in accordance with standard analytical procedures (Cleseeri, 1989). The samples were labeled and transported to the laboratory for analysis of selected parameters. Before analyses, all experimental apparatuses were washed by distilled water.

Physicochemical parameters such as temperature, pH, electrical conductivity (EC), total solids (TS), and total dissolved solids (TDS) were analyzed by using thermometer, calibrated pH meter (Hanna, pH meter), digital EC meter, filtration method, and Hach's gyrometric method, respectively (Gaikwad et. al., 2016). The pH and EC meters were calibrated by standard solution and all titrimetric analyses were done by using analytical grade chemicals. Alkalinity and chlorides were analyzed by titrimetric method and Mohr's method respectively (Salam et al., 2012, Sawyer et al., 2000), respectively, directly after sample collection. Each sample was tested three times for all parameters.

Heavy metal analyses involved digestion by using concentrated nitric acid. A 100 mL sample was used and then 5 mL concentrated HNO_3 was added for digestion on a hot plate. The digested samples were filtered by using Whatman no. 44 filter paper and kept in a 100 mL volumetric flask at 4°C until analysis by atomic absorption spectrophotometer (AAS) (Sharma and Tyagi, 2013). Concentrations of Fe, Mn, Pb, Cd, Cr, Co, Zn, Ag, Ni, and Cu were determined from prepared water samples by using flame atomic absorption spectrometer (Model: AA240FS, Varian, Australia). During analysis, for checking the calibration status of the AAS, a calibration blank and an independent calibration verification standard were analyzed for every 10 samples. Recovery rates of metals spiked in water fluctuated from 93 to 100%. The detection limits were 0.0677, 0.0193, 0.0198, 0.0031, 1.1970, 0.2910, 0.0190, 0.4068, 0.0062, and 0.0075 mg/L for Fe, Ag, Co, Mn, Pb, Cd, Ni, Cr, Cu, and Zn, respectively.

The obtained data were subject to statistical analysis using the SPSS statistical package. Mean ± standard deviations and other calculations of the different parameters were done by using Microsoft excel-2013. The mapping of sampling locations and the geospatial distribution was performed by the QGIS 2.18.2 and ArcGIS 10.5 respectively.

4. Water quality indices

The *WQI* index is an efficient method summarize and communicate information on the quality of water to concerned citizens and policy makers. It was first proposed by (Horton, 1965), which was later generalized by (Brown et al., 1972). Comparison of measured water quality variables with standard limits of WHO and other international guidelines may lead to confusion, especially where multiple parameters are used. *WQI* eliminates this problem by providing a single value after considering all the variables (Seelro et al., 2020; Kükrer et al., 2019). Similarly, the Degree of Contamination (C_d) that summarizes the level of pollution. A third useful pollutant indicator is the Metal Index (*MI*) defined by (Tamasi and Cini, 2004). The *WQI* as well as the *Cd* and *MI* is a single number that rates the water quality by aggregating several water quality parameters and usually the lower score represents the better quality (Excellent, Good) and the higher score to degraded quality (Bad, Poor) (Hossain et al., 2020)

4.1. Water Quality Index (WQI)

Water quality index (*WQI*) is a technique of rating combined influence of individual water quality parameters on the overall quality of water (Bhat and Pandit 2014; Mirza et al. 2020; Seelro et al., 2020). *WQI* was calculated to evaluate the suitability of pond water by using the water quality rating scale (Q_i), relative weight (W_i), and overall *WQI*

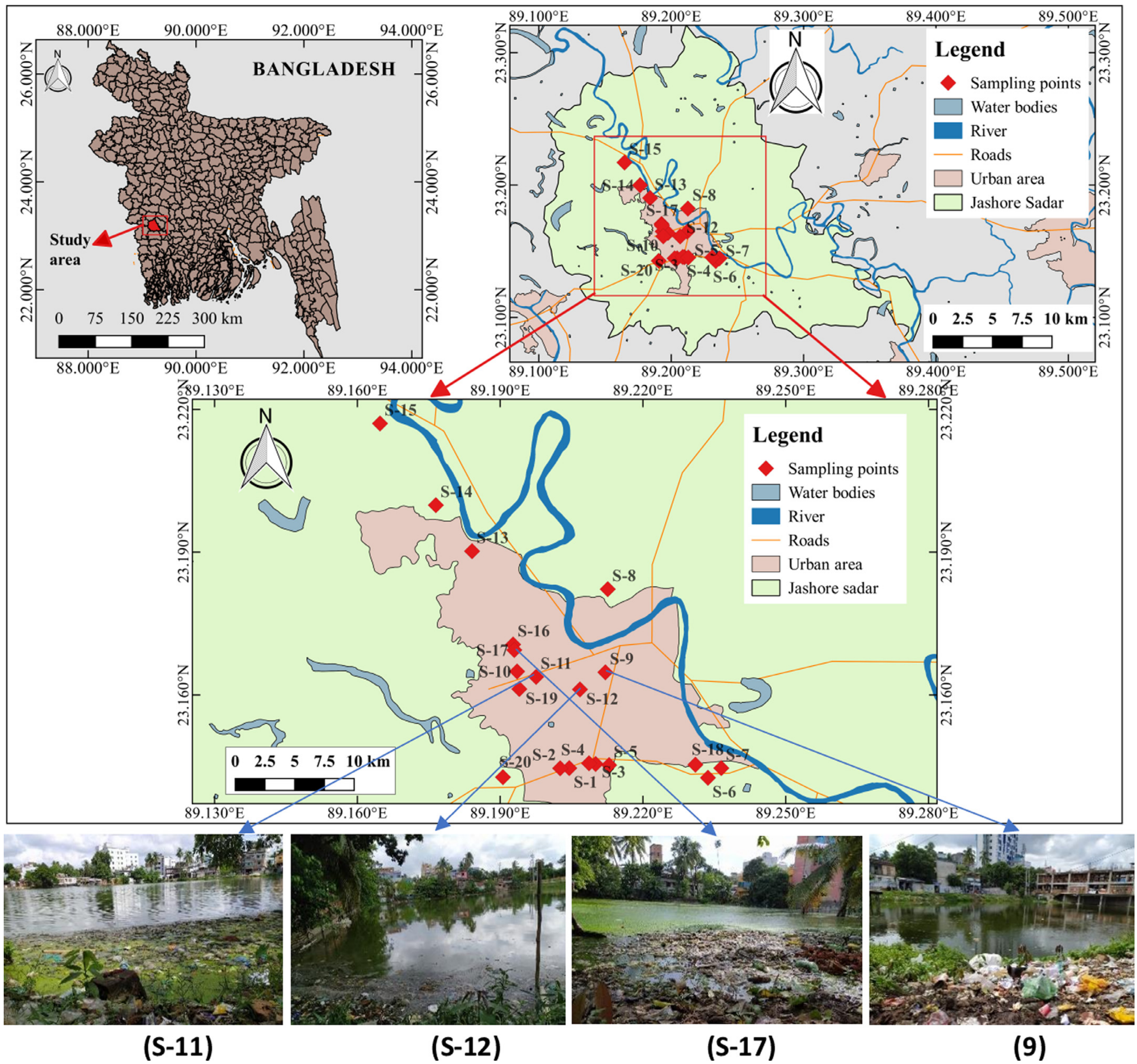

Fig. 1. Locations showing the study area in Bangladesh, sampling points in Jashore Sadar upazila, and sampling points in four ponds S-9, S-11, S-12, and S-17.

according to:

$$Q_i = \left[\left(V_i - V_o\right)/\left(S_i - V_o\right)\right] \tag{1}$$

where, V_i = analytical value of i-th parameter, S_i =standard allowable value of i-th parameter, V_o = ideal value of i-th parameter in pure water, and this value is zero for other parameters (except pH =7.0 and DO = 14.6 mg/l). The unit weight (W_i) is proportional to maximum allowable concentration (standard value) calculated as:

$$W_i = \frac{K}{S_i} \tag{2}$$

here K is the proportionality constant for the different water quality characteristics according to (Elhdad, 2019):

$$K = \frac{1}{\sum_i^n \frac{1}{S_i}} \tag{3}$$

The overall *WQI* is calculated as (Goher et al., 2014):

$$WQI = \sum_{i=1}^{n} Q_i W_i / \sum_{i=1}^{n} W_i \tag{4}$$

The *WQI* value falls into five categories (Hamaidi-Chergui and Errahmani, 2019) such as *WQI*: 0-25 → Excellent, 26–50 → Good, 51–75 → Poor, 76–100 → Very poor, and >100 → Unfit for drinking purposes.

4.2. Contamination index (C_d)

The Contamination index (C_d) is calculated by (Akter et al., 2016; Abu EI-Hamid and Hegazy, 2017; Hasan et al., 2020; Lorestani et al., 2020):

$$C_d = \sum_{i=1}^{n} Cf_i \tag{5}$$

Table 1
General information of the study area.

Sample ID	Sampling station	Upazila	Area[a] (Ha)	Types of use	GPS Location	
					Latitude (N)	Longitude (E)
S-1	Shibsagor pond	Jashore	0.606	Fish production, bathing, domestic uses, washing, at the rituals, and irrigation.	23.144623°	89.204518°
S-2	Molla bari pond	Jashore	0.585	Fish farming, bathing, domestic uses, and washing	23.144585°	89.202615°
S-3	Babla tola fish hatchery pond	Jashore	0.898	Fish farming, bathing, domestic uses, washing, and irrigation.	23.145488°	89.210055°
S-4	Sannyasi dighi pond	Jashore	0.830	Fish production, bathing, domestic uses, washing, and irrigation.	23.145636°	89.208674°
S-5	Rajbari pond	Jashore	0.068	Fish production, bathing, washing, irrigation, domestic and industrial uses.	23.145259°	89.212897°
S-6	Jamtola mor pond	Jashore	2.360	Fish production, bathing, domestic uses, washing, and irrigation.	23.142586°	89.233661°
S-7	Haji mohammed mohashin school pond	Jashore	0.379	Fish production, bathing, domestic uses, and washing	23.144619°	89.236460°
S-8	Bottala pond	Jashore	5.200	Fish production, bathing, domestic uses, and washing.	23.182212°	89.212604°
S-9	Lal dighi pond	Jashore	0.335	Fish production, bathing, domestic uses, and washing.	23.164757°	89.212111°
S-10	Dhormotola pond	Jashore	0.814	Fish production, bathing, domestic uses, and washing.	23.164937°	89.193557°
S-11	Karbala pond	Jashore	1.191	Fish production, bathing, domestic uses, to perform ablution, and washing.	23.163788°	89.197555°
S-12	Jessore zila school pond	Jashore	0.507	Fish production, bathing, domestic uses, and washing	23.161155°	89.206769°
S-13	Khoertola moor pond	Jashore	0.239	Fish production, bathing, domestic uses, and washing	23.190198°	89.184097°
S-14	Cantonment pond	Jashore	0.190	Fish production, bathing, domestic uses, washing, irrigation.	23.199864°	89.176494°
S-15	Churamonkati Railway station pond	Jashore	0.273	Fish production, bathing, domestic uses, to perform ablution, washing, and irrigation.	23.217030°	89.164760°
S-16	Arabpur stand pond	Jashore	0.174	Fish production, bathing, domestic uses, and washing	23.170601°	89.192723°
S-17	Tin khambar moor pond	Jashore	0.260	Fish production, domestic uses, and washing, irrigation	23.169437°	89.192969°
S-18	Jamtola rail gate pond	Jashore	0.114	Fish production, bathing, domestic uses, washing, and irrigation.	23.145336°	89.231024°
S-19	Gazir bazar pond	Jashore	0.146	Fish production, bathing, domestic uses, washing, and irrigation.	23.161246°	89.194031°
S-20	Pulerehat jama mosque pond	Jashore	0.053	Fish production, bathing, domestic uses, washing, and to perform ablution.	23.142710°	89.190585°

[a] The area of the pond was collected from Google Earth Pro; https://www.google.com/earth/download/gep/agree.html

where, $Cf_i = \frac{CA_i}{CN_i} - 1$. Here, Cf_i represents the contamination factor, CA_i is the measured value, and CN_i denotes the upper permissible concentration of the *i*-th component. The N denotes normative value and hence CN_i is taken as standard value of WHO (maximum allowable concentration). The calculated C_d is classified as <1 → Low contamination, 1-3 → Medium, and >3 → High contamination (Jahan and Strezov, 2017).

4.3. Metal Index (MI)

Metal Index (*MI*) is a joint evaluation of the present status (Khoshnam et al., 2017; Ojekunle et al., 2016; Sisira et al., 2018):

$$MI = \sum_{i=1}^{n} \frac{C_i}{(MAC)_i} \quad (6)$$

where, C_i represents concentration of each element and, *MAC* denotes maximum allowable concentration. When *MI* is greater than 1, the water is considered as polluted (Bakan et al., 2010).

5. Results and discussion

Results of the physico-chemical and toxicological analyses are summarized and compared to WHO, USEPA, Department of Environment (DoE) (Department of Environment, Peoples' Republic of Bangladesh, 1997), Department of Public Health Engineering (DPHE) (Department of Public Health Engineering, 2021)(;) set for health risk and Canadian Council of Ministers of the Environment (CCME) (Canadian Council of Ministers of the Environment, 2007) set for fisheries and aquatic live standards in **Table 2** and **3**. The pH range indicates that all pond water is alkaline. The average pH was 8.76 that exceeds standards set for health according to WHO, DoE, and USEPA (**Table 2**). According to (Shaibur et.al., 2021) and (Sarder et.al., 2017), the pH value in the ground water samples in this area ranged from 7.10 to 7.80 and 6.4 to 7.8 respectively. The higher pH values observed in pond water suggests that municipal and household waste containing hydroxide (caustic soda), carbonate (soda ash), bicarbonates, and calcium oxide or calcium hydroxide (lime slurry) are discharged into the pond water.

Alkalinity is mainly affected by carbonates and bicarbonates, but phenolphthalein alkalinity was not present in any of the samples.

Alkalinity is a measure of ion content for carbonate, bicarbonate, phosphate, borate, orthosilicate, and sulfides that buffers low pH water. Rainwater itself is a source for bicarbonate ions. CO_2 dissolved in water may form carbonic acid and the carbonic acid will also dissociate to form bicarbonate. Again, bicarbonate concentration might be enriched by the decomposition of organic matter and root respiration in the soil zone. Bicarbonate is the strongest buffer (largest Ka value), and the effect of other buffers becomes insignificant in its presence. This buffer action may affect the correlation between pH and alkalinity.

Water hardness is primarily the amount of calcium and magnesium, and to a lesser extent, iron in the water. Hardness of water was found from 193.00 ± 1.73 to 469.31±2.08 mgL^{-1}. The average was 308.66 mgL^{-1}. The major sources of hardness in pond water are from dissolved polyvalent metallic ions that comes from sedimentary rocks, seepage, and stormwater. Hard water may be detrimental to human health (Akram et al., 2018; Hori et al., 2021).

All the sampling points except for S-13, S-15, and S-20 had higher EC than the DPHE standard limit (**Table 2**). Conductive ions may come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides, and carbonate compounds. High EC indicates large presence of these ions.

The TDS was lower than all standards (**Table 2**). TDS originates from natural sources, sewage, urban runoff, and wastewater. Sources of total dissolved solids can include all dissolved cations and anions.

Average TSS was 743.95 mgL^{-1} that much higher than the DPHE maximum limits. However, the samples for S-19 was at the maximum limit. High TSS content may have ecotoxic effects on aquatic organisms and potentially harmful substances such as heavy metals, PAHs,

Table 2
Comparative study of physicochemical parameters of pond water in Jashore City, Bangladesh, with USEPA, DoE, and DPHE Standards.

Sample ID	Temp. (0C)	pH	EC (μScm^{-1})	TDS mg/L	TSS mg/L	Chloride mg/L	Alkalinity mg/L	Total hardness mg/L	Salinity mg/L
S-1	30.66±0.58	8.96±0.15	812.66±4.17	205.35±3.79	241.00±20.07	6.44±0.10	104.00±2	376.61±11.93	41.75±0.79
S-2	31.33±0.58	8.77±0.05	542.66±2.08	265.67±5.69	209.00±25.71	1.94±0.05	85.33±1.56	336.38±10.06	33.38±0.41
S-3	30.00±0.00	8.80±0.04	693.33±2.51	224.5±3.46	170.66±28.68	3.56±0.04	95.66±4.04	330.67±7.31	36.39±0.48
S-4	30.33±0.58	8.20±0.10	589.33±3.05	261.45±4.08	313.68±10.01	3.83±0.20	75.00±1.00	245.00±2.00	36.89±0.04
S-5	30.0±0.00	8.58±0.03	697.33±4.04	286.7±6.02	285.56±15.17	4.28±0.02	96.33±0.57	304.93±2.51	37.13±0.97
S-6	30.66±0.58	8.75±0.07	750.00±5.00	322.33±6.02	74.33±11.58	2.64±0.03	121.00±1.0	250.54±2.54	35.83±1.01
S-7	30.66±0.58	8.74±0.08	848.33±3.51	225.16±3.69	144.64±11.15	2.76±0.02	124.00±1.00	436.0±4.58	35.77±0.95
S-8	31.33±0.58	8.77±0.05	590.33±3.05	276.97±3.54	191.00±15.53	4.89±0.02	78.33±0.57	261.81±2.08	38.41±0.38
S-9	30.33±0.58	7.83±0.05	722.00±4.00	418.93±6.56	245.00±16.09	7.55±0.02	83.00±3.00	286.85±9.51	43.61±0.42
S-10	30.00±0.00	8.94±0.03	1088.66±4.50	285.3±4.52	5430.33±26.5	6.10±0.05	155.66±3.51	469.31±2.08	41.61±0.94
S-11	29.33±0.58	8.94±0.03	741.80±5.51	299.16±4.01	257.45±15.84	5.05±0.01	95.33±1.15	415.81±1.52	39.45±0.24
S-12	30.66±0.58	8.90±0.04	784.00±6.24	168.22±5.48	225.67±10.59	9.32±0.02	81.00±1.00	243.00±2.64	46.67±0.37
S-13	30.66±0.58	9.69±0.09	439.87±2.59	311.00±3.74	257.00±14.78	6.54±0.02	75.66±4.93	263.71±2.08	41.74±0.100
S-14	29.33±0.58	9.77±0.04	816.328±2.51	185.47±1.75	344.16±14.96	7.57±0.05	118.00±2.00	241.00±1.00	43.81±0.21
S-15	31.00±0.00	9.63±0.05	490.00±3.60	313.28±3.15	5440.16±31.8	6.59±0.03	70.00±2.00	345.87±13.42	41.94±0.08
S-16	30.66±0.58	8.73±0.12	714.33±2.08	265.67±2.08	456.98±25.14	5.48±0.03	40.29±1.15	193.00±1.73	39.49±0.45
S-17	30.66±0.58	8.29±0.03	667.00±4.00	396.54±3.54	158.83±13.64	4.15±0.09	40.00±1.00	242.67±3.21	37.7±0.18
S-18	30.66±0.58	8.64±0.07	670.00±4.00	255.00±3.00	356.00±8.00	9.59±0.03	40.00±2.00	262.00±2.00	47.17±0.14
S-19	30.33±0.58	8.22±0.05	767.68±4.93	295.33±1.53	10.01±1.01	5.28±0.02	52.00±1.00	331.00±4.36	39.55±0.05
S-20	31.00±0.00	8.09±0.61	280.74±2.67	2788.74±6.11	67.67±9.07	3.90±0.01	48.00±1.00	337.00±2.65	37.31±0.51
Max.	31.33±0.58	9.77±0.04	1088.66±4.50	2788.74±6.11	5440.16±31.8	9.59±0.03	155.66±3.51	469.31±2.08	47.17±0.14
Min.	29.33±0.58	7.83±0.05	280.74±2.67	168.22±5.4	10.01±1.01	1.94±0.05	40.00±1.00	193.00±1.73	33.38±0.41
Avg.	30.47	8.76	685.31	402.54	743.95	5.37	83.93	308.66	39.78
STD Dev.	±0.55	±0.51	±170.17	±565.01	±1607.89	±2.11	±31.26	±73.62	±3.71
WHO[a]	-	6.5-8.5	-	1000	-	250	-	500	-
USEPA[b]	-	6.5-8.5	-	500	-	250	-	-	-
DoE[c]	20-30	6.5-8.5	-	1000	-	150-600	-	-	-
CCME[d] (Fish and aquatic live)	-	7.0-8.7	-	-	-	120	-	-	-
DPHE[e]	20-30	-	500	1000	10	150-600	-	200-500	-

[a] World Health Organization (WHO) (World Health Organization, 1984)
[b] United State Environmental Protection Agency (USEPA) (USEPA, 2009)
[c] Department of Environment (Department of Environment, Peoples' Republic of Bangladesh, 1997)
[d] Canadian Council of Ministers of the Environment Canadian Council of Ministers of the Environment, 2007
[e] DPHE= Department of Public Health Engineering (Department of Public Health Engineering, 2021)

and organic matter maybe related to high contents of TSS (Rossi et. al., 2006).

The values of chloride of all samples ranged were within acceptable limits. Sources of chloride pollution in water includes fertilizers, sewage, effluents from drainage, salts and human as well as animal waste (Sawant et. al., 2013). Increasing chloride means increasing salinity and negative effects on irrigation and soil that may decrease crop yield. Furthermore, long-term exposure to saline water through drinking and cooking may cause high rates of preeclampsia and gestational hypertension (Ayers et. al., 2017).

The salinity values of water samples varied between 33.38±0.41 to 47.17±0.14 mg/L. Again, according to (Sardar et.al., 2017) the salinity value of ground water in Jashore district was ranged from 0.0-0.25 mg/L.

Iron in our study area ranged from 0.39±0.03 to 5.25±0.43 with a mean of 1.56 mg/L (**Table 3**). Iron concentration of groundwater may vary from 0.46 to 1.42 mg/L (Shaibur et al., 2021) and for river water from 2.32 to 5.52 mg/L (Khan et al., 2019). Thus, the ponds had higher concentration than ground water samples as well as WHO, USEPA, DoE, and DPHE maximum permissible levels. But iron (Fe) concentration in river water is higher than the pond water, it is may be due to dissolved iron from heavy industrial waste of different heavy industry situated beside riverbank. As many car workshops are situated close to the ponds, different types of construction works are probably the source for this iron pollution. Geogenic sources may also be responsible for high level of iron content.

The Mn exceeded the recommended WHO, USEPA, DoE, and DPHE permissible levels set for health for all sampling points (**Table 3**). The Mn concentration of river water in this area ranges from 0.12-0.33 mg/L (Khan et al., 2019). This is due to heavy industrial and municipal waste discharge into the rivers. However, high contents of Mn may also be due to geogenic sources and Mn occurs naturally in many surface waters. The Earth's crust is a major source of Mn to the atmosphere, soil, and water. In surface waters, Mn occurs in both dissolved and suspended forms. The major anthropogenic sources of Mn may be municipal wastewater discharge, sewage sludge, emissions from alloy, steel, and iron and the combustion of fossil fuels (UNEP; ILO; WHO; Inter-Organization Programme for the Sound Management of Chemicals; International Programme on Chemical Safety, 2004).

Lead (Pb) contents varied from 0.08±0.02 to 0.39±0.12 mg/L with a mean of 0.15 mg/L. This is greatly exceeding recommended maximum contents by WHO, USEPA, DoE, and DPHE (**Table 3**) set for health. Lead concentration in groundwater in the Jashore district below 0.03 mg/L (Sardar et.al., 2017). High Pb contents in pond water are probably related to car exhaust and runoff from road and car workshops during the rainy season. As a result of the extensive use of alkyl-lead compounds as fuel additives, vehicular traffic may be the largest source of lead in this urban area. Lead acid batteries contribute to the contamination of all environmental media during their production, disposal, and incineration. Lead compounds may also be used as stabilizers in plastics. Other lead-based products include food-can solder, ceramic glaze, crystal glassware, and lead-jacketed cables.

The mean cadmium (Cd) concentration (0.0036 mg/L) exceeded the recommended value set by the WHO for health risk and CCME for aquatic live. However, some ponds (S-3, S-4, S-5, and S-6) were below the maximum limit. All ponds exceeded the standard value of CCME set for fish and aquatic life (**Table 3**). Seven sampling sites S-1, S-7, S-9, S-11, S-14, S-16, and S-18 did not exceed the maximum concentration limit but reached the maximum standard limit of WHO (0.003 mg/L) set for health risk. The cadmium concentration of groundwater in the area is below 0.004 mg/L (Sardar et al., 2017). Cadmium can be released from car exhaust, metal processing industries, battery and paint, and

Table 3
Comparative study of toxicological parameters of pond water in Jashore City, Bangladesh, with WHO, USEPA, DoE, and DPHE Standards.

Sample ID	Fe mg/L	Mn mg/L	Pb mg/L	Cd mg/L	Cr mg/L	Co mg/L	Zn mg/L	Ag mg/L	Ni mg/L	Cu mg/L
S-1	1.2±0.10	0.52±0.04	0.10±0.03	0.003±0.0005	<0.005	0.170±0.01	0.290±0.03	0.016±0.001	0.003±0.0003	0.018±0.001
S-2	0.93±0.1	0.51±0.04	0.09±0.03	0.004±0.0007	<0.005	0.479±0.04	0.144±0.02	0.006±0.0003	0.004±0.0003	0.082±0.01
S-3	3.85±0.31	0.49±0.03	0.15±0.05	0.002±0.0003	<0.005	0.327±0.03	0.115±0.01	0.012±0.001	0.001±0.0001	0.111±0.01
S-4	1.58±0.13	0.45±0.03	0.08±0.02	0.002±0.0003	<0.005	0.959±0.01	0.136±0.02	0.014±0.001	<0.001	0.033±0.002
S-5	0.93±0.10	0.80±0.07	0.11±0.03	0.002±0.0003	0.01±0.001	0.566±0.04	0.127±0.02	0.236±0.01	0.006±0.001	0.021±0.002
S-6	0.51±0.06	0.37±0.03	0.09±0.03	0.002±0.0003	<0.005	0.023±0.002	0.076±0.01	0.006±0.0003	<0.001	0.003±0.001
S-7	1.50±0.12	0.62±0.04	0.09±0.03	0.003±0.0005	<0.005	0.015±0.001	0.078±0.001	0.004±0.0002	0.017±0.001	0.014±0.001
S-8	1.26±0.10	0.37±0.03	0.14±0.04	0.005±0.0008	<0.005	0.016±0.001	0.090±0.01	0.009±0.001	<0.001	0.001±0.0001
S-9	0.96±0.10	0.38±0.03	0.11±0.03	0.003±0.0005	<0.005	0.213±0.02	0.529±0.1	0.008±0.0004	0.009±0.001	0.028±0.002
S-10	0.39±0.03	0.38±0.03	0.09±0.03	0.004±0.0007	<0.005	0.028±0.002	0.074±0.01	0.007±0.0004	0.001±0.0001	0.007±0.001
S-11	0.41±0.03	0.42±0.03	0.12±0.04	0.003±0.0005	<0.005	0.039±0.003	0.054±0.01	0.026±0.0014	0.003±0.0003	0.011±0.001
S-12	0.98±0.10	0.45±0.03	0.12±0.03	0.005±0.0008	<0.005	0.011±0.001	0.216±0.03	<0.001	0.005±0.0004	0.024±0.002
S-13	1.00±0.10	0.34±0.02	0.11±0.03	0.004±0.0007	<0.005	0.023±0.002	0.036±0.01	0.008±0.0004	0.012±0.001	0.005±0.02
S-14	0.50±0.04	0.12±0.01	0.17±0.05	0.003±0.0005	0.011±0.002	0.015±0.001	0.082±0.01	0.005±0.0003	0.021±0.002	0.006±0.001
S-15	1.84±0.15	1.02±0.07	0.16±0.05	0.004±0.0007	<0.005	0.181±0.014	0.479±0.06	0.012±0.001	<0.001	0.237±0.02
S-16	1.19±0.10	0.15±0.01	0.20±0.06	0.003±0.0005	<0.005	0.013±0.0001	0.254±0.03	0.003±0.0002	0.141±0.012	0.004±0.0003
S-17	1.20±0.10	0.16±0.01	0.11±0.03	0.006±0.001	0.011±0.001	0.019±0.001	0.132±0.02	0.004±0.0002	0.028±0.003	0.001±0.001
S-18	4.07±0.33	0.22±0.02	0.36±0.11	0.003±0.0005	<0.005	0.013±0.001	0.257±0.03	0.242±0.013	0.154±0.013	0.008±0.001
S-19	1.65±0.13	0.54±0.04	0.39±0.12	0.004±0.0007	0.001	0.017±0.001	0.176±0.02	0.006±0.0003	0.433±0.04	0.006±0.0004
S-20	5.25±0.43	0.14±0.01	0.18±0.06	0.007±0.0012	<0.005	0.006±0.001	0.134±0.02	0.007±0.0004	0.048±0.004	0.010±0.001
Max.	5.25±0.43	1.02±0.07	0.39±0.12	0.007±0.0012	0.011±0.002	0.959±0.01	0.529±0.1	0.242±0.013	0.433±0.04	0.237±0.02
Min.	0.39±0.03	0.12±0.01	0.08±0.02	0.002±0.0003	<0.005	0.006±0.001	0.036±0.01	<0.001	<0.001	0.001±0.001
Avg.	1.56	0.4225	0.1485	0.0036	0.0083	0.1566	0.1736	0.0332	0.0554	0.0315
STD Dev.	±1.31	±0.22	±0.08	±0.001	±0.005	±0.25	±0.13	±0.07	±0.10	±0.06
WHO[a]	0.3	0.1	0.05	0.003	0.05	-	5	-	0.07*	1.0
USEPA[b]	0.3	0.05	0.015	0.005	0.1	-	5	0.10	-	1.3
DoE[c]	0.3-1.0	0.1	0.05	0.005	0.1	-	5	-	0.1	1
CCME[d] (Fish and aquatic live)	-	0.43	-	0.0009	0.001 (VI), 0.0089 (III)	-	0.007	0.00025	-	-
DPHE[e]	0.3-1.0	0.1	0.05	0.005	0.05	-	5	0.02	0.1	1

[a] World Health Organization (WHO) (World Health Organization, 1984; World Health Organization, 2008)
[b] United State Environmental Protection Agency (USEPA) (USEPA, 2009)
[c] Department of Environment (Department of Environment, Peoples' Republic of Bangladesh, 1997)
[d] Canadian Council of Ministers of the Environment Canadian Council of Ministers of the Environment, 2007
[e] DPHE= Department of Public Health Engineering (Department of Public Health Engineering, 2021)

Table 4
Correlation matrix among the physicochemical and toxicological parameters

Correlations Parameters	Temp	pH	EC	TDS	TSS	Chloride	Alkalinity	Total hardness	Salinity	Fe	Mn	Pb	Cd	Co	Zn	Ag	Ni	Cu
Temp	1																	
pH	-0.161	1																
EC	-.510*	0.063	1															
TDS	0.236	-0.352	-0.579**	1														
TSS	-0.003	0.369	0.215	-0.086	1													
Chloride	-0.181	0.26	0.183	-0.181	0.186	1												
Alkalinity	-0.401	0.345	0.628**	-0.297	0.309	-0.164	1											
Total hardness	-0.184	0.055	0.335	0.082	0.436	-0.225	0.553*	1										
Salinity	-0.2	0.27	0.222	-0.173	0.21	0.995**	-0.112	-0.183	1									
Fe	0.259	-0.3	-0.520*	0.646**	-0.129	0.005	-0.480*	-0.011	-0.006	1								
Mn	0.102	0.18	0.011	-0.298	0.413	-0.148	0.235	0.414	-0.161	-0.156	1							
Pb	-0.003	-0.136	-0.064	0.08	-0.098	0.376	-.549*	-0.17	0.36	0.455*	-0.152	1						
Cd	0.466*	-0.126	-0.4	0.604**	0.076	0.076	-0.405	-0.002	0.075	0.277	-0.298	0.091	1					
Co	-0.043	-0.25	-0.178	-0.142	-0.057	-0.343	0.034	-0.074	-0.386	-0.02	0.378	-0.318	-0.448*	1				
Zn	0.239	-0.18	-0.097	-0.038	0.276	.448*	-0.315	-0.114	0.433	0.101	0.301	0.171	-0.023	0.056	1			
Ag	-0.113	-0.089	0.005	-0.095	-0.093	0.334	-0.17	-0.111	0.295	0.242	0.151	0.34	-0.285	0.185	0.048	1		
Ni	0.081	-0.308	0.012	-0.01	-0.153	0.098	-0.494	-0.162	0.085	0.18	-0.037	0.885**	0.053	-0.286	0.12	0.061	1	
Cu	0.202	0.316	-0.291	-0.088	0.552*	-0.045	-0.04	0.168	-0.058	0.173	0.681**	-0.064	-0.081	0.278	0.493*	-0.093	-0.263	1

'*' Mean correlation is significant at the 0.05 level.
'**' Mean correlation is significant at the 0.01 level.

waste. Once cadmium is released into the air, it spreads with the wind and settles onto the ground or surface water as dust.

The cobalt (Co) concentration ranged from 0.006-0.959 mg/L with average value of 0.1566 mg/L (**Table 3**). Co probably stems from car emission and runoff from roads, vehicle garages, and cars washing effluents. Heavy metals can also enter pond water from a variety of sources, such as bedrocks and soils, decomposing dead organic matter, and from different human activities. Copper, chromium, nickel, and zinc are trace metals that may occur in significant quantities in the bedrock. Concentrations in rock range from about 10.0 to 100.0 mg/kg. Concentrations in soil are similar.

Mean concentration of silver (Ag) was higher than the DPHE stnadard for health and CCME permissible limit set for fish and aquatic life (**Table 3**).

Mean nickel (Ni) concentration was 0.0554 mg/L (**Table 3**). Nickel and its compounds are naturally present in the Earth's crust and are released to the environment from geogenic sources as well as from anthropogenic activities. Burning of fuel, municipal incineration, and coal combustion may be responsible for high contents of Ni in the area.

Zinc contents for all sampling ponds were much higher than the CCME standard limit set for aquatic life and fish (0.007 mg/L). Copper (Cu) content was not exceeded any of the standards set for health and aquatic live (**Table 3**).

In general, the surface water quality deterioration of this area can be caused by a combination of anthropogenic and geogenic sources. Geogenic contamination is defined as the exceeding thresholds (e.g., drinking water guidelines) in the aquifer without direct or indirect anthropogenic influence (Grützmacher et al., 2013).

5.1. Correlation between contaminants

Pearson's correlation (r) was used to study linear relationships between the various contaminants. Significance levels were established at $P < 0.01$ and $P < 0.05$ level (Ahmed et. al., 2013; Molla et al., 2015). Strong correlation may be indicated by $r > 0.7$, moderate correlation may be at hand for r between 0.4 and 0.7, and weak correlation up to 0.3 (Popoola et al., 2019; Saleem et al., 2012). The Pearson correlation between physicochemical and toxicological parameters of assessed pond water samples is shown in **Table 4**. The correlation can indicate geochemical relationships or common pollution sources as well as mutual dependences or identical behavior in the transport process (Sisira et al., 2018, Leventeli and Yalcin, 2021). Significant positive correlations were found between EC and alkalinity at $P < 0.01$, between TDS and Cd at $P < 0.01$, TSS and Cu at $P < 0.05$; strong positive correlation was found between chloride and salinity at $P < 0.01$. Total alkalinity was moderately correlated with total hardness. Positive correlation was found between Fe and Pb at $P < 0.05$, Mn with Cu, and Pb had strong correlation with Ni at $P < 0.01$. Parameters that correlated positively with one another including TDS showed moderate correlation with Fe and Cd, pH with alkalinity and TSS, and TSS with TH. Chloride was strongly correlated with salinity. Alkalinity was moderately correlated with TH; TH with Mn; salinity with Pb, Fe with Pb; Mn with Cu; Pb had strong correlation with Ni; and Zn was moderately correlated with Cu. High correlation between metals indicates common sources of pollution such as car emissions, runoff from roads and parking areas, municipal and household waste, transport of hazardous goods, and runoff from roadside soil as well as geogenic sources (Zhao et al., 2017).

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5.2. Spatial distribution analysis

GIS was used to improve the understanding of the spatial distribution of the three different water quality indices (Adnan and Iqbal, 2014; Honarbakhsh et al., 2019; Maliqi and Penev, 2019; Munna et al., 2015; Nakagawa et al., 2019). Kriging method in SURFER (version, 22), and color method of QGIS (version 2.18.2) were used to create contour layer maps as spatial distribution for the different water quality indices. However, due to the fact that samples from the pond water represent point measures, it should be noted that the spatially contour maps in **Fig. 2-4** represent a fictious spatial distribution of pollutants and indices. The spatial maps should be interpreted as indicative of the general pollutant load for an area close to the ponds resulting from a multitude of pollution sources rather than exact pollution distribution over the water and land surfaces.

The *WQI* was calculated from physicochemical parameters **(Table 2)** whereas *MI*, and *Cd* were calculated from toxicological heavy metal pollutants **(Table 3)** using the WHO standards. The metal contamination was very high in the study area and *MI* and *Cd* exceeded the maximum recommended limits. **Table 5** shows the calculated values of *WQI, MI*, and *Cd* based on analyzed physicochemical and toxicological parameters. The spatial distribution of different pond water quality indices was carried out with respect to calculated value of *WQI, MI*, and *Cd*.

For *WQI* it can be concluded that the north-western region of the study area has the highest pollution levels **Fig. 2**). Again, it should be

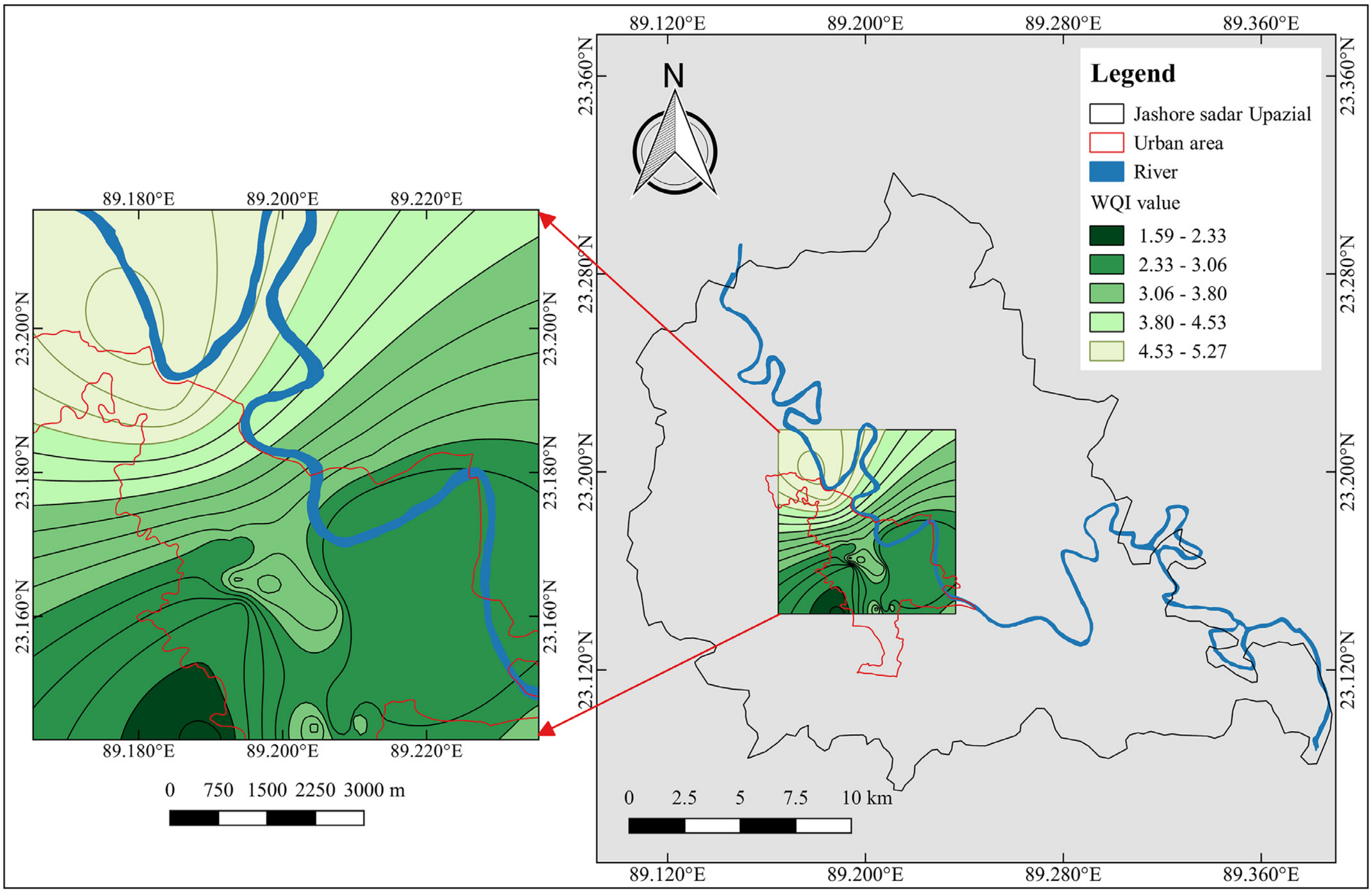

Fig. 2. Spatial distribution of Water Quality Index (*WQI*).

Table 5
Calculated values of Water quality index (*WQI*), Metal index (*MI*), and Contamination index (*Cd*)

Sample ID	Water quality index (*WQI*)	Metal Index (*MI*)	Contamination Index (C_d)	Pollution status
S-1	3.737	12.319	4.319	Highly polluted
S-2	3.375	11.501	3.501	Highly polluted
S-3	3.432	21.548	13.548	Highly polluted
S-4	2.290	12.094	4.094	Highly polluted
S-5	3.014	14.299	6.299	Highly polluted
S-6	3.335	7.885	-0.115	Highly polluted
S-7	3.321	14.272	6.272	Highly polluted
S-8	3.373	12.386	4.386	Highly polluted
S-9	1.589	10.462	2.462	Highly polluted
S-10	3.703	8.269	0.269	Highly polluted
S-11	3.701	9.031	1.031	Highly polluted
S-12	3.620	11.972	3.972	Highly polluted
S-13	5.122	10.450	2.450	Highly polluted
S-14	5.273	7.809	-0.191	Highly polluted
S-15	5.010	21.536	13.199	Highly polluted
S-16	3.295	12.536	4.536	Highly polluted
S-17	2.462	10.447	2.447	Highly polluted
S-18	3.127	26.226	18.226	Highly polluted
S-19	2.330	26.280	18.280	Highly polluted
S-20	2.101	25.556	17.556	Highly polluted

emphasized that the point measures represent individual ponds, not land areas between the ponds. The ponds in this more polluted area are located close to local bazars, shops, and a railway station with many landfills and garbage dumps including municipal waste. Some agricultural areas are also associated with the adjacent ponds in this area. Probably these are the main pollution sources responsible for increasing the physicochemical pollutants and hence *WQI*. The lowest *WQI* is in the south and south-eastern parts of the area. In some cases, the ponds were not directly associated with household areas. Lower WQI for ponds here is due to a more remote location from residential areas.

The spatial distribution of *MI* indicates that the south-east and south-western region of the study area are stands out with a very high pollution pressure. There is an individual high value in a north-western pond (Fig. 3). However, it should be noted that the high metal concentrations in the pond water can be both geogenic and anthropogenic. The anthropogenic sources of metals and *MI* index in ponds of this area are prob-

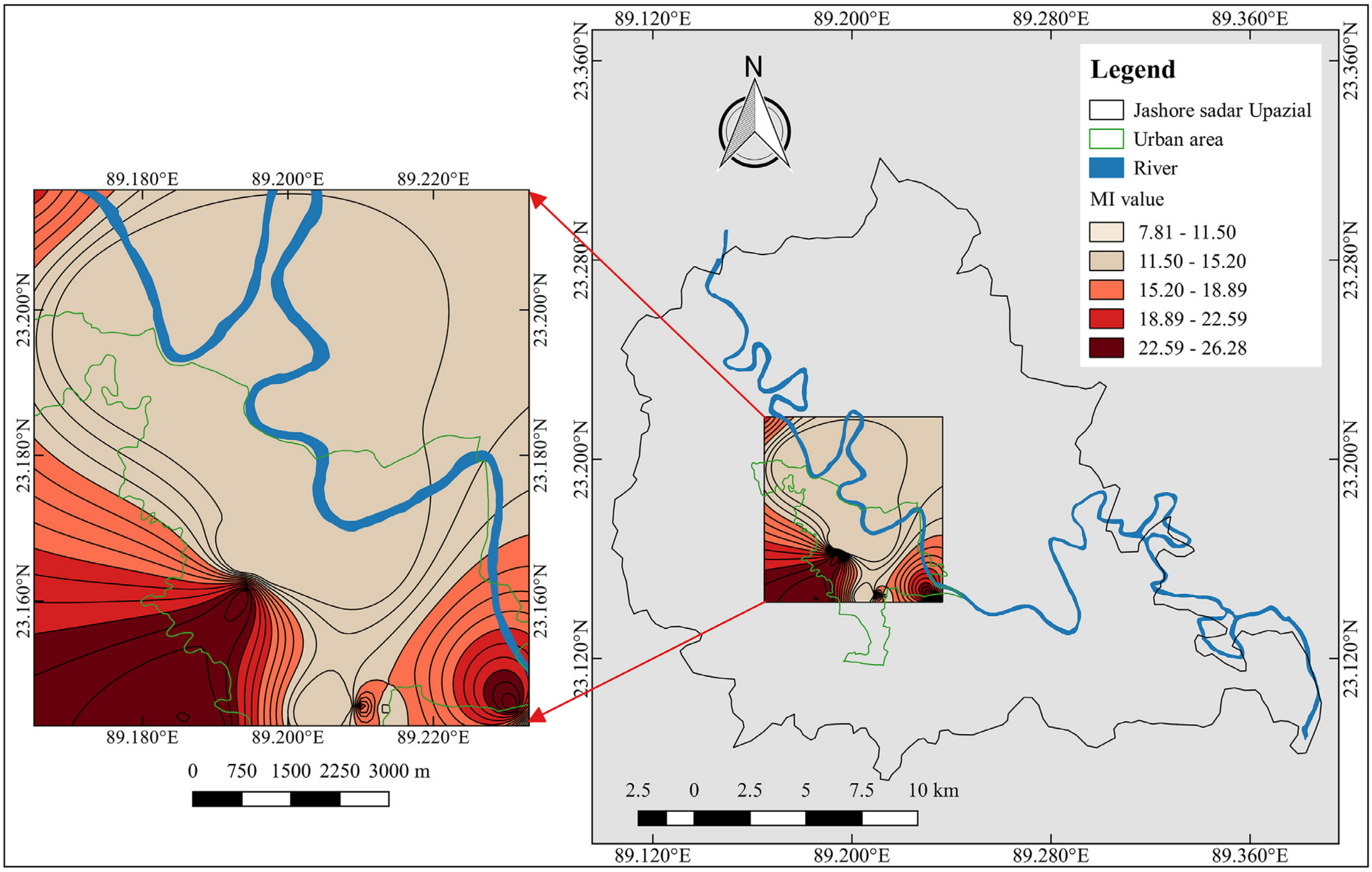

Fig. 3. Spatial distribution of Metal Index (*MI*).

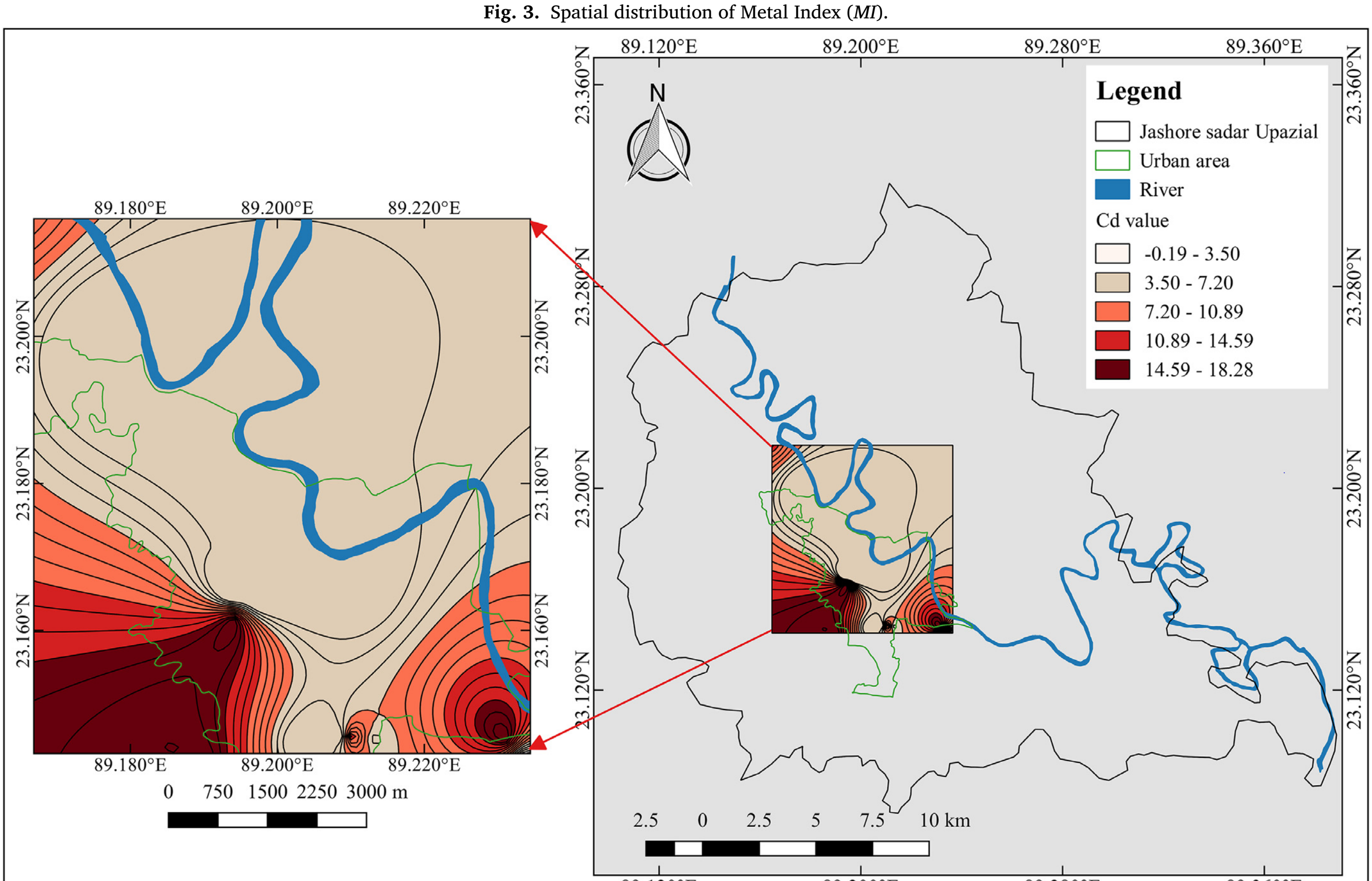

Fig. 4. Spatial distribution of Contamination Index (C_d).

ably due to vehicle emissions combined with a multitude of small-scale industry such as car workshops, vehicle cleaning facilities, bus, truck, and car terminals, auto CNG (compressed natural gas) stations situated beside the ponds. In general, heavy traffic and the transport sector probably have a significant impact on pond metal pollution (Adewoyin et al., 2013). Transport networks passing through environmentally sensitive areas can be considered as a potential pollution source (Yannopoulos et al., 2013). Thus, it can be concluded that the ponds of this area are seriously polluted by heavy metals, and this threatens the health of pond water users.

The spatial distribution of *Cd*, follows the same trend as for *MI*. Again, the south and south-eastern region of the area is most polluted and a high value in a north-western pond. In general, the central, north-west region, and small area of south reagion is associated with lower *Cd* (**Fig. 4**). Both *Cd* and *MI* include metal variables, and thus, should display a high similarity. Therefore, also contamination sources of this area, are similar as for the *MI* including both geogenic and anthropogenic sources. It is, however, expected that car emissions and vehicle washing waste contribute to the high metal pollution of affected ponds. Different types of pollution sources such as leachate from landfills, small industry wastewater and stormwater, and agricultural runoff contribute to the high metal pollution load and then *Cd*. Probably all these sources are contributing to the high metal contamination level (Zhao et al., 2017). It appears that the pollution indices increase with distance from the major river. This is probably due to that pond water has less ability to dilute the pollution as compared to the large river flow. Chemical fertilizers are widely used in modern agriculture, to improve crop yield. Nutrient leakage from agricultural soil into pond water causes eutrophication. High water temperature, oxygen concentration, basic pH, and hardness increases the heavy metal toxicity (Roosmini et al., 2010). Besides the pollution from industrial effluents, urban, and agricultural waste, may cause high levels of toxicity in some pond water (Samad et al., 2015).

6. Conclusions

The main objective of this study was to improve the knowledge on the pollution status of road-side pond water with the determination of physiochemical and toxicological parameters and representative water pollution indices. Thus, a geospatial analysis of pond water quality was performed with GIS software. Water quality indices and spatial analyses provided useful information for pond water quality assessment. The pH for the entire study area exceeded the maximum allowable WHO limit for health risk and other recommended standards.

Among the metals Cu, Cr, and Zn were within acceptable limits of DoE, WHO, DPHE, and USEPA standards for health risk but Zn exceeded the CCME standard set for fish and aquatic life. Water contents of Fe, Mn, Pb, and Cd were much higher than recommended standards of DoE, WHO, and DPHE. It is evident that many of the urban ponds are highly polluted by especially metals and this was confirmed by the *MI* and C_d indices that ponds in the entire study area are not suitable to use for domestic purposes and fish production. Health authorities are responsible to prohibit the use of the polluted water by residents and to limit further pollution release to the ponds.

This pioneering study in the investigated area should, thus, can be used to inform local authorities like managers and decisionmakers about the urgent needs to improve the water quality of the ponds used for fish production and different household activities. It is of paramount importance to develop adequate policies and concrete measures to control the pond water pollution. Reduction and removal of heavy metals are probably a priority to limit negative health effects. Techniques like phyto-remediation may be a possible way forward here. As well, traditional treatment techniques are necessary for water used domestic purpose and fish production. Furthermore, the results obtained in this study provide a useful reference for future monitoring programs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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