



SPATIAL DISTRIBUTION AND THE ASSESSMENT OF POND WATER SUITABILITY FOR AQUACULTURE IN THE SONADANGA AND KOTWALI THANAS OF KHULNA CITY CORPORATION

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Abstract

In Bangladesh, aquaculture has become an extensive practice, and over 12% of the population is involved in it. It is well-recognized that water quality determines the metabolic and physiological activities of fishes and negatively affects fish production. However, both groundwater and surface water resources in many places are affected by various pollutants. This research was conducted to assess the suitability of pond water for aquaculture in Sonadanga and Kotwali thanas in Khulna City Corporation Area of Bangladesh using spatial distribution. For doing this, samples from 23 fish cultivated ponds in those two thanas were collected for analyzing the basic physical and chemical parameters. Results revealed that only the pH of the ponds was in a favorable range (8.03 to 7.37) for aquaculture, but other water quality parameters like electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), calcium (Ca^{2+}), magnesium (Mg^{2+}), water hardness (WH), total iron (Fe^{2+} and Fe^{3+}), sodium (Na^+), chloride (Cl), bicarbonate (HCO_3^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), and sulfate (SO_4^{2-}) were present in excessive concentrations. The Pearson correlation among these parameters were found to be significant. Although, the water bodies in both thanas were unsuitable for fish farming, the Kotwali thana had more degraded ponds compared to the Sonadanga thana. It is recommended that the local administration should undertake necessary actions to improve the suitability of aquaculture and to conserve these water bodies in the area.

Keywords: Aquaculture; spatial distribution; Khulna City Corporation; pond water quality

Introduction

Water pollution is a common problem for fish farming in many parts of the world. Water bodies are polluted due to the haphazard dumping of the untreated industrial effluents from different industries and anthropogenic sources containing toxic pesticides, metals (Hatje *et al.*, 1998). Therefore, there is a crying need for monitoring of the water quality around the world. If the water resources could be protected from pollution, it would possibly help in sustaining the population of the world. Most of the water bodies are now disappeared because of pollution and encroachment (Yogendra and Puttiah, 2008). Fishes are quite sensitive to toxicity in water as their metabolic activities depend on the water quality of the ponds. Ignoring water quality parameters is a major cause for reducing the productivity in fishery industries, which in turn, leads to losses to the aquaculture industry of a country. Unfortunately, water quality is an overlooked aspect of pond

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management until it starts affecting fish production. Therefore, quality water, should be ensured for the growth and development of fish (Hu, 1995).

The fisheries sectors of Bangladesh play a major role in the socio-economic development as it contributes approximately 3.50% to the national Gross Domestic Product (GDP) and 25.72% to the agricultural GDP (BER, 2019), and more than 12% of the total population are directly or indirectly depends on aquaculture and fisheries for their livelihoods. Total production of fish in Bangladesh has increased by six times in last three decades. Freshwater fish farming has become an extensive practice in Bangladesh nowadays (Azim, *et al.*, 2012).

The fisheries resources in Bangladesh are categorized into marine fisheries and inland fisheries. Inland aquaculture covers around 4.71 million ha and has been subcategorized into two sub-sectors – inland culture and inland capture. Inland culture system covers 0.82 million ha and includes fisheries in ponds, ditches, baors, prawn farms, or seasonal cultured water bodies. On the other hand, inland capture covers 3.89 million ha and comprises estuaries, lakes, and rivers (DoF, 2019). Total area converge by ponds in Bangladesh has been increased by 1.54% in 2018-2019 compared to at in 2017-2018. The annual fish production of inland water bodies was highest in Chattogram Division (712643 metric tons) followed by the Khulna division (679838 metric tons) during the fiscal year 2018-2019 (DoF, 2019).

Good quality water is essential for higher fish production (Boyd and McNevin, 2015). Since the aquatic environment controls the health of the fishes, the water quality should be suitable for fish farming (Rahman, 1992). However, the surface water bodies in Bangladesh are being polluted in various ways (Islam *et al.*, 2009). Therefore, it is emphasized that the water quality of ponds should fit the requirements of the cultured fishes to ensure optimal growth. The aim of this study is to create spatial distribution maps of different water quality parameters and to assess the suitability of ponds for aquaculture in Sonadanga and Kotwali thanas of Khulna City Corporation.

Methodology

Study area and sample collection

This study was conducted in the Southern region of the Khulna City Corporation (KCC) area. The total population and the area of the KCC are respectively 770498 and 18889 sq. km. The city corporation consists of five thanas – i) Khan Jahan Ali, ii) Daulatpur, iii) Khalishpur, iv) Sonadanga, and v) Kotwali. Sonadanga and Kotwali thanas were selected as our study areas because these two areas have the highest population density of 26524 per km² and 20437 per km², respectively. Also, Sonadanga and Kotwali thanas are relatively developed and more industrialized than other thanas in the City Corporation Area. Water samples with three replications (two from the corners and one from the center) were collected from 23 fish cultivated ponds located in this locality during March (2019). The study area, along with central sampling points is shown in Figure 1. Very few of these ponds are used for fish farming where farmers cultivate native carps, like *Catla catla* and *Labeo rohita*, as well as exotic carps, like silver carp and grass carp. However, they did not follow any specific brands for feeding.

Plastic water bottles were prepared by rinsing with distilled water and HCL (1:1) for sterilization. At the sampling spots, the bottles were washed three times thoroughly by the pond water. Every sample was collected at the depth of 2 feet from the water surface. The bottle was filled with the sample water and capped tightly leaving no space for air to cause any transformation in the chemical compounds or biological activities. The temperature of the ponds located in the region was around 28±2 °C. Immediately after sampling, the presence of fecal coliforms was analyzed. After that, the samples were preserved in the refrigerator at 8°C for further analyses and to minimize biological activities.

Laboratory analyses

Total Dissolved Solids (TDS) and Total Suspended Solids (TSS): A specific amount (50 ml) of water sample was filtered using WN-42 filter paper and the filtered water was taken to a beaker. Both the filter paper and the beaker were oven-dried for 24 hours at 105^o. The weight of this filtered paper was subtracted from the blanked filter paper to achieve the TSS and the weight of the dried beaker was subtracted from an empty beaker to achieve TDS.

Acidity/Alkalinity (pH): The pH of the water samples was determined by using a pH meter (HANNA, pH 211).

Electrical Conductivity (EC): EC of the water samples was determined by using a conductivity meter (HANNA EC214).

Bicarbonates (HCO₃⁻): Bicarbonates were determined by the titrimetric method. (Jackson, 1973).

Chloride (Cl⁻): The chloride ions were determined by using the titrimetric method with standard AgNO₃ solution. (Jackson, 1973).

Nitrate (NO₃⁻): Nitrate content was determined by following the steam-distillation method (using Devarda's alloy). (Bremner and Keeney, 1965).

Phosphate (PO₄³⁻): The phosphate of the water samples was determined using the Vanadomolybdo phosphoric acid (yellow color) method with spectroscopy (APEL, PD-303 UV) (Jackson, 1967).

Sulfate (SO₄²⁻): The sulfate was determined by turbidimetric method with spectrophotometer (APEL, PD-303 UV) at 420 nm wavelength. (Hunt, 1980).

Calcium (Ca²⁺), Magnesium (Mg²⁺) and Water Hardness: Calcium and magnesium were determined by titrimetric method given by Schwarzenbach *et al.*, (1946). From the water samples, the calcium ions were determined first. To determine the magnesium content, calcium and magnesium were determined together and the value of calcium ion was subtracted from the value of calcium + magnesium. Water hardness of the water samples was determined by using the following equation (Eq. 1) (Freeze and Cherry, 1979):

$$\text{Water hardness} = 2.5 \times [\text{Ca}^{2+}] + 4.1 \times [\text{Mg}^{2+}] \quad (\text{Eq. 1})$$

Iron (Fe): Total iron content (both Fe²⁺ and Fe³⁺) of the water samples was determined by using hydroxyl amine hydrochloride (HAH) reducing agent and colorimetric method with spectrophotometer (APEL, PD-303 UV) at 510 nm wavelength.

Sodium (Na⁺): The sodium ions were determined by the flame photometer (JENWAY, PFP7).

Spatial Distribution

Spatial distribution is a technique that is used to predict the values at the unsampled locations from the sampled locations. There are two types of interpolation techniques – geostatistical and deterministic. Geostatistical techniques, such as Kriging, conduct a statistical analysis to predict the values of unknown sites, while deterministic technique, such as Inverse Distance Weighting (IDW), is a technique for multivariate interpolation using the known values to predict the unknown values. We used ArcGIS 10.4.1 to create spatial distribution maps of the study area by following IDW interpolation method.

Inverse Distance Weighting (IDW): IDW is a popular deterministic interpolation method for studying spatial variation. This method assumes that the connection and resemblance among several contiguous points is approximate to the gap between the points. The following equation (Eq. 2) is used in IDW to determine the value of an unknown point –

$$Z(x_0) = \frac{\sum_{i=1}^n \frac{z_i}{h_{ij}^p}}{\sum_{i=1}^n \frac{1}{h_{ij}^p}} \quad (\text{Eq. 2})$$

Here, $Z(x_i)$ is the predicted value of an unknown point, n is the value of the total sampling data, x_i is the data value at i th point, h_{ij} is the distance between sampled data and predicted value, and β is weighting power.

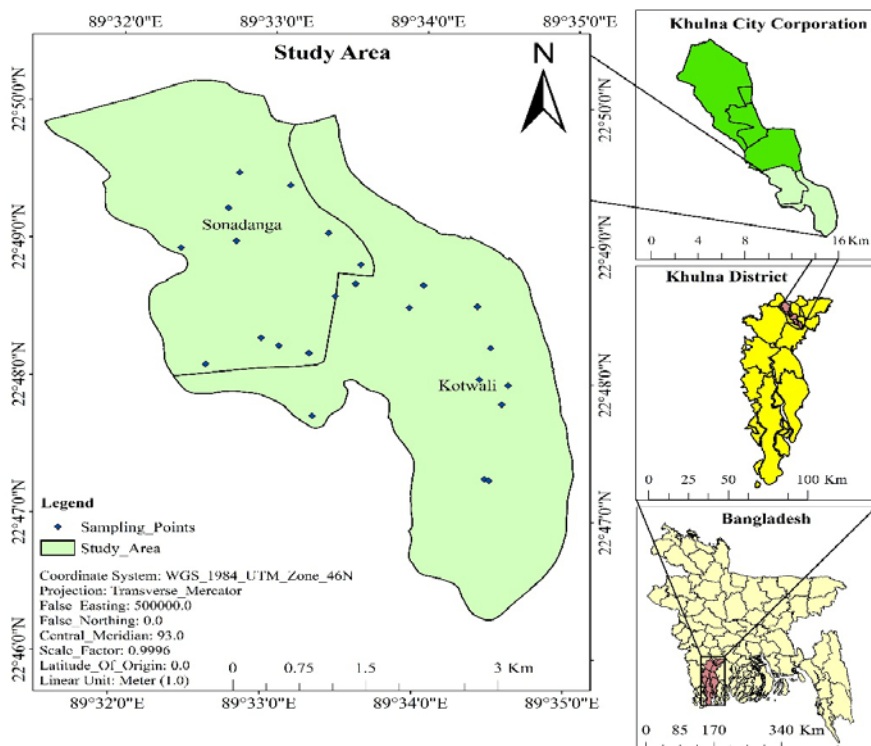


Figure 1. Study area and sampling points.

Results and Discussion

Spatial distribution of different water quality parameters of Sonadanga and Kotwali thanas in Khulna city corporation area is presented in Figure 2, Figure 3 and Figure 4. The pH of the water bodies ranges from 8.03 to 7.37 (Figure 2a), while the EC value is found between 1.3 dS/m and 0.3 dS/m (Figure 2b). The concentration of TSS and TDS of the study area ranges from 1600 mg/l to 400 mg/l (Figure 2c) and from 1696 mg/l to 400 mg/l (Figure 2d), respectively. Though the pH value indicates that the study area has a favorable pH range for growing a wide variety of fish species as the optimum pH range for aquaculture is 6.5 to 9 (Boyd *et al.*, 2016), EC is too high. TSS decreases the DO level of the water by absorbing more heat compared to the water molecules. The suspended particles then transfer the heat to the water molecules by conduction, which increases the temperature of the water, and warmer water bodies cannot hold the dissolved oxygen as effectively as the cold water bodies can do (Hickin, 1995). TDS increases the water density and decreases the solubility of gases.

The concentration of DO varies between 7 mg/l and 2 mg/l (Figure 2e). Different fish species have different DO requirements, and it changes with the activities and sizes of the fishes (Mallya 2007). For instance, the optimum DO requirement for Channel Catfish is 3 mg/l, but it falls below 1 mg/l for Tilapia fish (Boyd and Hanson, 2010). Fishes grow best when the concentration of DO is above 5 mg/l, and as the level of DO falls below 5 mg/l, the fishes start compensating for the reduced DO status through a series of physiological and behavioral changes, and < 1 mg/l level can be lethal (Swingle, 1969).

In the study area, the calcium (Figure 2f) and magnesium (Figure 3a) concentrations ranged from 460 mg/l to 80 mg/l and 263 mg/l to 0.02 mg/l, respectively, and the water hardness (Figure 3b) was found between 2226 mg/l and 299 mg/l. Luo *et al.*, (2016) and Alavi and Cosson (2006) found that total hardness of >480 mg/l has an adverse effect on the fertilization of certain fish species by inhibiting sperm mobility. Also, larval abnormality has been observed in African catfish when the hardness level exceeds 200 mg/l (Spade and Bristow, 1999). A higher concentration of calcium and magnesium can also cause low fertilization (Lahnsteiner, 2014).

Total Fe concentration of the study area was found between 9.1 mg/l and 0.79 mg/l (Figure 3c). Fe content can reduce production and interstitial space that may smother aquatic animals (USEPA, 1976). USEPA in 1976 set up a Fe criterion to protect aquatic lives and established a chronic value of 1 mg/l, which is underproductive of the sensitive fish species (Cadmus *et al.*, 2018). Following the similar methodology of USEPA (1976), Stephan *et al.* (1985) established another Fe criterion by using single-species toxicity and set the chronic value to 0.499 mg/l. However, Linton *et al.*, (2007) suggested that for the sensitive species, the chronic value should be reduced to 0.251 mg/l. According to the criterion, it can be stated that Fe concentration in our study area is very high for aquaculture.

Figure 3d and Figure 3e indicate the spatial distribution of Na⁺ and Cl⁻ in the study area, where the highest concentration of Na⁺ and Cl⁻ was 700 mg/l and 7998 mg/l and the lowest concentration was 175 mg/l and 806 mg/l, respectively. Chloride can burn the fish's gills and kill the nitrifying bacteria present in the water bodies. The toxicity of chloride depends on the fish species, temperature, duration of the exposure, and other conditions. El-Bouhy *et al.*, (2006) found that *Xiphophorus helleri* and *Cyprinus carpio* varieties exposed to respectively 1.375 mg/l and 2.4425 mg/l for 96 hours showed restlessness, abnormal swimming behavior, lower respiratory rate, congested gill tissues, fade coloration, etc.

Figure 3f represents the spatial distribution of HCO₃⁻ in the study area and reveals that the concentration of HCO₃⁻ ranged between 671 mg/l and 122 mg/l. NO₃⁻ is another nitrogenous compound that is toxic to the fishes even in a small concentration. Nitrate ranged between 98 mg/l and 39 mg/l (Figure 4a). High nitrate level leads to the rapid growth of unwanted lives and the reduction of dissolved oxygen. Fishes exposed to a higher nitrate concentration may have decreased hemoglobin concentration because nitrate converts hemoglobin into methemoglobin that reduces the transportation of oxygen in aquatic animals (Sampaio *et al.*, 2006).

Figure 4b and Figure 4c reveal the concentration (mg/l) of PO₄³⁻ and SO₄²⁻ in our study area. The highest value of PO₄³⁻ and SO₄²⁻ was found 176 mg/l and 51 mg/l, while the lowest value was 137 mg/l and 24 mg/l, correspondingly. Although phosphate doesn't have any direct toxic effects on fish species, it can degrade the water quality of an aquatic ecosystem by causing eutrophication, which reduces dissolved oxygen in the water and causes aquatic organisms to die (Kim *et al.*, 2013). On the other hand, SO₄²⁻ showed a negative correlation with pH and a positive correlation with TDS. Higher concentration of sulfate can be toxic to the freshwater aquatic lives. The province of British Columbia demonstrated the sulfate value of 100 mg/l for the protection of aquatic lives in freshwater. Sulfate toxicity is, however, dependent on the water hardness as the toxicity decreases with the increase in water hardness (Elphick *et al.*, 2011). In our research, we found that the pond water had a high value of water hardness (minimum 299 mg/l). Therefore, we can assume that the sulfate concentration in the study area does not pose a threat to fish farming.

Land use systems and human activities are mainly responsible for causing pollution to the surface and subsurface water bodies. Each of the studied ponds was located near different land use patterns (e.g. industries, schools, settlements, agricultural lands, restaurants. etc.). The predicted interpolation maps indicated the region where water pollution was high. This study revealed that the water bodies located in relatively industrialized areas (e.g. north and southwest of Sonadanga thana and east of Kotwali thana) were more polluted than less developed areas (e.g. south of Kotwali thana).

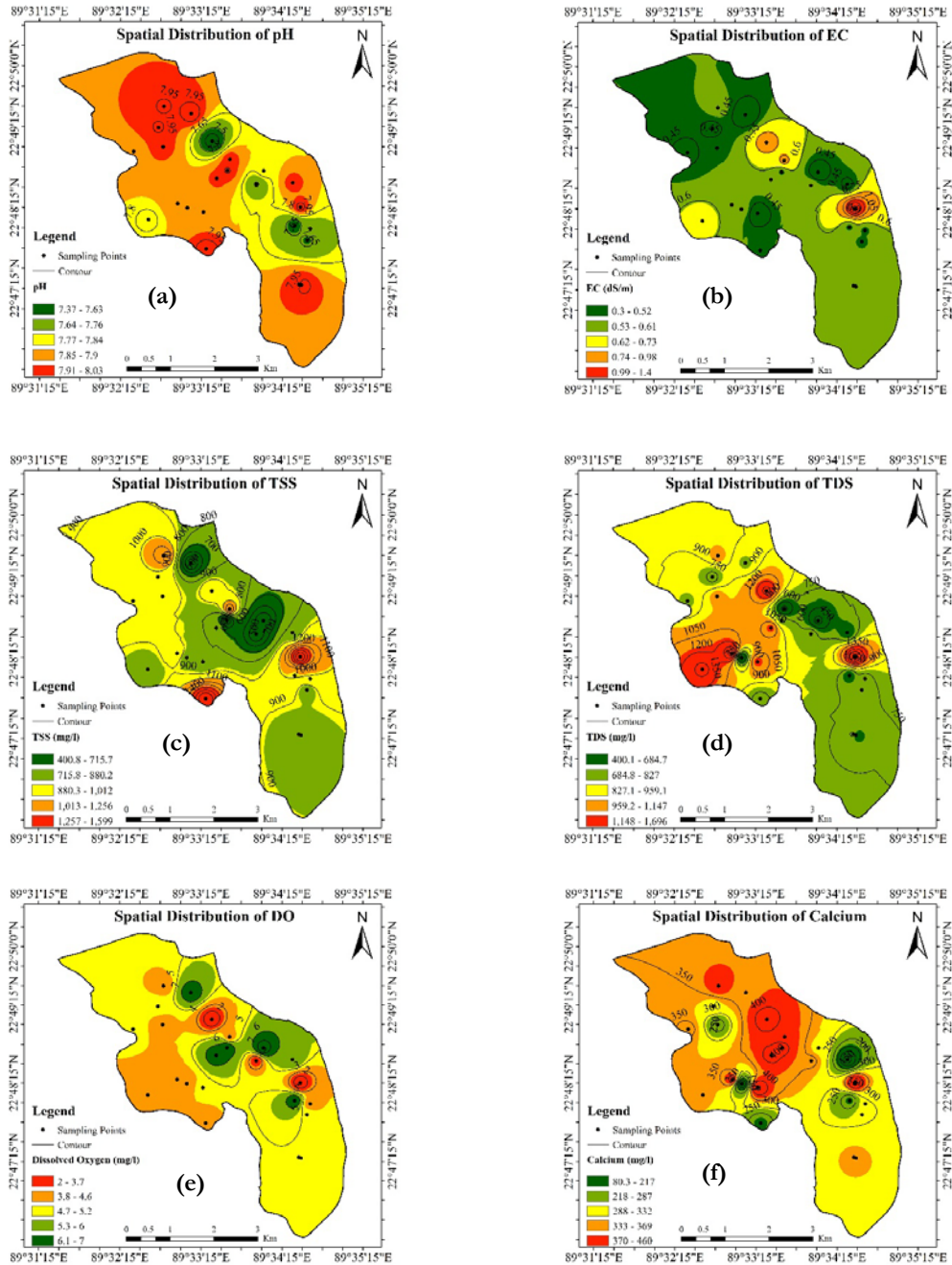


Figure 2. Spatial distribution of a) pH, b) Electrical conductivity (EC), c) Total suspended solids (TSS), d) Total dissolved solids (TDS), e) Dissolved oxygen (DO), and f) Calcium (Ca) in Sonadanga and Kotwali Thanas in Khulna city corporation

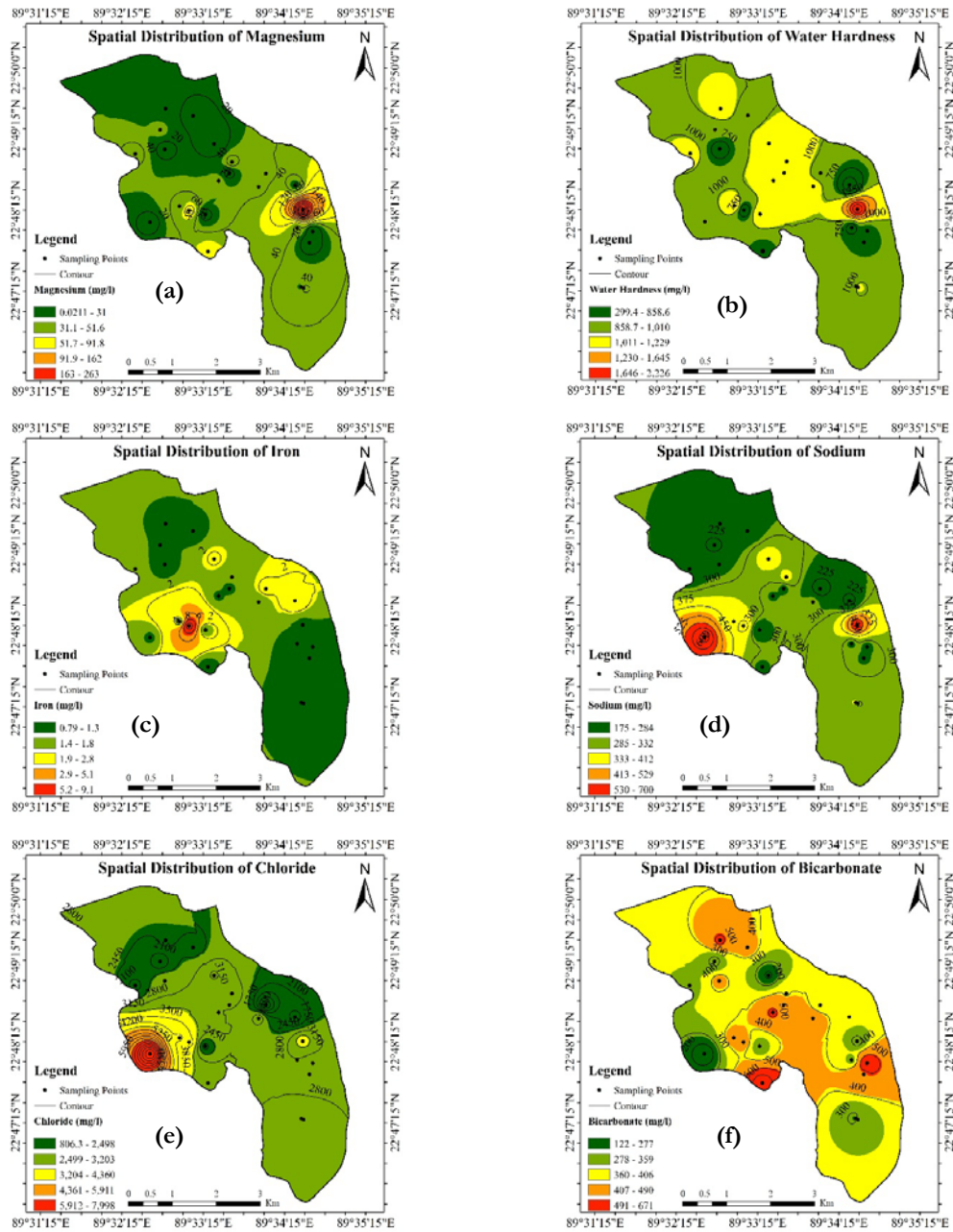


Figure 3. Spatial distribution of a) Magnesium (Mg), b) Water Hardness (WH), c) Iron (Fe), d) Sodium (Na), e) Chloride (Cl), and f) Bicarbonate (HCO₃⁻) in Sonadanga and Kotwali Thanas in Khulna city corporation

The correlation matrix (Figure 5) reveals that pH was negatively correlated with sulfate ($p < 0.001$) and nitrate ($p < 0.001$), and nitrate and sulfate had a significant correlation at $p < 0.01$ with each other. EC was positively correlated with TSS ($p < 0.01$), TDS ($p < 0.01$), Mg ($p < 0.001$), water hardness ($p < 0.001$), Na ($p < 0.001$), and Cl ($p < 0.05$), but negatively correlated with DO ($p < 0.001$). DO also showed a negative correlation with TSS ($p < 0.01$) and TDS ($p < 0.05$). Water hardness, which is considered an important factor for aquaculture, had a positive correlation with calcium ($p < 0.001$), magnesium ($p < 0.001$), sodium ($p < 0.05$) and TDS ($p < 0.01$). Sodium also showed a positive correlation with Cl ($p < 0.001$), Mg ($p < 0.05$), and TDS ($p < 0.01$) and negative correlation with DO ($p < 0.01$) and bicarbonate ($p < 0.05$).

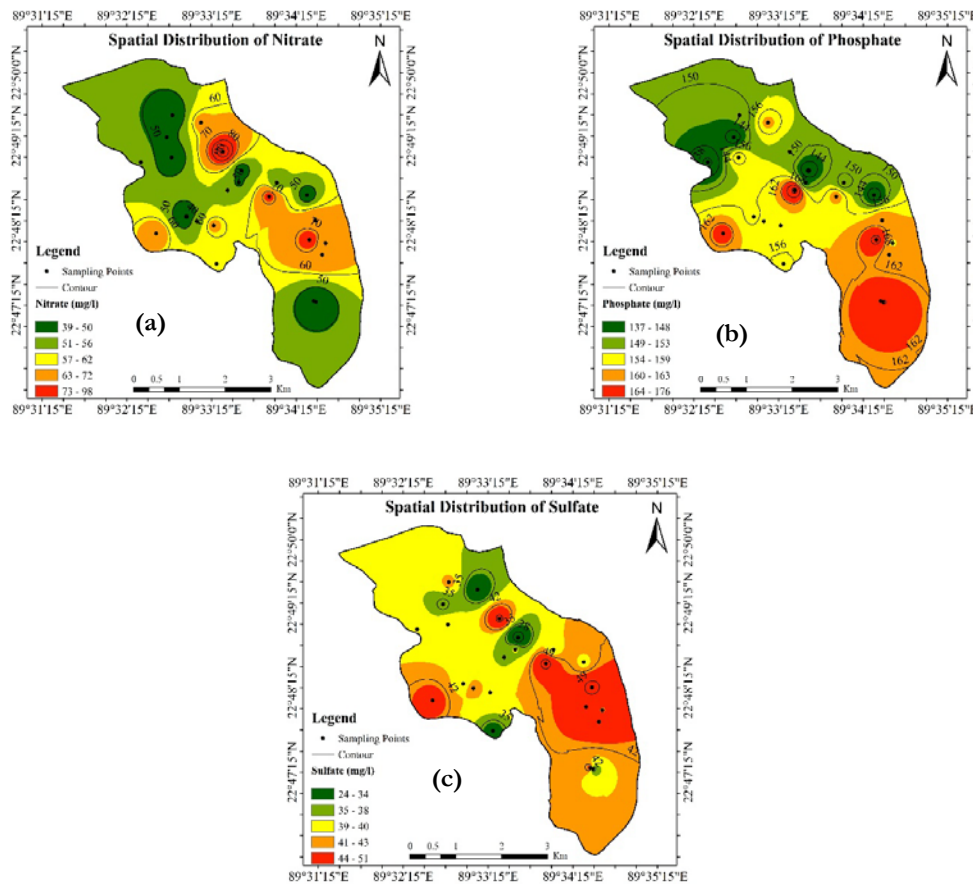


Figure 4. Spatial distribution of a) Nitrate (NO_3^-), b) Phosphate (PO_4^{3-}), and c) Sulfate (SO_4^{2-}) in Sonadanga and Kotwali Thanas in Khulna city corporation.

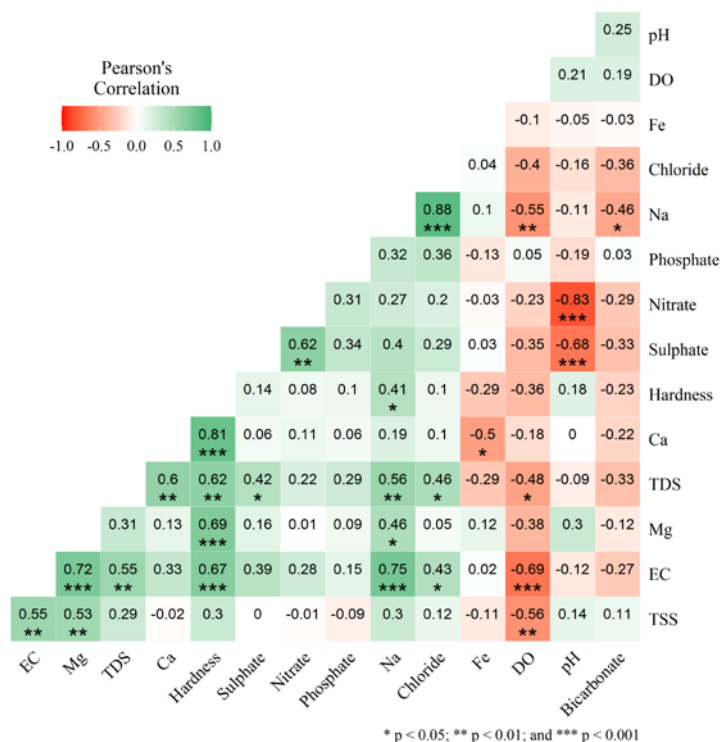


Figure 5. Pearson correlation matrix of different water quality parameters.

Conclusion

Bangladesh has huge water resources by nature, but these resources are being continuously polluted by human activities. Most of the ponds in urban areas are either polluted or filled up for settlements or industrialization. The study indicated that the ponds located in the comparatively developed thanas (Sonadanga and Kotwali) of Khulna City Corporation area were not suitable for fish farming because most of the water quality parameters, except pH and sulfate, were not in a favorable range for fish cultivation. We recommend that actions should be taken to improve the water quality of the ponds located in the study area not only for socio-economic benefits and fish production but also for conserving the water bodies to ensure better environmental health.

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