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GIS-Based Modelling of Water Quality in Different Hilsha Spawning Grounds and Sanctuaries of Bangladesh

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Authors' contributions

This work was carried out in collaboration between both authors. Author RY designed the study, managed the literature searches, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Author MI helped in data acquisition and managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

The current study was performed to monitor in situ condition and spatio-temporal modelling of the present status of water quality parameters of different spawning grounds and sanctuaries of Hilsha. The study was conducted in nine sites in lower Padma River (Maowa) to lower Meghna River (Bhola, Patuakhali) from 1 August 2015 to 31 January 2016. This study demonstrates surface water temperature, salinity, conductivity and transparency were ranged from 19.00-33.00°C, 0.10-2.90 ppt, 125.60-4720.00 µS/cm and 6.60-74.00 cm respectively. The values of pH, DO, free CO_2, total alkalinity, total hardness and free NH_3 were varied from 6.00-9.50, 4.50-11.60 mg/L, 3.46-24.00 mg/L, 33.00-172.50 mg/L, 34.20-1291.00 mg/L and 0.20-1.40 mg/L respectively. Moreover, water quality model reveals that the present status of some water quality parameters (free CO_2, free NH_3, transparency) deviated from optimum condition suitable for the normal physiological process and spawning of Hilsha.

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Keywords: Bangladesh; water quality; GIS; Hilsha; spawning grounds; sanctuaries.

1. INTRODUCTION

The only flagship fish species of Bangladesh, *Tenualosa ilisha*, the Padma River shad is the foremost and most important single species fishery of Bangladesh which is plentiful in virtually most of the river systems, estuaries and the sea, contributing about 12% of the total fish production and 50% of the total marine catch of the country. Its contribution to the GDP is 1% [1]. The average annual production of Hilsha is around 0.313 million tons, worth TK. (TAKA) 70,000 million [1]. At present, 50-60% of global Hilsha catch is reported from Bangladesh [1]. Hilsha spawns throughout the year, commencing from the upstream to the seashore [2]. The crowning spawning period is considered as the month of September and October and the month of January and February [3]. The lower expenses and estuarine portion of the meghna river, (1) kalirchar island (down of sandwip), (2) moulavirchar (south of hatia), (3) surrounding of monpura island (east of bhola) and (4) dhalchar island (charfashion, bhola) were found as the most noteworthy areas of hilsha spawning [4,5,6].

On the other hand, Juvenile Hilsha (jatka) is very common in virtually all of the focal rivers. But, The Meghna river from Shatnol (Gazaria/Munshiganj) in the upper expanses throughout the Nilkamol of Chandpur in the lower expanses which is stretched to Char Alexander of Luxmipur along with Andharmanik river are documented as major nursery grounds [6,7]. In recent times, the pollution of the upper Meghna and its distributaries are attaining a damaging action [8]. This pollution will also affect the lower part and distributaries of this river and additionally diminishing the production of Hilsha [8]. Afterwards, it is mandatory to study in a larger extent to determine the magnitude of this pollution on Hilsha stock and receive apposite management tactic to mitigate it. There is a probability of an enormous devastation of Hilsha stock in the forthcoming future, if we do not receive any satisfactory actions to regulate this pollution earlier. Nevertheless, there is a dearth of pertinent water quality inspection, water quality data, a basic database of water quality and a water quality model about different Hilsha spawning grounds and sanctuaries but production of Hilsha mostly depends on water quality. As water quality modelling is very complex and become problematic through other traditional means. So, GIS (Geographic Information System) have the benefit over time, and cost effectiveness as it assists in accomplishing an additional inclusive and unified approach of water quality modelling. In Bangladesh, it is a fact that geographic information system (GIS) is essential and the decision makers at the national/regional levels are paying awareness to obtain the expertise [9]. GIS as a tool for Hilsha fisheries management needs a better management technique to ensure the sustainability of the Hilsha stock.

Therefore, the main purpose of the present study was to monitor and provide thematic information and baseline data model of present surface water quality status of different hilsha spawning grounds and sanctuaries of bangladesh for the sustainable and better management of hilsha fisheries.

2. MATERIALS AND METHODS

2.1 Study Area

The study was accomplished at nine sites (1,2,3,4,5,6,7,8,9) of different spawning grounds and sanctuaries of Hilsha from the lower Padma (Lauhajang) to lower Meghna (Tajumuddin) of Bangladesh (Fig. 2). It was stretched from 23.525° N - 90.174° E to 21.841° N - 90.259° E and 22.591°N - 91.294°E (Fig. 1).

2.2 Water Sample Analysis

Primary data about water quality were derived directly from an onsite experiment in field and laboratory analysis. For assessing the water quality, Temperature, Electrical Conductivity, Salinity, pH, Transparency, Dissolved Oxygen & Free Carbon-di oxide was assessed onsite while Hardness, Alkalinity and Ammonia were analysed later in the laboratory.

2.2.1 Sample collection and preservation

About three samples of water were collected from each sampling station during August 2015 for monsoon, peak Hilsha spawning period (when the catch of Hilsha was banned from 25 August to 9 October 2015) and January 2016 for winter sampling to compare the water quality of peak spawning period to monsoon and winter. Only the surface water was sampled with a previously washed plastic tub and 500 mL

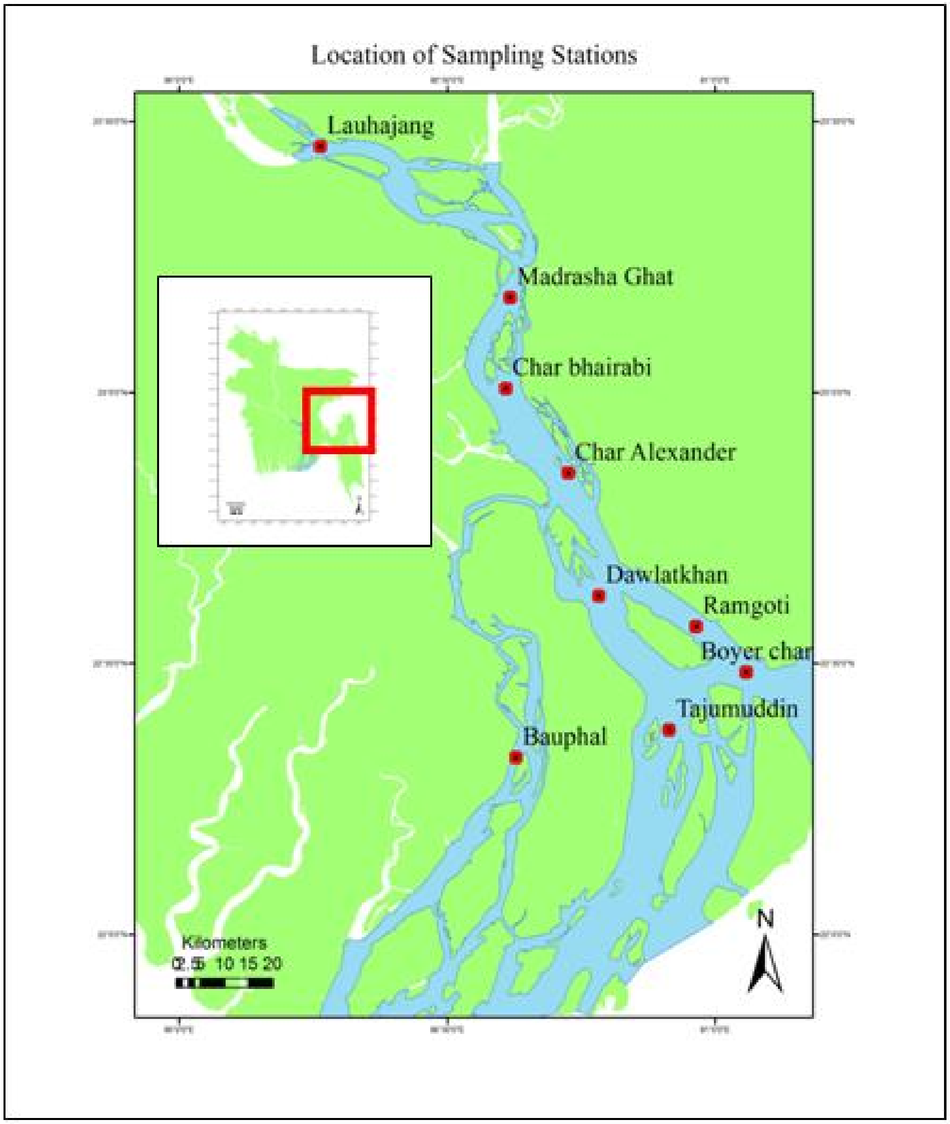


Fig. 1. Location of sampling stations

acid-washed polyethene sample bottles and then filtered using a membrane with 0.45 µm. Collected water sample was preserved for laboratory analysis as suggested by Chattopadhyay [10] and Khondker [11].

2.2.2 Water quality analysis

The measurement of temperature, salinity and Electrical Conductivity of water was carried out by conductivity meter (YSI 30 Salinity Conductivity Temperature); pH with pH meter (EcoSense® pH100, YSI Inc.); Dissolved Oxygen with DO meter (EcoSense® DO200, YSI Inc.); Transparency with the help of Secchi Disk visibility. Titration method with 0.02 N H_2SO_4 was used to determine the total alkalinity of sample water, and the determination of hardness of sample water was carried out by a complexometric titration method with ethylene diamine tetraacetic acid (EDTA) as suggested by Chattopadhyay [10]. For determining, the NH_4-N, method described by Khondker [11] using spectrophotometer (Digital UV Spectrophotometer, Labtronocs). For titrimetric determination of free carbon-di-oxide of water 0.045 N Na_2CO_3 were used to titrate as described by APHA [12].

2.3 GIS Analysis

Satellite image and the Historical map was georeferenced. GPS (eTrex Legend H, GARMIN) based field survey was carried out through the study area. Values of water quality parameters (Temperature, Electrical Conductivity, Salinity, pH, Transparency, Dissolved Oxygen (DO), Free Carbon-dioxide, Hardness, Alkalinity, Ammonia) used for GIS modelling by Arc GIS (V 10.0.0) developed by ESRI Inc., USA.

3. RESULTS AND DISCUSSION

The national fish of Bangladesh, Hilsha is anadromous, and the development of Hilsha is habitually dependent on the physicochemical characteristics of its habitat (both spawning and nursery grounds) such as temperature, DO, Free carbon dioxide, pH, alkalinity, hardness, transparency etc. Habitats of Hilsha [8] display an extensive array of inconsistency in its physicochemical characteristics concerning the alteration of seasons. As the greatest abundance of gravid Hilsha is observed in Peak spawning period nonetheless the young are originated commonly in winter [8].

3.1 Distribution of Water Characteristics

Surface water temperature was recorded 29.1-33.30°C, 29.01-32.00°C, 19.00-28.00°C from the lower part of Meghna River and 28.00-31.01°C, 27.00-30.20°C, 19.0-21.11°C in lower Padma River with 28.0-33.3°C, 27.00-32.00°C, 19.00-28.00°C seasonal range during monsoon, peak spawning period and winter respectively (Fig. 2.i). Fluctuation of surface water temperature was high in winter (19.00-27.90°C) and low in peak spawning period (27.00-32.00°C). Overall, seasonal fluctuation of surface water temperature was high in Tajumuddin (20.50-33.00°C) and low in Dawlatkhan (27.90-31.50°C) with an overall lowest value near Maowa and highest value in the southern part of the river during the study period. The overall temperature was excellent and more or less similar to the previous studies [3] and more or less similar to the criteria for most of the sub-tropical species (short-term maximum 32.2°C and maximum true daily mean 29.4°C) as described by USEPA [13] but near Bhola it was very high than the other parts of the study area in winter. So, it can be predicted that the range is still now suitable for spawning of Hilsha.

4.50-10.00 mg/L, 5.00-8.12 mg/L, 4.57-11.60 mg/L surface dissolved oxygen concentration were recorded from the lower part of Meghna River and 6.37-7.19 mg/L, 6.17-7.37 mg/L, 7.06-9.89 mg/L in lower Padma River with 4.50-10.00 mg/L, 5.00-8.46 mg/L, 4.57-11.60 mg/L seasonal range during monsoon, peak spawning period, winter (Fig. 2. ii). Fluctuation of surface dissolved oxygen concentration was high in winter (4.57-11.60 mg/L) and low in peak spawning period (5.00-8.12 mg/L). Overall, seasonal fluctuation of surface dissolved oxygen was high in Bauphal (6.00-11.6 mg/L) and low in Ramgati (4.50-5.50 mg/L) with an overall lowest value near Noakhali and Vola and high near Maowa during the study period. The overall DO was excellent and within a suitable range for most of the fishes (> 5 mg/L) as described by Swingle [14] and Lawson [15] and it can be predicted that the range is still now favourable for spawning of Hilsha.

pH was more or less similar through all of the sampling stations in monsoon, peak spawning period of Hilsha and winter. From this study it is revealed that pH varies 6.10-8.00 6.10-8.00, 6.00-9.50, 8.00-9.00 surface water pH was recorded from the lower part of Meghna River and 7.53-8.00, 7.42-8.10, 8.57-9.00 in lower Padma River with 6.10-8.00, 6.00-9.5, 8.00-9.00 seasonal range during monsoon, peak spawning period, winter (Fig. 2. iii). Fluctuation of surface water pH was high in peak spawning period (6.00-9.50) and low in winter (8.00-9.00). Overall, seasonal fluctuation of surface water pH was high in Char Alexander (6.00-8.00) and low in Tajumuddin (7.30-8.00) but there was no fluctuation of surface water pH in Madrasha Ghat with overall high value near Maowa during the study period with an average 7.23±0.24, 6.00-9.50 with an average 7.82±0.35, 8.00-9.00 with an average 8.33±0.14 in monsoon, peak spawning period of Hilsha and winter respectively. The overall pH was excellent and within suitable range for most of the fishes (6.5-9) as described by Lawson [15] and most of the freshwater aquatic life (6.5-8.5) and more or less similar to the criteria for most of the marine aquatic life (6.5-8.5) as described by USEPA [13] and it can be predicted that the range is still now appropriate for spawning of Hilsha.

Uniform surface water salinity (0.10 ppt) were recorded during monsoon, peak spawning period but 0.10-2.90 ppt was recorded from the lower part of Meghna River and 0.10-0.76 ppt in lower Padma River with 0.10-2.90 ppt seasonal range during winter (Fig. 3. i). Fluctuation of surface water salinity was recorded in winter. Overall, seasonal fluctuation of surface water salinity was low in Ramgati (0.10-1.10 ppt) and high in Station Boyer Char (0.10-2.90 ppt) but there was no seasonal fluctuation of surface water salinity in Lauhajang, Madrasha Ghat, Char Bhairabi and Bauphal (0.10 ppt) during the study period.

6.61-48 cm, 11.25-35.00 cm, 7.00-74.00 cm transparency were recorded from the lower part of Meghna River and 6.61-28.36 cm, 11.25-21.49 cm, 23.03-46.15 cm in lower Padma River with 6.61-48.00 cm, 11.25-35.00 cm, 7.00-74.00 cm seasonal range during monsoon, peak spawning period, winter (Fig. 3. ii). The fluctuation was high in winter (7.00-74.00 cm) and low in peak spawning period (11.25-35.00 cm). Overall, seasonal fluctuation of transparency was high in Madrasha Ghat (35.00-74.00 cm) and low in Ramgati (10.00-12.00 cm) with lowest value near Maowa and southern part of the river and highest near Chandpur during 6.55-19.80 mg/L, 5.91-18.20 mg/L, 3.47-24.00 mg/L free CO_2 concentration of surface water were recorded from the lower part of Meghna River and 11.23-19.80 mg/L, 10.74-18.20 mg/L, 3.47- 7.98 mg/L in lower Padma River with 6.55-19.8 mg/L, 5.91-18.20 mg/L, 3.47-24 mg/L seasonal range during monsoon, peak spawning period, winter (Fig. 3. iii). Fluctuation of the free CO_2 concentration of surface water was high in winter (3.46-24.00 mg/L) and low in peak spawning period (5.90-18.20 mg/L). Overall, seasonal fluctuation of the free CO_2 concentration of surface water was high in Lauhajang (3.96-16.60 mg/L) and low in Bauphal (15.40-18.20 mg/L) with an overall low value near Noakhali and high value near Lakshmipur, Vola and Patuakhali during the study period.

GIS analysis shows that distribution of salinity was uniform and similar in monsoon and peak spawning period (0.1 ppt). In winter, salinity was very low near Munshiganj (0.1 ppt) and successively increased towards the lower Meghna River (0.1-2.9 ppt). 0.0 ppt salinity of major Hilsha spawning grounds was observed by DOF [8] which is less than the salinity found over the period of the study. This study shows a good indication of salinity intrusion into the inland waters as well as Hilsha spawning grounds and sanctuaries which is crucial for the spawning and recruitment of Hilsha as it needs freshwater (0.00 ppt) for its spawning. But, it can be predicted that the range is still now apposite for spawning and recruitment of Hilsha as it is an anadromous fish.

33.00-65.00 mg/L, 36.00-76.00 mg/L, 93.01-172.5 mg/L total alkalinity of surface water were recorded from the lower part of Meghna River and 54.72- 65.00 mg/L, 55.62-67.53 mg/L, 109.22- 139.13 mg/L in lower Padma River with 33.00-65.00 mg/L, 36.00-76.00 mg/L, 93.01-172.48 mg/L seasonal range during monsoon, peak spawning period, winter (Fig. 4. i). Fluctuation of Total alkalinity of surface water was high in winter (93.00-172.50 mg/L) and low in monsoon (33.00-65.00 mg/L). Overall, seasonal fluctuation of total alkalinity of surface water was high in Char Bhairabi (40.0-172.5 mg/L) and low in Bauphal (61.0-93.0 mg/L) with overall highest alkalinity near Maowa during the study period. The overall total alkalinity was excellent and within suitable range for most of the fishes (30-150 mg/L) as described by Lawson [15] and higher than the minimum total alkalinity (>20) for most of the aquatic life as described by USEPA [13] and it can be predicted that the range is still now apposite for spawning of Hilsha but near Chandpur it was slightly higher than the suitable range in winter.

34.20-120.00 mg/L, 57.12-81.28 mg/L, 98.22-1291.00 mg/L total hardness of surface water were recorded from the lower part of Meghna River and 34.20-56.40 mg/L, 50.00-64.11 mg/L, 98.22-408.84 mg/L in lower Padma River with 34.20-120.00 mg/L, 50.00-81.28 mg/L, 98.22-1291.00 mg/L seasonal range during monsoon, peak spawning period, winter (Fig. 4. ii). Fluctuation of total hardness of surface water was high in winter (98.00-1291.00 mg/L) and low in peak spawning period (50.00-81.28 mg/L). Overall, seasonal fluctuation of total hardness of surface water was low in Bauphal (60.00-110.00 mg/L) and high in Tajumuddin (75.00-1291.00 mg/L) with an overall lowest value near Maowa and highest value in the southern part of the river during the study period. The overall total hardness was within the range in monsoon and peak spawning period of Hilsha which is the characteristics of most inland waters (5-200 mg/L) as described by Boyd [16] but high in some stations in winter. Though, it was higher than the suitable range in winter due to salinity intrusion but may not affect Hilsha as it is an anadromous fish. So, it can be predicted that the range is still now suitable for spawning of Hilsha.

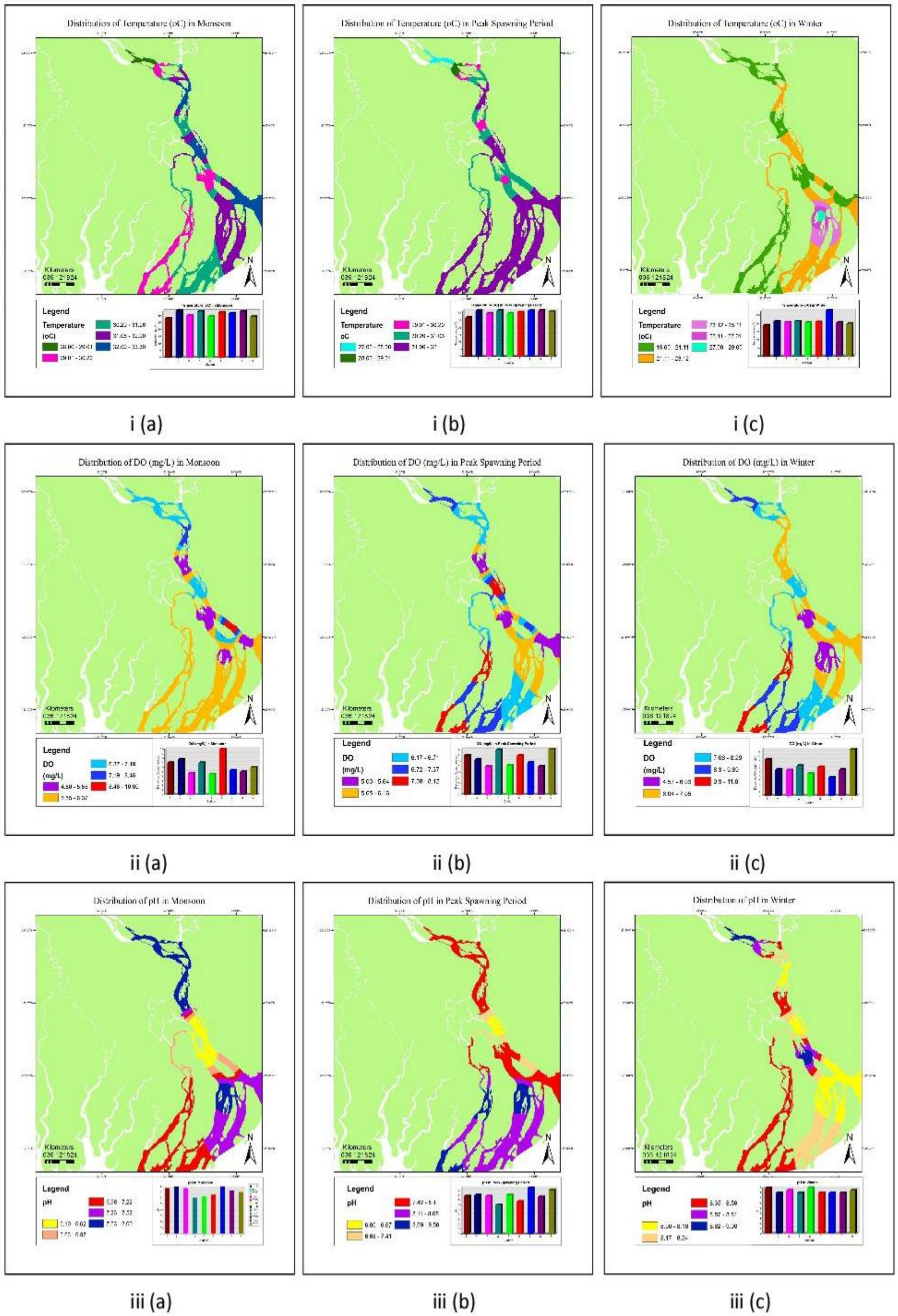


Fig. 2. Distribution of i) Temperature in a) Monsoon, b) Peak Spawning period, c) Winter; ii) DO in a) Monsoon, b) Peak Spawning period, c) Winter; iii) pH in a) Monsoon, b) Peak Spawning period, c) Winter; (August 2015 – January, 2016)

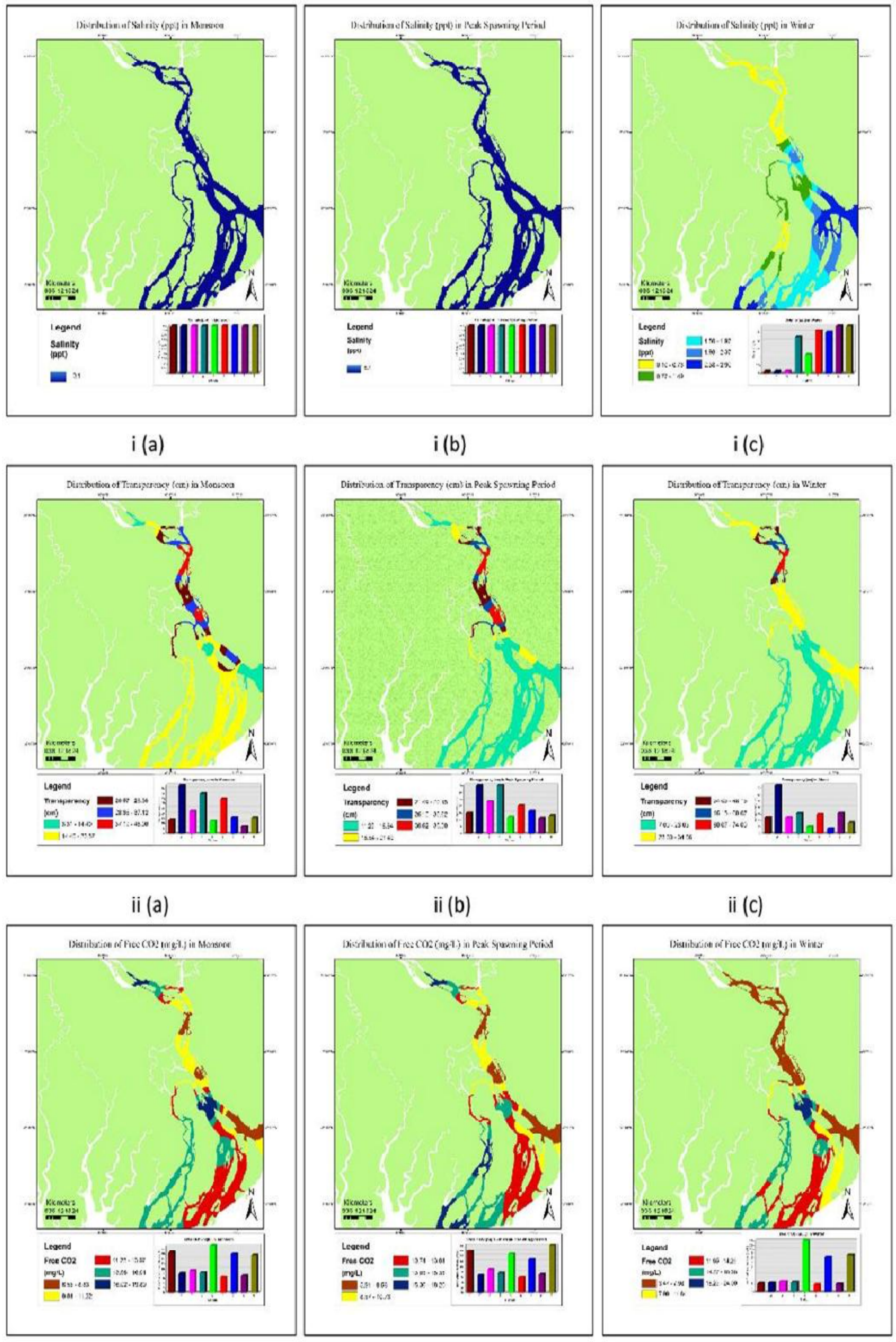


Fig. 3. Distribution of i) Salinity in a) Monsoon, b) Peak Spawning period, c) Winter; ii) Transparency in a) Monsoon, b) Peak Spawning period, c) Winter; iii) Free CO_2 in a) Monsoon, b) Peak Spawning period, c) Winter; (August, 2015 – January, 2016)

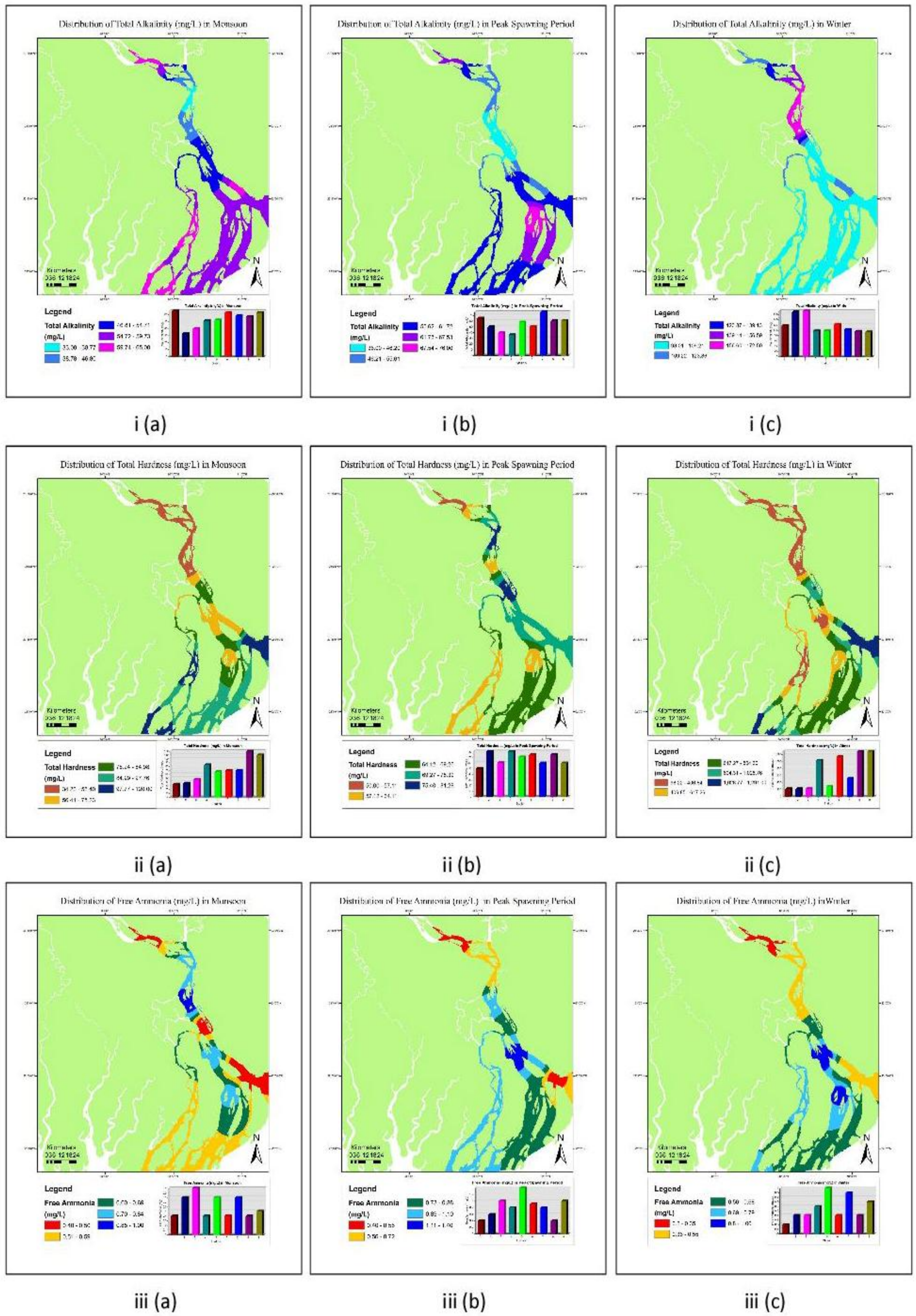
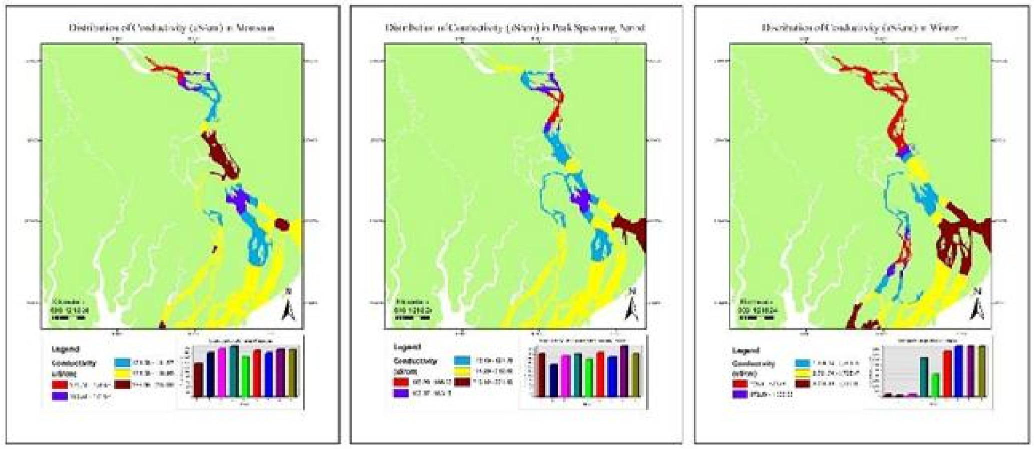


Fig. 4. Distribution of i) Total alkalinity in a) Monsoon, b) Peak Spawning period, c) Winter; ii) Total hardness in a) Monsoon, b) Peak Spawning period, c) Winter; iii) Free NH_3 in a) Monsoon, b) Peak Spawning period, c) Winter; (August 2015 – January 2016)



iii (a) iii (b) iii (c)

Fig. 5. Distribution of Conductivity in a) Monsoon, b) Peak Spawning period, c) Winter (August 2015 – January 2016)

153.48-204.00 µS/cm, 148.20- 234.00 µS/cm, 125.60-4720.00 µS/cm conductivity of surface water were recorded from the lower part of Meghna River and 135.10-171.57 µS/cm, 183.19-210.09 µS/cm, 125.60-972.28 µS/cm in lower Padma River with 135.10-204.00 µS/cm, 148.20-234.00 µS/cm, 125.60-4720.00 seasonal range during monsoon, peak spawning period, winter (Fig. 4. iii). Fluctuation of the conductivity of surface water was high in winter (125.60-4720.00 µS/cm) and low in peak spawning period (135.10-204.00 µS/cm). Overall, seasonal fluctuation of Conductivity of surface water was high in Dawlatkhan (176.50-4710.00 µS/cm) and low in Char Bhairabi (181.00-194.60 µS/cm) with an overall lowest value near Chandpur and highest in the south most of the river during the study period.

0.40-1.00 mg/L, 0.40-1.40 mg/L, 0.36-1.00 mg/L free ammonia concentration of surface water were recorded from the lower part of Meghna River and 0.40-0.69 mg/L, 0.40-0.72 mg/L, 0.2-0.55 mg/L in lower Padma River with 0.40-1.00 mg/L, 0.40-1.40 mg/L, 0.20-1.00 mg/L seasonal range during monsoon, peak spawning period, winter (Fig. 5). Fluctuation of free ammonia concentration of surface water was high in winter (0.20-1.00 mg/L) and low in peak spawning period (0.40-1.40 mg/L). Overall, seasonal fluctuation of free ammonia concentration of surface water was high in Char Bhairabi (0.4-1.0 mg/L) and low in Lauhajang (0.20-0.4 mg/L) and no seasonal fluctuation in Tajumuddin with overall lowest value in Maowa and high value in the lower part (south) of the river during the study period. Ammonia concentration recorded during this study was higher than the criteria (acute toxic concentration 0.083-4.60 mg/L and chronic toxic concentration 0.0017-0.612 mg/L for aquatic life) described by USEPA [13]. So, in consort with all other factors; it may correspondingly be blameable for the dwindling trend of Hilsha stock through affecting its physiological process and spawning.

So, the overall water temperature, pH, DO, total hardness, total alkalinity, salinity, conductivity of different Hilsha spawning grounds and sanctuaries is still now favourable for the physiological process and spawning of Hilsha and any alteration in water temperature of these areas due to global climate change may become stressful to Hilsha and may hamper its spawning and recruitment. Also, free CO_2, free ammonia, transparency may impede the physiological process, spawning and recruitment of Hilsha and along with other reasons; it may likely be responsible for the decrease in Hilsha stock.

4. CONCLUSION

This study demonstrates the contemporaneous in situ condition and GIS-based spatio-temporal monitoring of water quality of different Hilsha spawning grounds and sanctuaries which eventually depicts the variation of water quality in response to spatial and seasonal change. Existing overall condition of most of the water quality parameters i.e. temperature, pH, dissolved oxygen, total alkalinity, salinity, total hardness and conductivity are still now not reflecting much deviation from the congenial environment which is crucial for the regular physiological performances and spawning of Hilsha whereas there exists significant inconsistency in the present condition of few parameters (free carbon dioxide, free ammonia, transparency) which needs a great concern. In near future, as a consequence of water quality deterioration along with other climatological factors such as water flow change, decrease in depth of river, siltation etc. the physiological performance and spawning of Hilsha may hinder if proper management measures are not taken for the conservation, restoration and rehabilitation of those habitats otherwise production of Hilsha will gradually decrease. As a consequence, further researches on water flow rate and direction, siltation and current velocity, CPUE (Catch Per Unit Effort) is needed. Moreover, the findings of the present study are correspondingly revealing the practicality, effectiveness, convenience and modelling power of GIS for its usefulness and if reinforced by additional thematic and field survey, it can be practiced predominantly to improve the models in forthcoming future. GIS will quickly identify and categorize the quantity, extent, magnitude, range and condition of habitats at a scale valuable for highlighting regional safeguard or restoration effort. There is a substantial prospect for additional utilization of GIS in stock abundance, fishing mortality, biological and social impact analysis (management, fishing effort, fishing mortalities), catch density by location, gear, boat use, mesh regulation area, selection of areas for potential closure and mortality reduction, bycatch analysis modelling. Nevertheless, for instance, the exactitude of the result is entirely governed by the spatio-temporal quality of input data as a valid and georeferenced spatio-temporal data are obligatory. Moreover, the concurrent study also has established the practicality and effectiveness of GIS modelling to monitor and characterize the water quality for better management of Hilsha.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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