CAUSAL EFFECT OF HYDRO-ECOLOGICAL ATTRIBUTES ON SPATIO-TEMPORAL DISTRIBUTION OF ABIOTIC AND BIOTIC FACTORS OF MEGHNA RIVER BASIN (BANGLADESH)

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ABSTRACT

The Meghna River, vital for Bangladesh’s ecosystems and livelihoods, faces threats from urbanization, agriculture, industrialization, pollution, and climate change. This study examines the basin’s spatio-temporal dynamics, focusing on hydro-physico-chemical properties (temperature, pH, dissolved oxygen, salinity) and bio-resources (phytoplankton, zooplankton, and benthic macroinvertebrates). Field surveys, laboratory analyses, and satellite imagery revealed consistent patterns, highlighting the ecosystem’s vulnerability and the urgent need for conservation strategies to sustain ecological balance and livelihoods.

RÉSUMÉ: Effet causal des attributs hydro-écologiques sur la distribution spatio-temporelle des facteurs abiotiques et biotiques du bassin du fleuve Meghna (Bangladesh).

Le fleuve Meghna, crucial pour les écosystèmes et les moyens de subsistance du Bangladesh, est confronté par l’urbanisation, à l’agriculture, l’industrialisation, la pollution et au changement climatique. Cette étude examine la dynamique spatio-temporelle du bassin en se concentrant sur les propriétés hydro-physico-chimiques (température, pH, oxygène dissous, salinité) et les bio-ressources (phytoplancton, zooplancton, et macroinvertébrés benthiques). Les relevés de terrain, les analyses en laboratoire et l’imagerie satellite ont révélé des tendances cohérentes, soulignant la vulnérabilité de l’écosystème et la nécessité de stratégies de conservation pour maintenir l’équilibre écologique et les moyens de subsistance.

REZUMAT: Efectul cauzal al atributelor hidro-ecologice asupra distribuției spațio-temporale a factorilor abiotici și biotici din bazinul râului Meghna (Bangladeș).

Râul Meghna, crucial pentru ecosistemele și mijloacele de trai din Bangladeș, se confruntă cu amenințări tot mai mari din cauza urbanizării, agriculturii, industrializării, poluării și schimbărilor climatice. Acest studiu examinează dinamica spațio-temporală a bazinului Meghna, concentrându-se pe proprietățile hidro-fizico-chimice (temperatură, pH, oxigen dizolvat, salinitate) și bio-resurse (fitoplancton, zooplancton și macronevertebrate bentonice). Sondajele din teren, analizele de laborator și imaginile din satelit au relevat modele consistente evidențiind vulnerabilitatea ecosistemului și nevoia implementării unor strategii de conservare pentru a susține echilibrul ecologic și mijloacele de trai.

INTRODUCTION

The complex aquatic ecosystems of the world have a huge conservation and economic importance (Bănăduc et al., 2020; Melack, 2016; Sender and Maślanko, 2014; Liao and Huang, 2011; Sedeño-Diaz and López-López, 2009).

The Meghna River flows through Bangladesh. It is a lifeline and a life support system, which feeds the land, sustains millions of people's livelihoods, and hosts a complex system of biotic communities. Here in the region where the sedimentary waters of the river expand the green ambience of the countryside, a dynamic ecosystem unfolds. The Meghna River is one of the eastern Himalayan rivers and a major river of the Ganges-Brahmaputra-Meghna Delta, the largest deltaic system in the world. In the course of its meandering journey through Bangladesh the Meghna River both sculpts the terrain, creating wide, fertile alluvial plains, and sustains a diverse biome from its delta to its uplands. Its waters are critical supplying water and food to millions who depend on its resources. (Sultana et al., 2023)

However, this major complex of ecosystems are facing several key challenges. It is in threatened by pollution, deterioration of its physical environment, climate change, human interference, etc. This study seeks a better understanding of the Meghna River basin's dynamics to allow the planification of future conservation and management strategies and policies. Studying the Meghna River basin entails deciphering a puzzle of spatio-temporal distribution in the basin. The hydro-physico-chemical characteristics and bio resources create a very complex picture of this ecosystems mosaic. These patterns offer fundamental insights into the health status of the basin and help us guide sustainable management practices. The main hydro-physico-chemical features of the Meghna River have also been presented here, explaining the current state of the river, the ways the river has changed in response to different stressors, and the levels of these changes.

Recognizing characteristic attributes helps evaluate the river's state and make estimations about its future development (Miah et al., 2021). Key parameters such as water temperature, turbidity, dissolved oxygen, phosphate content, total dissolved solids alkalinity, carbon dioxide concentration, and salinity are all considered. These factors affect the aquatic life in addition to indicate the general environment status characteristics (Rabbani et al., 2018). The main bio resources of the Meghna River basin include phytoplankton, benthic macroinvertebrates, and fish. These are not just inhabitants but essential components of this complex group of ecosystems. The river water favors the growth of phytoplankton, which are the foundation of the aquatic food chain. Their abundance, composition and distribution give insights into the ecosystems. Similarly, all tissues are involved in maintaining the balance of an ecosystem, including zooplankton, rotifers, copepods, cladocerans and other aquatic organisms. Diverse and occupying a significant ecological position in the ecosystem, benthic macro-invertebrates inhabit silt at the river bottom. Given population density and species richness, their presence and abundance can reflect the conditions for the riverbed and indicate the general state of the environment (Sarker et al., 2020).

Literature on the causal effect of spatio-temporal distribution of abiotic-biotic factors on hydro-ecological attributes in the Meghna Basin is limited. A study conducted by the Bangladesh Water Development Board, Ministry of Water Resources (Mes, 2001), explored its spatial and temporal characteristics, its hydro-physico-chemical characteristics, and bio resources. It will thus become easier to ensure the Meghna River remains pristine areas conservation as a source of good livelihood. Analysis of all those parameters in the Meghna Basin is not only an academic exercise. This research has key implications for the region's future development. This research will provide understanding of appropriate management practices needed to support the conservation and utilization of the current resources.

MATERIAL AND METHODS

Data collection procedure

Primary data used in this study were satellite data for sampling site selection, GPS based field survey, hydro-physico-chemical attributes, plankton, and macro-benthic community. Secondary data includes different thematic information and other relevant published information.

Satellite data for sampling site selection

Sampling sites were selected by analyzing real-time satellite imagery from Google Earth Engine, 2021. Twenty sampling stations with three sub-stations were selected along the Meghna River basin, starting near Brahmanbaria and extending through the Shahbazpur channel following the main river course, downwards to the Meghna Estuary including Hatiya and Monpura islands (Tab. 1, Fig. 1). The distance between sampling sites was approximate 20 km and the distance between three consecutive sub-stations was approximate one km covering a total of three-km stretch in each sampling site, to represent the whole Meghna River basin from upper to lower Meghna.

Table 1. List of selected sampling stations.

Stations	Location name	District
S1	Singapore Jame Mosque (sub-station 1, 2, and 3)	Brahmanbaria
S2	Ashuganj Ferry Terminal (sub-station 1, 2, and 3)	
S3	Sahabnagor Bazar (sub-station 1, 2, and 3)	
S4	Nazarpur Natural Park (sub-station 1, 2, and 3)	Narsingdi
S5	Tidirchar (sub-station 1, 2, and 3)	Comilla
S6	Gazaria (sub-station 1, 2, and 3)	Munshiganj
S7	Ekhlashpur Launch Terminal (sub-station 1, 2, and 3)	Chandpur
S8	Horina Ferry Terminal (sub-station 1, 2, and 3)	
S9	Altaf Master Launch Ghat (sub-station 1, 2, and 3)	Laksmipur
S10	Motirhaat Machh Bazar (sub-station 1, 2, and 3)	
S11	Alexander New Launch Terminal (sub-station 1, 2, and 3)	
S12	Ruhulamin Market Masque (sub-station 1, 2, and 3)	Noakhali
S13	Sukh Char (sub-station 1, 2, and 3)	
S14	Sonadia (sub-station 1, 2, and 3)	
S15	Daulatkhan Launch Terminal (sub-station 1, 2, and 3)	Bhola
S16	Tajumuddin Launch Terminal (sub-station 1, 2, and 3)	
S17	Char Annadaprasad (sub-station 1, 2, and 3)	
S18	Char Kukri Mukri (sub-station 1, 2, and 3)	
S19	Monpura Launch Terminal (sub-station 1, 2, and 3)	
S20	Monpura Bangla Bazar (sub-station 1, 2, and 3)	

Figure 1: Location of the sampling stations.

Analysis of hydro-physico-chemical attributes

Primary data regarding hydro-physico-chemical properties were obtained through field experiments conducted on-site, followed by laboratory analysis. Temperature, electrical conductivity, salinity, pH, transparency, dissolved oxygen, TDS, and turbidity were measured on-site to evaluate the hydro-physico-chemical characteristics; subsequently analyses of free carbon dioxide, hardness, alkalinity, and ammonia were conducted in the laboratory (Water Quality Laboratory, Bangladesh Fisheries Research Institute, Riverine Station, Chandpur).

Collection of samples

Each sampling station yielded three subsamples of water. Using a 500 ml bottle and a previously cleaned plastic tube only the surface water was sampled.

Preservation of samples

Collected water samples were preserved for laboratory analysis through specific methods (Tab. 2).

Table 2: Use of preservatives in chemical analysis of water (Sarker et al., 2020).

Parameter	Preservative	Permissible time
Carbon-dioxide	Cooling at < 4°C	24 hrs
Alkalinity	Cooling at 4°C	24 hrs
Hardness	1 ml Conc. HNO3 L^{-1}	7 days
Ammonia	1 ml Conc. H_2SO_4 L^{-1}	7 days

Analysis of physico-chemical properties of water

The EC300A conductivity meter was used to measure the temperature, salinity, electrical conductivity, and total dissolved solids (TDS) in the water. The pH meter (EcoSense® pH100, YSI Inc.) was used to measure the pH level. The transparency of the water was determined using a Secchi disk. The Turbidity Meter (Portable) (Turb® 430 T WTW Germany) was used to test the turbidity of the water. As recommended by Sarker et al. (2020), the total alkalinity of the sample water was ascertained using the titration method with 0.02 N H_2SO_4. NH4-N was determined according to Sultana (2023) using a spectrophotometer (Digital UV Spectrophotometer, Labtronocs). According to Sarker et al. (2020), the complexometric titration method was used to determine the hardness of the sample water using ethylene diamine tetra acetic acid (EDTA). The water's dissolved oxygen content was measured using a DO meter (EcoSense® DO200, YSI Inc.). The titration method was used to measure free carbon dioxide. 0.045N Na_2CO_3 was used to titrate in accordance with APHA (1976), to determine free carbon dioxide in water.

Collection and identification of plankton

Plankton were collected at each sampling station by sieving 50 liters of water from about 10 to 12 cm below the surface, passing it through a 25 μm mesh net, and then condensing it to 25 ml. After the plankton population accumulated in the container, it was moved to another bottle, preserved in 4% formalin right away, labeled, and brought to the laboratory for additional testing. Before each sample was examined under a microscope, it was gently agitated. Using a wide mouth graduated pipette, one milliliter of the agitated sample was transferred to a Sedgewick Rafter counting cell. By counting the number of plankton per focus of the tiny field, the abundance of the organism was assessed.

The total number of plankton per litre of water was estimated using the following formula: $N = ((A*C)/L)$, where, A = Average number of plankton counted per ml concentrated sample, C = Volume of concentrated sample in ml, L = Volume of original water in litre passed through the plankton net, N = Total number of plankton/L of original water.

Collection and identification of macro-benthic community

The macro-benthos was collected from all sampling stations using the Ekman (15.2-by-15.2-cm cutting edge, 5.5 kg). The samples were processed following APHA (1976) standard procedures after being passed through a 0.595 mm sieve. With the exception of worms, which were classified by family, all organisms were recognized by genus or species.

Thematic information

Thematic data, including historical maps and other secondary data, were collected from Bangladesh Fisheries Research Institute, Department of Fisheries, Asiatic Society of Bangladesh, Bangladesh Water Development Board and Meteorological Department.

Post-hoc testing

This test was carried out after a statistical analysis where we have performed multiple significance tests. Post-hoc analysis is a way to adjust or 'reinterpret' results to account for the compounding uncertainty and risk of Type I error that is inherent in performing statistical tests.

RESULTS AND DISCUSSION

The study was designed for characterizing and performing spatio-temporal modelling of causal influences on niche resources using deterministic stressor modelling. For this study different primary and secondary data (hydro-physico-chemical attributes, riverbed attributes, data about bio-resource data, etc.) were collected and analyzed.

a) **Spatial distribution and fluctuation of hydro-physico-chemical attributes with bio resources**

Spatial fluctuation of hydro-physico-chemical attributes such as water colour (light greenish to blackish), depth (min. 5.65 m at Nazarpur and 60 m at Daulatkhan) water temperature (min. 18°C at Nazarpur and max. 32.87°C at Char Kukrimukri), pH (min. 7.20 at Nazarpur and max. 8.5 at Ashuganj), dissolved oxygen (min. 5.67 mg/L at Char Alexander and Tajumuddin, and max. 9.35 mg/L at Gazaria), free carbon dioxide (min. 6.27 mg/L at Ekhlaspur and max. 19.67 mg/L at Gazaria), alkalinity (min. 43 mg/L at Singapore Mosque (S.M.) and max. 124 mg/L at Char Kukrimukri), hardness (min. 58 mg/L at Shahebnagar and max. 257 mg/L at Char Annadaprasad), transparency (min. 35 cm at Tajumuddin and max. 113 cm at Singapore Mosque), salinity (min. 0 ppt from S. M. to Altaf Master Mach Ghat and max. 9.92 ppt at Sonadia), Turbidity (min. 1.89 FNU at Shahebnagar and max. 84.67 FNU at Motirhat), TDS (min. 62.33 ppm at S. M. and Nazarpur and max. 6,698.33 ppm at Char Kukrimukri), Conductivity (min. 144.33 µS/cm at S. M. and max. 9,826.67 µS/s at Char Kukrimukri) of sampling sites were monitored (Tab. 3, Figs. 1-2). All the hydro-physico-chemical parameters were found within acceptable ranges, although free carbon dioxide near Horina (18.02 mg/L), transparency near S. M. (111 cm), turbidity near Char Alexander (104 FNU) were found slightly high. Ammonia was detected only at Gazaria (0.35 mg/L) and Ashuganj (0.25 mg/L) only. Most attributes across all stations varied statistically (Fig. 7). Air temperature was positively associated with water temperature, DO, CO_2, NH_3 and plankton composition (Fig. 8). Among the three clusters, S2-S4, S8-S16, and S20 formed the biggest cluster with maximum similarity (Fig. 9). Among 16 driving factors, plankton and CPUE were found as a major driver factors, TDS and conductivity were secondary drivers (Fig. 10).

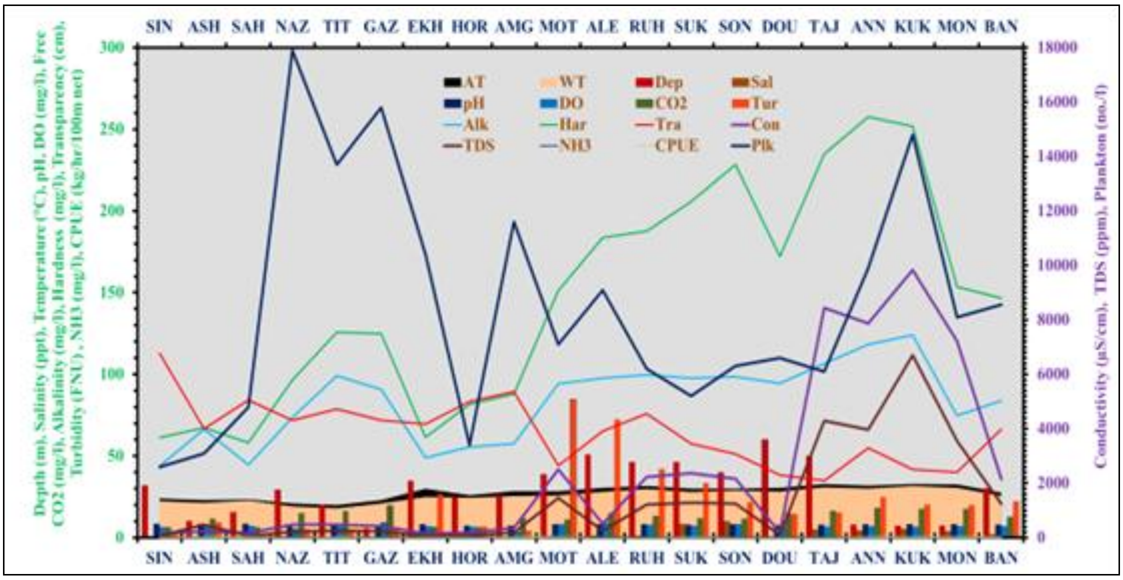


Figure 2: Spatial distribution and fluctuation of hydro-physico-chemical attributes along with bio resources.

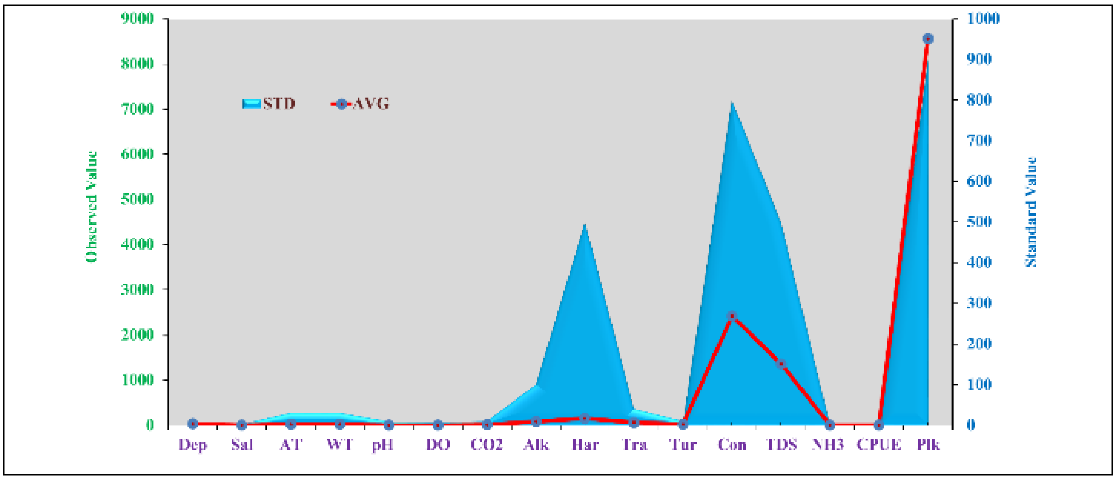


Figure 3: Contemporary distribution of hydro-physico-chemical attributes along with bio resources (in situ).

At every sampling station, the pH of the Meghna River's water was found to be within the range of 7.0 to 8.0, indicating a neutral or alkaline condition (Ahmed et al., 2005). Total alkalinity ranged from 48 to 98 mg/L, with mean values of 74.61 ± 11.37 mg/L, according to Hasan et al. (2015a). The concentrations of dissolved oxygen (DO) varied greatly, with mean values of 7.24 ± 1.03 mg/L and a range of 5.91 to 9.50 mg/L (Hasan et al., 2015a).

b) Temporal distribution and fluctuation of hydro-physico-chemical attributes with bio resources

Temporal fluctuation of hydro-physico-chemical attributes (Fig. 3) such as water colour (light greenish to blackish) water temperature (18-31.67°C, Avg. 25.88°C), pH (7.2-8.5, avg. 8.07), dissolved oxygen (5.67-9.35 mg/L, avg. 7.22 mg/L), free carbon dioxide (6.27-19.67 mg/L, avg. 13.11 mg/L), alkalinity (43.67-124 mg/L, avg. 64.91 mg/L), hardness (58-257.67 mg/L, avg. 146.98 mg/L), transparency (35-113 cm, avg. 60.46 cm), salinity (0-9.92 ppt, avg. 0.80 ppt), turbidity (1.89-84.87 FNU, avg. 22.07 FNU), TDS (62.33-6,698.33 ppm, avg. 1,356.65 ppm), conductivity (144.33-9,826.67 µS/cm, avg. 2417.58 µS/s) and ammonia (0-0.42 mg/L, avg. 0.04 mg/L) of sampling sites were monitored (Fig. 4 (A-D)). All the physico-chemical parameters were found within acceptable ranges, although free carbon dioxide, transparency and turbidity were slightly elevated throughout the winter season (Tab. 3). Ammonia was detected only at Gazaria and Ashuganj during winter. Most of the attributes of all stations differed statistically (Fig. 7).

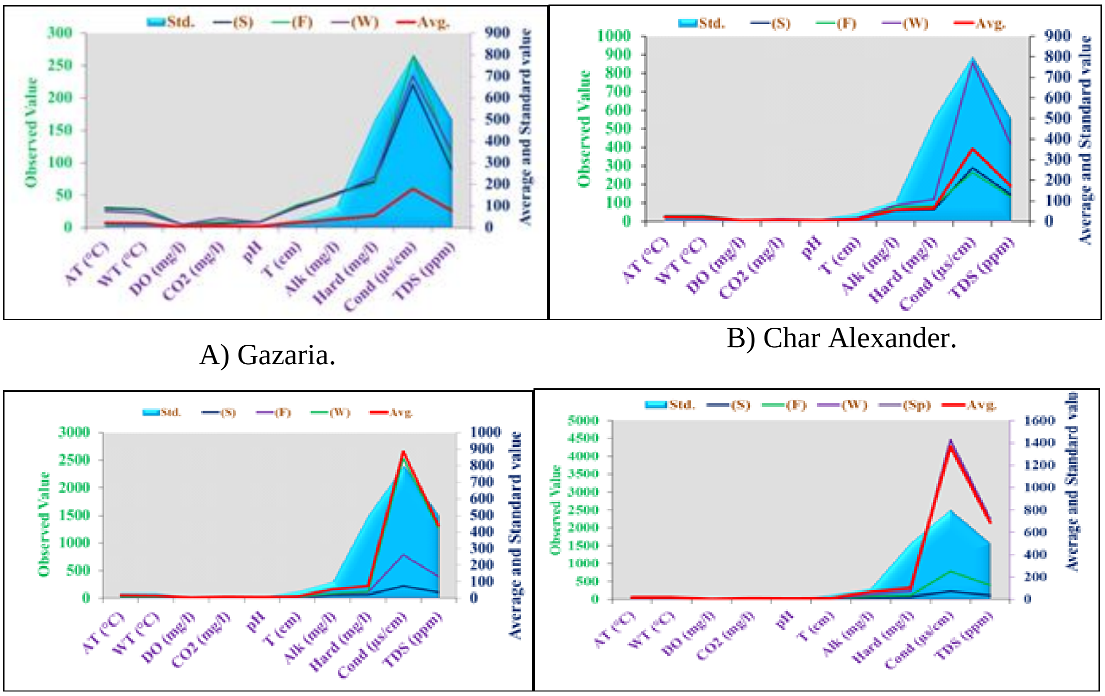
Hasan et al. (2015a) reported that variations in air temperature had an impact on the water temperature) According to Ahmed et al. (2005), the Meghna River's water surface temperature ranged from 24.1 to 30.5ºC, with a mean of 27.6 ± 0.68. The Hooghly-Bhagirathi River system's ideal water temperature was estimated by Bhaumik et al. (2011) ranged from 29.3 to 30.2ºC for breeding and migration of Hilsa fish. They also estimated the threshold values of physico-chemical parameters for hilsa migration, breeding, and rearing. Ahmed et al. (2005) reported that TDS had a mean of 0.20 ± 0.05 and varied between 0.12 and 0.32 mg/L. The Meghna River system had the highest conductivity value (220 mS/cm), according to Ahmed et al. (2005).

Rainfall and water temperature were also identified as significant factors influencing species distribution (Hossain et al., 2013a). According to Maes et al. (2004), one of the key factors influencing fish distribution and abundance is dissolved oxygen.

Table 3: Summary of observed data; Wid-Width, Dep-Depth, Sal-Salinity, AT-Air Temperature, WT-Water Temperature, pH-pH, DO-Disolved Oxygen, Alk-Alkalinity, Har-Herdness, Tra-Transparency, Con-Conductivity, TDS-Total dissolved solid, NH_3-Ammonia.

	Wid (m)	Dep (m)	Sal (ppt)	AT (° C)	WT (° C)	pH	DO (mg/L)	CO_2 (mg/L)
AVG	6.63	29.19	2.21	27.91	25.88	8.07	7.22	13.11
RANGE	31.73	54.33	9.92	12.87	13.67	1.30	3.69	13.40
SEM ±	1.91	3.74	0.68	0.92	0.91	0.07	0.30	0.94
CV%	1.29	0.57	1.38	0.15	0.16	0.04	0.18	0.32
PE ±	1.29	2.52	0.46	0.62	0.61	0.05	0.20	0.63
MaxE ±	25.60	50.15	9.18	12.41	12.19	0.96	3.98	12.59
Precision	0.19	0.09	0.21	0.02	0.02	0.01	0.03	0.05

	Alk	Har	Tra	Tur	Con	TDS	NH_3
AVG	83.51	146.98	64.91	22.07	2417.58	1356.65	0.04
RANGE	80.33	199.67	78.00	82.78	9682.33	6636.00	0.42
SEM ±	5.38	14.95	4.47	4.97	713.88	411.12	0.03
CV %	0.29	0.45	0.31	1.01	1.32	1.36	3.09
PE ±	3.63	10.08	3.02	3.35	481.51	277.30	0.02
MaxE ±	72.23	200.52	60.00	66.65	9577.75	5515.81	0.36
Precision	0.04	0.07	0.05	0.15	0.20	0.20	0.47



A) Gazaria. B) Char Alexander.

C) Daulatkhan. D) Char Annadaprasad.

Figure 4: Temporal (in situ) distribution and fluctuation of hydro-physico-chemical attributes (A-D).

c) Spatial distribution and variation of bio resources

Eight groups and 60 species of phytoplankton and seven groups and 35 species of zooplankton were recorded in the Meghna Basin (Tabs. 4 and 5). The abundance of plankton was highest in Nazarpur and lowest in Char Kukrimukri (Fig. 4a). The relative abundance of zooplankton was four times lower than phytoplankton (Figs. 4b-c). Among all phytoplankton groups, chlorophyceae was the most abundant and dinophyceae was least abundant (Fig. 4d). Among all seven zooplankton groups (35 species), cladocera was the most abundant and oligohymenophycae was least abundant (Fig. 4e). Hasan et al. (2015b) categorized six families of phytoplankton, including Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae, Dinophyceae, and Xanthophyceae, encompassing 58 genera. Additionally, they identified various groups of zooplankton, specifically Copepoda, Cladocera, and Rotifera.

The phytoplankton and zooplankton abundance in the Meghna Basin highlights the ecological dynamics of aquatic ecosystems, chlorophyceae dominated the phytoplankton community and cladocera prevailed in zooplankton. This pattern aligns with Hasan et al. (2015b), who reported similar phytoplankton diversity, supporting the notion that certain taxa thrive in specific conditions. The discrepancy between the abundance of phytoplankton and zooplankton suggests potential bottlenecks in the food web, with lower zooplankton biomass possibly impacting higher trophic levels, as noted in similar studies exploring the ecological implications of plankton dynamics in lotic systems (Reynolds, 2006; Wetzel, 2001).

Table 4: List of available phytoplankton.

Group	Genus	no
Cyanophyceae	*Spirulina, Scenedesmus, Microcystis, Polycystis, Anabaena, Nostoc, Oscillatoria, Coelosphaerium, Phormidium, Rivularia*	10
Chlorophyceae	*Pediastrum, Closterium, Ankistrodesmus, Eudorina, Crucigena, Chlamydomonas, Ceratium, Acanthocystis, Gonatozygon, Microspora, Genecularia, Pleodarina, Spirogyra, Volvox, Mougeotia, Zygnema, Oedogonium, Tetraspora, Penium, Coelastrum, Docidium, Tetrapedia*	22
Bacillariophyceae	*Naviculla, Melosira, Amphora, Tabellaria, Frustulia, Coscinodesmus, Cyclotella, Ditoma, Fragilaria, Nitzchia, Polycistis, Stphanodesmus, Gomphonema, Anomoeoneis, Asterionella, Campylodiscus, Gyrosigma, Stephanodiscus*	18
Zygnematophyceae	*Euastrum, Staurastrum, Netrium, Spirotenia, Cosmarium*	5
Ulvophycea	*Ulothix*	1
Fragilariophyceae	*Synedra*	1
Trebouxiophycae	*Botryococcus, Protococcus*	2
Dinophyceae	*Ceratium*	1

Table 5: List of available zooplankton.

Group	Genus	no
Protozoans	*Euglena, Phacus, Volvox, Difflugia, Colpoda, Euglepha, Spirostomum*	7
Rotifers	*Brachionus* sp., *Trichocera, Polyarthra, Asplancha, Keratella, Filinia, Rotaria, Lindia, Mytilina, Eubranchiopus, Trichocera*	12
Copepods	*Nauplius, Diaptomus, Cyclops, Mesocyclops, Limnocalanus*	5
Cladocerans	*Daphnia, Diaphnosoma, Sida, Leptodora, Eubranchipus*	5
Diaphanosoma	*Chydorus, Bosmina, Moina, Ceriodaphnia*	4
Ostracods	*Cypridopsis*	1
Oligohymenophorea	*Paramecium*	1

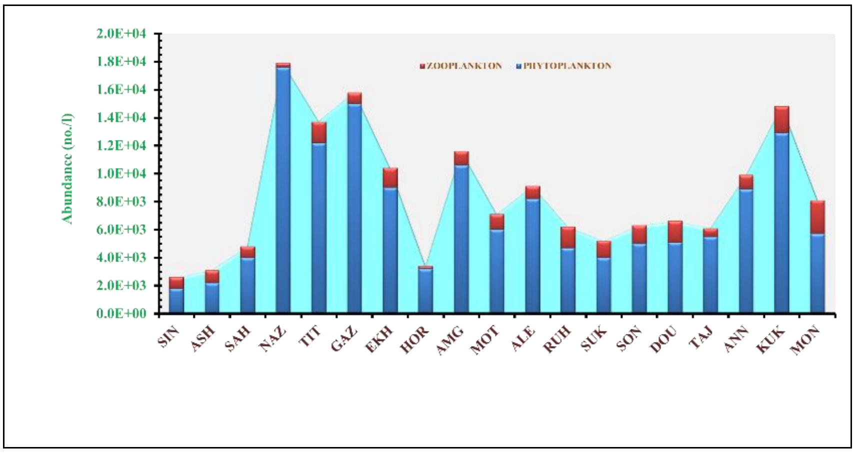


Figure 4a: Spatial distribution and abundance of plankton.

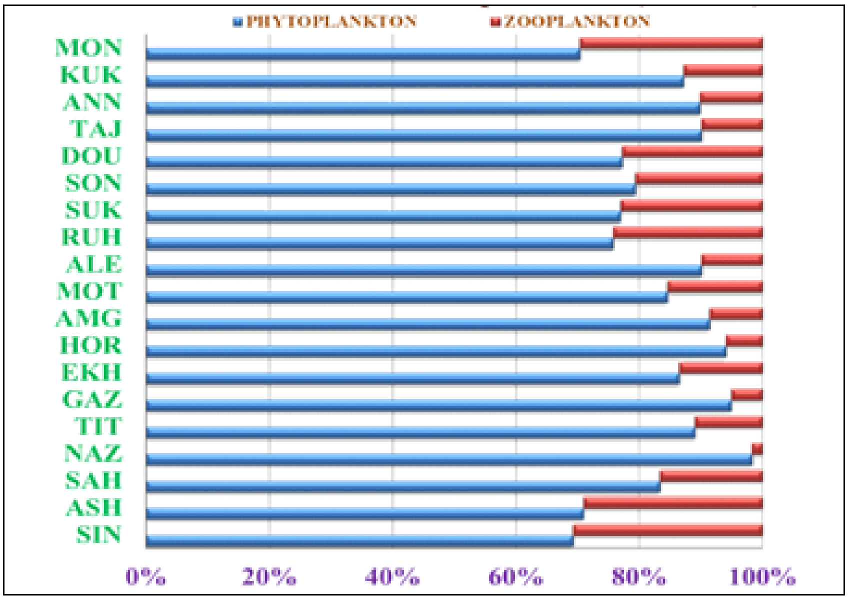
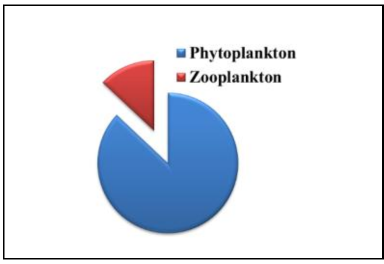
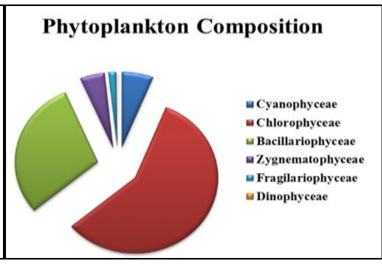


Figure 4b: Relative abundance of plankton.





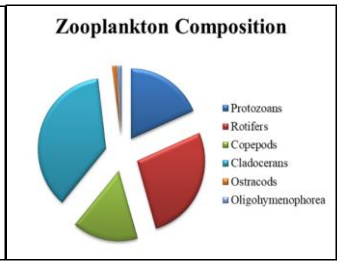


Figure 4c: Plankton. d) Phytoplankton. e) Zooplankton.

Six groups of benthic macro-invertebrates were abundant in the Meghna River basin, among which Annelida was the most abundant and pleuroceridae was the least abundant group (Fig. 6c). The Singapore Mosque site had the highest abundance and highest number of groups while the Ashuganj Ferry Terminal had the lowest abundance and number of groups of benthic macroinvertebrates (Figs. 6a-b).

In the Meghna River basin, research has indicated a significant diversity of benthic macro-invertebrate groups, with annelids (segmented worms) being the most abundant, likely due to their role in nutrient cycling and sediment aeration, which enhances ecosystem productivity (Wetzel, 2001). In contrast, the Pleuroceridae family, which includes freshwater snails, was noted as the least abundant group, potentially indicating habitat preferences and environmental stressors (Holt et al., 2004). The Singapore Mosque site displayed the highest abundance and variety of macro-invertebrate groups, suggesting optimal habitat conditions (e.g., stable substrates and availability of food resources conducive to biodiversity (Friedrich et al., 2015). Conversely, the Ashuganj Ferry Terminal's low abundance and limited group diversity may reflect anthropogenic impacts such as pollution and habitat alteration (Burdon et al., 2019), underscoring the importance of habitat conservation in maintaining aquatic biodiversity.

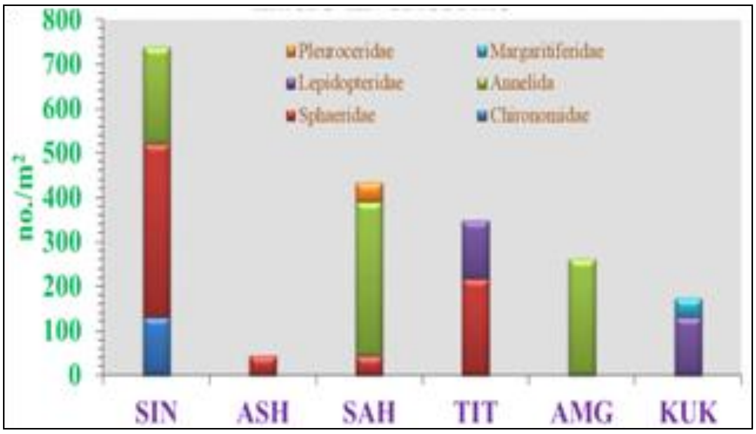


Figure 6a: Spatial distribution and abundance of benthic macro-invertebrates.

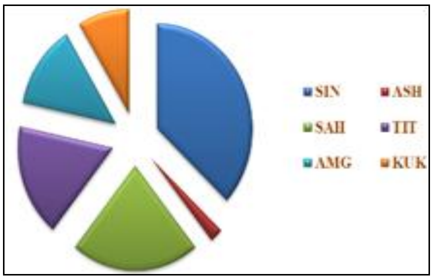


Figure 6b: In situ composition of benthic macro-invertebrates.

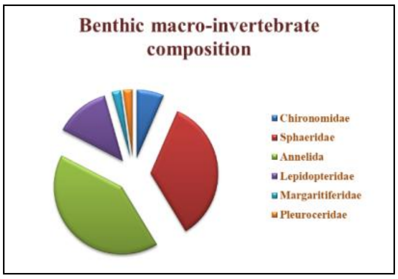


Figure 6c: benthic macro-invertebrates composition.

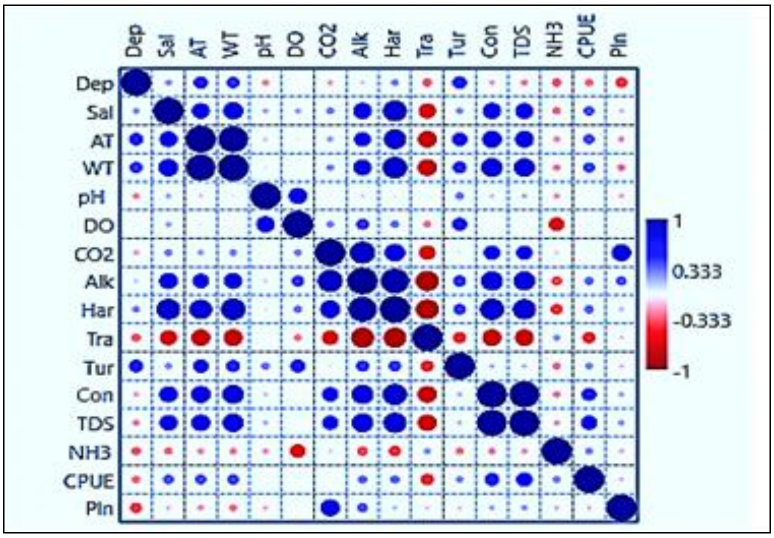


Figure 7: Degree of Association Plot.

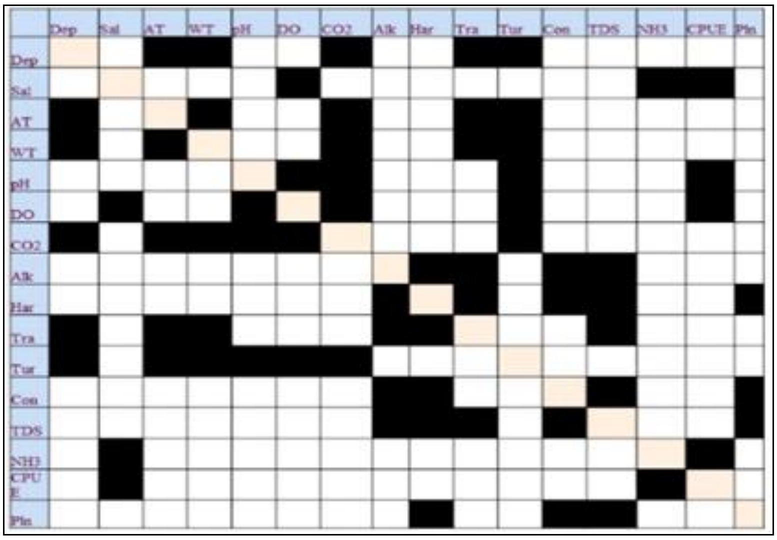


Figure 8: Post Hoc. Statistical test checker board.

The catch per unit effort (CPUE) of Hilsa fish (*Tenualosa ilisha*) exhibited positive associations with water quality parameters such as CO_2, alkalinity, and hardness (Fig. 7), suggesting that favorable nutrient conditions may enhance the availability of food resources and suitable habitats for this species (Mahmud et al., 2022). Conversely, the negative correlation with transparency (Fig. 7), suggests that turbidity may impair the visual foraging ability of Hilsa, potentially leading to decreased feeding efficacy and lower CPUE (Hossain et al., 2014b). Additionally, the negative relationship with the composition of available plankton implies that changes in the plankton community, possibly due to eutrophication or other anthropogenic impacts, could influence the growth and reproduction of fish species, further impacting fishery yields (Nõges et al., 2016). These findings underscore the importance of maintaining optimal water quality for sustaining Hilsa populations and highlight the need for effective management strategies to preserve critical aquatic ecosystems.

Post Hoc statistical test checkerboard visualizes the relationships between various water quality parameters and Catch per Unit Effort (CPUE). The black cells indicate statistically significant relationships between pairs of variables, while the white or blank cells show no significant association. The shaded cells may highlight specific levels of significance, providing further insight into noteworthy interactions (Fig. 8).The dendrogram provides a clear visualization of how the samples can be grouped based on similarity, with the clusters' proximity reflecting their degree of similarity (Fig. 9).

The PCA biplot illustrates the relationships between various water quality parameters and Catch per Unit Effort (CPUE), with the two principal components (Component 1 and Component 2) representing the most significant variations in the data. The black points represent individual samples, while the blue arrows show the direction and strength of correlations between variables. Variables that point in the same direction, like TDS and CPUE, are positively correlated, indicating that increases in one may correspond with increases in the other. The plot highlights how different water quality factors contribute to variations in CPUE, providing insight into the key environmental factors influencing fish abundance (Fig. 10).

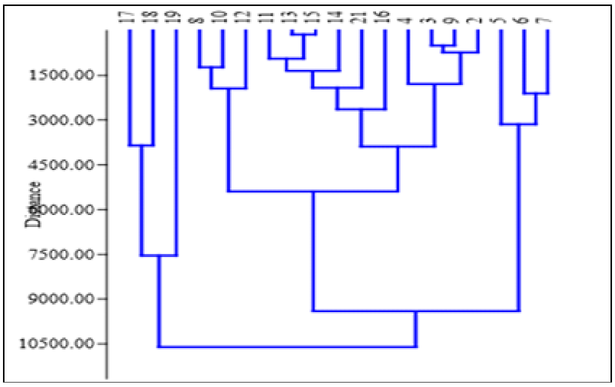


Figure 9: Dendrogram showing the hierarchical clustering of samples based on their similarity

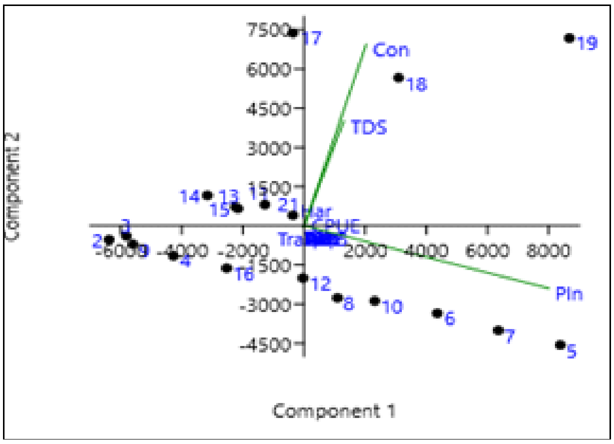


Figure 10: PCA (Principal Component Analysis) biplot, showing the relationship between different water quality variables and CPUE

CONCLUSIONS

The Meghna River Basin in Bangladesh is a critical complex of ecosystems that sustains livelihoods, biodiversity, and provides vital resources. Through careful data collection and analysis, this research sheds light on the complex dynamics of the Meghna River basin. It revealed the spatial and temporal fluctuations of hydro-physico-chemical attributes, including water temperature, pH, dissolved oxygen, and other key parameters. These attributes help identify specific aspects of river health and responses to external stressors, thus serving as indicators for ecological assessments. This study also revealed various types of bio resources present in the basin from plankton to benthic macroinvertebrates. It is important to understand the quantity, composition, and distribution of these taxonomic groups species for comprehensive environmental assessment. Besides, by clarifying the ecological importance of plankton and benthic macro-invertebrates data this study provides evidence for evaluating ecological balance in the basin. Ecologically and culturally, this study offers valuable insight that can help guide the protection and management of the Meghna River basin. Thus, by specifying and explaining the nature of these spatio-temporal dependencies within this ecosystem, this research provides critical information useful to policymakers and conservation organizations. The results can guide efforts to mitigate the impacts of pollution, habitat degradation, climate change, and anthropogenically induced pressures.

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