



Evaluating Seasonal Dynamics of Water Quality and Embankment Soil along the Gorai River in Kushtia, Bangladesh

**Miss. Nushrat Jahan Lima ^a, Md. Kamrul Hossain ^a,
Most. Suria Khatun ^a, Mohammad Omar Faruk Molla ^a
and Md. Anisul Kabir ^{b*}**

^a Department of Geography and Environment, Environmental Analysis Laboratory, Islamic University,
Kushtia-7003, Bangladesh.

^b Department of Geography and Environment, Islamic University, Kushtia-7003, Bangladesh.

Authors' contributions

This work was carried out in collaboration among all authors. Authors MNJL and MKH conceptualized, did the methodology, did the formal analysis, did the validation, did the visualization, roles/ wrote original draft. Author MSK conceptualized, did the formal analysis, did the validation, roles/ wrote original draft. Author MOFM conceptualized, did the formal analysis, roles/ wrote original draft. Author MAK conceptualized, did the investigation, did the methodology, supervised the study, did the validation, and wrote original draft. All authors read and approved the final manuscript.

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*Corresponding author: E-mail: anisgeo24@gmail.com;

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ABSTRACT

Background and Objectives: Water and soil are fundamental components of ecosystems, crucial for maintaining agricultural productivity, biodiversity, and human livelihoods. This study aims to observe the seasonal dynamics of water quality and embankment soil along the Gorai River, Kushtia, Bangladesh.

Methods: A total of 15 water samples and 15 embankment soil samples were collected along the river for both dry (January- February 2024) and wet (July- August 2023) seasons following random sampling techniques. The water and soil samples were analyzed at the Environmental Analysis Laboratory of Islamic University, Kushtia, and the regional laboratory of SRDI, Kushtia, Bangladesh respectively. To identify the relationship among variables, one-way ANOVA, Pearson correlation, and principal component analysis (PCA) were computed for this study.

Results: The results show that some parameters of water samples such as turbidity, total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), and electrical conductivity (EC) exhibit significant differences for both dry and wet seasons except dissolved oxygen (DO) and hardness; whereas, pH, EC, calcium (Ca), copper (Cu), iron (Fe), and manganese (Mn) of soil samples show differences for both seasons. The correlation analysis reveals a robust correlation between EC and TDS and turbidity and TSS in water samples from both the dry and wet seasons. Furthermore, a strong positive correlation exists between organic matter (OM) and total nitrogen (N₂), and both seasons show a positive correlation between Cu and Fe. The PCA analysis indicates that salinity-related factors such as EC and TDS greatly influence water quality during the dry season. In contrast, there is greater variability during the wet season, with N₂, phosphorus (P), and OM playing significant roles due to increased moisture and nutrient dynamics of soil samples.

Conclusion: This study's outcomes revealed that electrical conductivity (EC) showed significant differences for both soil and water samples in dry and wet seasons. This study will contribute to sustainable water and soil resource management by identifying the key seasonal elements affecting water quality and soil fertility in the Gorai River region.

Keywords: Gorai River; embankment soil; water quality; soil quality; seasonal variations.

1. INTRODUCTION

Water is a vital resource on this planet for the survival of all forms of life. Freshwater river systems are essential and inevitable for the sustenance of life [1]. Around 40% of the world's food supply is produced under irrigation, and different industrial processes rely on water [2]. Bangladesh's primary water sources are groundwater from shallow and deep aquifers and surface waters from rivers, lakes, reservoirs, canals, and ponds [3]. Bangladesh's environment, economic outgrowth, and development are greatly influenced by regional and seasonal water availability, as well as groundwater and surface water quality [4]. Besides water and air quality, soil quality is one of the three constitutive of environmental quality [5]. A decline in soil quality is directly linked to a significant agricultural yield drop [6], which results in crop failure and ultimately threatens food security [7]. In addition, soil quality deterioration is detrimental to the food supply stability, leading to economic vulnerability and nutrition deficiency at the household level [8].

Reduced freshwater flow from rivers disrupts the complex nutrient balance in soil. Consequently, arable land is threatened and unsuitable for traditional crops like rice [9].

Bangladesh possesses the lower riparian share of 3 major river systems, e.g., the Ganges-Padma River system, the Brahmaputra-Jamuna River system, and the Meghna River system (GBM), constituting about 8 percent of the total catchment area as well as receives over 92% of runoff annually, generated by the catchment areas [10]. Bangladesh's surface water system is comprised of the world's largest delta, major river networks, and massive flood plains, which become submerged for a short time during the monsoon season and are utilized for cultivation to supply the majority of the crops for the rest of the year [11]. By providing navigation, water for irrigation, fish, and fresh alluvial sediment to replenish the soil, these rivers contributed to the nation's agriculture and general economy. The physiography and monsoon climate of the country is significantly influenced by the surface and groundwater's spatial and seasonal

availability [12]. Even though human manipulation of river flow has many societal benefits, it also deteriorates and eliminates valuable ecosystem services, threatening freshwater and soil biodiversity [13,14].

Several studies demonstrated that the country's rivers' surface water quality is considerably polluting day by day [15-17], mentioned that compared to other rivers in the country, particularly the Buriganga River, is polluted and pollution becomes a great and multifaceted problem because of its diverse nature [18]. It also further analyzed the physicochemical parameters of the Turag River's water and stated that in the last five years, the water quality has worsened daily. Investigated the Bheramara point of the Padma River, Kushtia, and highlighted that overall, the river's water quality is suitable for fish farming and in far better condition than the Turag, Dhaleswari, and Pungli Rivers [19]. Multivariate statistical techniques have been used by numerous researchers to assess the surface water quality's seasonal variation in different periods, considering river toxicity, water quality parameters, and physicochemical properties [20-24]. Hence, updated water quality data are crucial for water quality assessment since variation in water quality is an ongoing process.

The Padma and Gorai are the two major rivers in the Kushtia region and have supplied fresh water to Bangladesh's southwest part for hundreds of years. The Gorai River is important for drinking water, agriculture, fisheries, and industry and the freshwater flow is prime to maintaining the region's environmental, economic, and social balance [25,26]. Day by day, the water quality of the Gorai River is deteriorating due to a decrease in water flow during the dry season, industrial discharge, pesticide overuse, and household wastewater disposal, and the embanked soils also have an impact. Thus, conserving both water and soil resources is crucial to meet freshwater needs and lessen intensive agriculture's effect on soil degradation to produce food for the sustenance of life. However, there is still a lack of knowledge regarding the seasonal dynamics of the Gorai River's water quality and associated embankment soil, which will make us more aware of river usage to keep the river alive as well as to know the socio-economic change which has gone through and the problems they are facing. This study tries to fill this critical gap by exploring the seasonal dynamics of water quality and the embankment soil along the Gorai

River in Kushtia, Bangladesh. The study's findings can help academics, researchers, stakeholders, and policymakers involved in river conservation and sustainable management in that area. This research will also create a new dimension to address river water shortage-induced problems in the selected portion of this river and other river water shortage areas of the country, especially the impacts of embankment soil quality on agricultural production, to take cost-effective initiatives for the socio-economic development of the locals.

2. MATERIALS AND METHODS

2.1 Study Area

The present study has been conducted on the Gorai River, from the Padma-Gorai estuary to the Kumarkhali Bridge, Kushtia, Bangladesh, located between 23.94° and 23.88° north latitudes and between 89.11° and 89.18° east longitudes [27]. The Gorai River is the Padma River's only and largest perennial tributary and provides a significant amount of water to agricultural, industrial, and domestic activities in its surroundings. The entire river has been selected based on the presence of several industrial and domestic functions, which contribute to both point and non-point sources of pollution. The point sources include the household and sugar mill's wastewater from the Kushtia Pourashova and the market area. Furthermore, untreated sewage and solid waste disposal led to contaminants as point sources. Fig. 1 depicts the study area and sampling points.

2.2 Water and Soil Sample Collection

For the current study, 15 water and 15 soil samples have been collected in the dry (January-February 2024) and wet (July- August 2023) seasons from the Gorai River and its embanked soil following random sampling techniques. Water samples were collected during the day in each season at a water depth of approximately 20–30 cm at each point in the midstream of the Gorai River. At each sampling point, we collected water samples in sterilized bottles (250 mL) with double-capping protections; before sampling, the bottles were cleaned, rinsed, and treated with 5% HNO₃ for an overnight period. Finally, we rinsed the bottles with distilled water and dried them. Once we collected each sample, the bottles were kept airtight, immediately preserved with 0.1 M HNO₃ acid, and marked with the corresponding identification number. On the other hand, soil

samples were collected from riverbank field soil at depths of approximately 0–15 cm using a hand auger and then stored in poly bags with proper labeling. GPS devices were also utilized to

geolocate the sampling points during sample collection. Details of information collected and analyzed for both water and soil samples are presented in Table S1-S4.

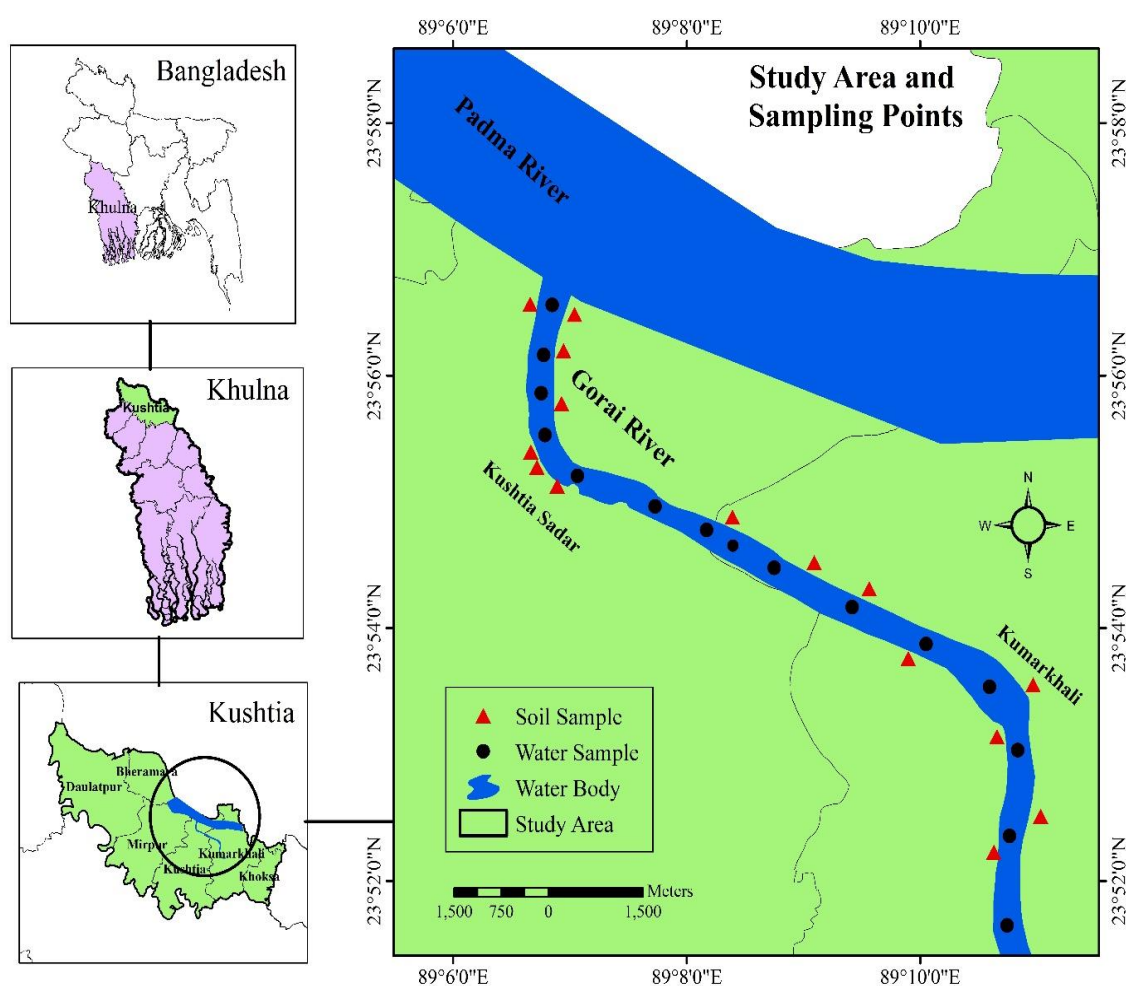


Fig. 1. Study area – The Gorai River and distribution of sampling points

Table 1. Methods and equipment used in laboratory analysis

Parameters	Materials/Equipment	Unit
Temperature	Portable Glass Mercury Thermometer	(°C)
pH	Model EZD0-6011	**
Salinity	Water Quality Tester (Five in One)	ppm
TDS	Ezdo TDS-5031	ppm
EC	OHAUS Conductivity Portable Meter	µs/cm
Turbidity	Turbidity and Suspended Solids Meter TSS- LH-XZ03	NTU
TSS	Turbidity and Suspended Solids Meter TSS- LH-XZ03	mg/l
DO	Portable Dissolved Oxygen Meters	mg/l
COD	Titrimetric Method	mg/l
Hardness	Hanna Total Hardness Test Kit HI3812	mg/l

Table 2. Methods and equipment used in laboratory analysis

Parameters	Materials/Equipment	Methods of Extraction
pH	Soil pH and Moisture Analyzer	-----
Temperature	Soil Analyzer Tester	-----
Moisture	Soil Moisture Meter VG-200	-----
EC	Conductivity Meter	1: 10 volume method
OM	Titration	Wet oxidation method
Total N ₂	Digestion & Distillation Unit	Kjeldahl method
K	Flame photometer	Ammonium Acetate Extraction
Ca	Atomic Absorption Spectrophotometer	Ammonium Acetate Extraction (Atomic Absorption/Emission Spectrophotometric Method)
Mg	Atomic Absorption Spectrophotometer	Ammonium Acetate Extraction (Atomic Absorption/Emission Spectrophotometric Method)
P	Spectrophotometer	Modified Olsen's method for Neutral & Calcareous Soil/ Bray and Kurtz Method for Acidic Soil
S	Spectrophotometer	Calcium Dihydrogen Phosphate Extraction (Turbidimetric method)
B	Spectrophotometer	Calcium Chloride Extraction
Cu	Atomic Absorption Spectrophotometer	DTPA Extraction
Zn	Atomic Absorption Spectrophotometer	DTPA Extraction
Fe	Atomic Absorption Spectrophotometer	DTPA Extraction
Mn	Atomic Absorption Spectrophotometer	DTPA Extraction

2.3 Sample Analysis

All the collected water samples were analyzed at the Environmental Analysis Laboratory, Department of Geography and Environment. The soil samples were analyzed at the regional laboratory, the Soil Resources Development Institute (SRDI) in Kushtia.

2.3.1 Water Sample Analysis

Water samples were analyzed by the following methods as shown in Table 1.

2.3.2 Soil sample analysis

Table 2 represents soil samples analyzed using these methods as follows:

2.4 Statistical Analysis

A comprehensive statistical analysis was conducted to assess the seasonal dynamics of the Gorai River's water quality and embankment soil quality. The statistical analyses and graphical presentations were performed using Origin Pro 2024 and IBM SPSS statistics (version 25). Before the statistical analysis, we checked the homogeneity of the data following the Shapiro-Wilk test using Origin Pro; the concentrations of

the parameters were normally distributed separately for each season (Prob. < 0.05) and presented in Table S5-S8.

2.4.1 One-way ANOVA test

A statistical method known as one-way between-subjects analysis of variance, or one-way ANOVA, examines the variability in scores within and across groups [28]. The process entails the application of novel concepts, but the fundamental suppositions are that within and across the samples, the observations are both random and independent, the variability is uniform, there are no anomalous data points, and in each category, the observations adhere to a normal distribution [29]. Additionally, it experiments with the null hypothesis that among different category groupings, there is an equality of means [30]. In this study, we utilized the One-way ANOVA test to identify the mean concentration of soil and water parameters for both dry and water seasons.

2.4.2 Pearson correlation

The Pearson correlation coefficient, a statistical metric is used to quantify the direction and strength of a linear relationship between two variables, values ranging from -1 to 1. According

to Yang et al. [31] an inverse relationship lies between the coefficient's absolute value and the linear correlation of these two variables. The coefficient's higher absolute value indicates a lower linear correlation, while a lower absolute value denotes a higher linear correlation. Insights of the various characteristics' overall influence on each other can be obtained by investigating the connection between different soil or water quality parameters [32]. For this study, Pearson's correlation analysis was used to observe the relationship among water and soil quality parameters for both dry and wet seasons separately.

2.4.3 Principal Component Analysis (PCA)

Principal component analysis (PCA) is a frequently used multivariate statistical method employed to determine the connection between the key indicator variables and convert these into independent principal components [33]. A Principal Component identifies the most significant variables in a dataset, aiding in data reduction while conserving as much of the main information as possible [34]. Assessing the water quality of an entire river basin, determining the elements that influence water quality, and augmenting the river basin's overall water environment quality is a challenging and complex procedure [35]. In the current study, PCA was applied to identify the main factors contributing to the variability in water and soil quality for both dry and wet seasons in particular.

3. RESULTS

3.1 Statistical Analysis

3.1.1 Descriptive statistics of measured water quality parameters (dry and wet Season)

Table 3 presents the measured water quality parameters for Gorai River during both dry and wet seasons and compares them with the standard values established by the World Health Organization (WHO) and the Department of Environment (DoE). The pH values ranged between 6.5 and 7.39 in the dry and wet seasons from 6.87 to 8.7, with average values of 6.99 and 7.6, respectively, falling within the acceptable limit of 6.5 to 8.5. Measured temperature showed upward readings from the dry season (e.g., 20-21.3°C) to the wet season (e.g., 29.4-31.9°C), with averages of 20.88°C and 31.04°C, exceeding the WHO standard slightly in the wet

season (20-30°C). Salinity levels were considerably higher in the dry season (averaging 234.4 mg/l) compared to 109.3 mg/l during the wet season, both below the 700-3000 mg/l standard value. Total Dissolved Solids (TDS) also displayed a significant decrease from an average of 438.3 mg/l (dry season) to 161.3 mg/l (wet season), both fall within the acceptable range (0-1000 mg/l), though the dry season average tends to the DoE limit (500 mg/l). Electrical Conductivity (EC) pursued a similar trend, with higher values (average 468.06 $\mu\text{S}/\text{cm}$) in the dry season in comparison to the wet season values (average 218.6 $\mu\text{S}/\text{cm}$), both falling below the standard limit of 700-3000 $\mu\text{S}/\text{cm}$.

Turbidity and Total Suspended Solids (TSS) both were much higher in the wet season, averaging 300 NTU for turbidity (compared to 4.73 NTU during the dry season), and averaging 53.25 mg/l for TSS (compared to 0.79 mg/l during the dry season), both surplus the standard ranges of 5-25 NTU and undiscerned limits for TSS. Dissolved Oxygen (DO) levels were comparatively stable across seasons, with an average of 5.41 mg/l (dry season) and 5.33 mg/l (wet season), both within the acceptable limit. Chemical Oxygen Demand (COD) was observed slightly higher in the wet season (averaging 4.09 mg/l) than in the dry season (averaging 3.32 mg/l), both well within the standard value (15 mg/l). Lastly, hardness exerted minimal seasonal variation in the dry (averaging 186.2 mg/l) and wet seasons (averaging 192.33 mg/l), both falling within the acceptable range (200-500 mg/l). The comparisons of water quality parameters for both dry and wet seasons are also presented in Fig. 2A.

3.1.2 Descriptive statistics of measured soil quality parameters (dry and wet seasons)

Table 4 provides comprehensive data on the embankment soil quality parameters during both dry and wet seasons, comparing them with optimum values specified by SRDI (2010) for upland and wetland soils. During the dry season, the pH values averaged 7.41 ± 0.14 , and this value in the wet season, 7.26 ± 0.23 , both are higher than the optimum limit (6-7) for upland and wetland soils. Soil temperature asserted a significant increase in the dry season from an average of $20.71 \pm 0.16^\circ\text{C}$ to in the wet season $33.62 \pm 2.68^\circ\text{C}$, though no specific optimum limits are provided for temperature. Salinity levels

Table 3. Descriptive statistics of measured water quality parameters (dry and wet seasons)

Parameters	Number of Samples	Minimum		Maximum		Average ± SD		Standard Values	
		Dry	Wet	Dry	Wet	Dry	Wet	[36]	[37]
pH	15	6.5	6.87	7.39	8.7	6.99 ± .21	7.6 ± .527	6.5-8.5	6.5-8.5
Temperature	15	20	29.4	21.3	31.9	20.88 ± .30	31.04 ± .59	20-30	--
Salinity	15	192	106	568	116	234.4 ± 92.5	109.3 ± 2.41	700-3000	--
TDS	15	360	120	1050	200	438.3 ± 170.05	161.3 ± 22.94	0-1000	500
EC	15	385	213	1134	228	468.06 ± 184.80	218.6 ± 3.88	700-3000	--
Turbidity	15	1.6	163	6.7	482	4.73 ± 1.42	300 ± 106.5	5-25	25
TSS	15	.23	29.4	1.2	84	.79 ± .263	53.25 ± 18.05	60	--
DO	15	3.9	3.8	7.1	7.8	5.41 ± .99	5.33 ± 1.11	--	6
COD	15	2.5	3	4.5	5.1	3.32 ± .64	4.09 ± .703	15	4
Hardness	15	175	173	198	230	186.2 ± 7.41	192.33 ± 17.26	100	200-500

TDS = Total Dissolved Solid; EC = Electrical Conductivity; TSS = Total Suspended Solid; DO = Dissolve Oxygen; COD = Chemical Oxygen Demand; Unit: TDS; Salinity; TSS; DO; COD; Hardness = PPM mg/l; EC = µs/cm and Turbidity = NTU

Table 4. Descriptive statistics of measured soil quality parameters (dry and wet seasons)

Parameters	Unit	Number of Samples	Minimum		Maximum		Average \pm SD		Optimum value [38]	
			Dry	Wet	Dry	Wet	Dry	Wet	Upland	Wetland
pH	--	15	7.2	6.9	7.6	7.5	7.41 \pm 0.14	7.26 \pm .23	6-7	6-7
Temperature	($^{\circ}$ C)	15	20.4	28.7	21	38.4	20.71 \pm .16	33.62 \pm 2.68	--	--
Salinity	ppm	15	36	17	271	43	88.73 \pm 59.4	26.6 \pm 7.01	--	--
TDS	ppm	15	80	200	520	700	168 \pm 110.33	473.33 \pm 116.29	--	--
Electrical Conductivity	μ s/cm	15	74	32	550	87	182.93 \pm 118.14	53 \pm 14.35	<4000	<4000
Moisture	(%)	15	17	21	75	77	44.13 \pm 17.02	48.93 \pm 19.35	--	--
Organic Matter	(%)	15	.71	28.7	2.05	38.4	1.29 \pm .40	1.24 \pm .23	--	--
Total N ₂	(%)	15	.05	.05	0.1	.09	0.06 \pm .01	.057 \pm .01	0.27 - 0.36	0.27-0.36
Potassium (K)	meq/100g soil	15	.14	.08	.24	.48	0.192 \pm .03	.19 \pm .09	0.27-00.36	0.22-0.30
Calcium (Ca)	meq/100g soil	15	2.54	10.3	6.78	24.7	3.81 \pm 1.31	18.92 \pm 4.47	4.51 - 6	4.51-6.0
Magnesium (Mg)	meq/100g soil	15	1.12	.45	2	2.64	1.42 \pm .27	1.22 \pm .64	1.126 -1.5	1.12-1.5
Phosphorus (P)	meq/100g soil	15	6.7	5.1	45.5	26.1	13.92 \pm 11.35	8.64 \pm 5.11	22.51 - 30	18.1-24
Sulfur (S)	ppm	15	6.7	5.3	19.2	17.9	11.3 \pm 3.62	10.09 \pm 3.42	22.51-30	27.1-36
Boron (B)	ppm	15	.21	.12	.49	.57	.31 \pm .08	0.238 \pm .134	0.451-0.6	0.45-0.6
Copper (Cu)	ppm	15	1.19	.17	4.61	1.75	2.82 \pm .95	0.92 \pm .56	0.451-0.6	0.45-0.6
Zinc (Zn)	ppm	15	.19	.07	.85	2.11	.4 \pm .2	0.47 \pm .64	1.351-1.8	1.35-1.8
Iron (Fe)	ppm	15	14.8	5	65	33.6	40.53 \pm 15.45	14.75 \pm 7.84	9.1-12	9.1-12
Manganese (Mn)	ppm	15	2.63	1.1	13.3	3.7	7.70 \pm 2.41	1.83 \pm .72	2.256-3	2.25-3.0

were much higher in the dry season, with an average of 88.73 ± 59.4 mg/l, compared to 26.6 ± 7.01 mg/l during the wet season. Total Dissolved Solids (TDS) further showed an upward trend from 168 ± 110.33 mg/l (dry season) to 473.33 ± 116.29 mg/l (wet season). Electrical Conductivity (EC) ranged higher during the dry season (182.93 ± 118.14 μ S/cm) than the wet season (53 ± 14.35 μ S/cm); both surpass the optimum limit of <4 μ S/cm. During the dry season, moisture content was $44.13 \pm 17.02\%$ (average) and slightly onward to $48.93 \pm 19.35\%$ during the wet season. However, organic Matter (OM) extent was relatively stable throughout seasons, averaging $1.29 \pm 0.40\%$ (dry season) and $1.24 \pm 0.23\%$ (wet season). Nitrogen (N₂) content was also consistent across seasons; in the dry season (averaging $0.06 \pm 0.01\%$) and in the wet season (averaging $0.057 \pm 0.01\%$), both remained below the optimum values of 0.27-0.36%.

Potassium (K) levels ranged averaging $0.192 \pm 0.03\%$ (dry season) and $0.19 \pm 0.09\%$ (wet season), lower than the optimum limits of 0.27-0.36%. Calcium (Ca) content significantly increased from $3.81 \pm 1.31\%$ (dry season) to $18.92 \pm 4.47\%$ (wet season), exceeding the optimum values of 4.51-6%. Magnesium (Mg) levels in the dry season averaged $1.42 \pm 0.27\%$ and in the wet season averaged $1.22 \pm 0.64\%$, falling within the optimum range (1.126-1.5%). Phosphorus (P) content reduced from $13.92 \pm 11.35\%$ (dry season) to $8.64 \pm 5.11\%$ (wet season), both below the optimum level (22.51-30%) for upland soils but for wetland soils well within the ranges of 18.1-24%. Sulfur (S) levels were consistent with an average of $11.3 \pm 3.62\%$ in the dry season and $10.09 \pm 3.42\%$ in the wet season, both falling below the optimum limit (22.51-30%) for upland and 27.1-36% for wetland soils. Boron (B) levels were comparatively stable, averaging $0.31 \pm 0.08\%$ (dry season) and $0.238 \pm 0.134\%$ (wet season), within the optimum values of 0.451-0.6%. Copper (Cu) levels were contrarily higher during the dry season, (averaging $2.82 \pm 0.95\%$) than $0.92 \pm 0.56\%$ during the wet season, both exceeding the optimum limits (0.451-0.6%). Zinc (Zn) levels averaged $0.4 \pm 0.2\%$ (dry season) and $0.47 \pm 0.64\%$ (wet season), which were lower than the optimum values of 1.351-1.8%. Iron (Fe) levels were significantly higher with an average of $40.53 \pm 15.45\%$ in the dry season, compared to $14.75 \pm 7.84\%$ during the wet season, both surpass the optimum range (9.1-12%). Manganese (Mn) levels were also higher in the

dry season (averaging $7.70 \pm 2.41\%$) in comparison to the wet season (averaging $1.83 \pm 2.72\%$), within the optimum limit of 2.256-3%, particularly for the wet season. The comparisons of soil quality parameters for both dry and wet seasons are also presented in Fig. 2B.

3.2 One-way ANOVA (using soil and water samples)

In Fig. 3, the one-way ANOVA test results show that there were statistically significant variations among mean values (p value < 0.05) of water samples' physicochemical parameters for both dry and wet seasons except DO and Hardness because any statistically significant differences have not been observed among mean values (p value > 0.05).

In contrast, the one-way ANOVA test results in Fig. 4 depict that there is a statistically significant dissimilation among mean values (p value < 0.05) of the collected soil samples' pH, EC, Ca, Cu, Fe, and Mn for both dry and wet seasons but significant differences were not found among moisture, OM, total N₂, K, Mg, P, S, B, and Zn's mean values (p value > 0.05).

3.3 Correlation Analysis

3.3.1 Pearson correlation among water quality parameters (dry and wet season)

Fig. 5A illustrates the Pearson correlation coefficients among different measured water quality parameters during the dry season. pH exhibits a moderate positive correlation with EC suggesting that the parameter tends to rise if pH increases. Temperature demonstrates a weak negative correlation with salinity (-0.18), indicating that lower salinity levels are slightly associated with higher temperatures. However, the temperature almost shows no correlation with other parameters, expressing minimal direct influence. Salinity exhibits strong positive correlations with EC (1.0) and TDS (1.0), indicating that these parameters rise together. It can also be seen that there remains a moderate negative correlation between salinity and turbidity, suggesting that higher salinity is linked with lower turbidity levels. TDS and EC are quite correlated (1.0), as expected conferred their interrelated definitions. Furthermore, both parameters show strong negative correlations with TSS (-0.59 and -0.6, respectively), and turbidity (-0.61 and -0.63, respectively). A strong positive correlation is found between turbidity

and TSS (0.88), indicating that higher TSS levels are associated with higher turbidity levels. It also displays a weak negative correlation with COD (-0.1), and moderate positive correlations with DO (0.5). TSS shows a weak negative correlation with COD (-0.16), a moderate positive correlation with DO (0.48), and a strong positive correlation with turbidity (0.88). DO exhibits a moderate positive correlation with TSS turbidity (0.5), and moderate negative correlations with TDS (-0.40), and salinity (-0.43), EC (-0.44), and pH (-0.52)

suggesting that lower TDS, salinity, EC, and pH levels are associated with higher DO levels. COD demonstrates weak to moderate positive correlations with TDS (0.21) and pH (0.36), and weak negative correlations with turbidity DO (-0.15), turbidity (-0.1), and TSS (-0.16). Finally, hardness shows a moderate negative correlation with COD (-0.35), and weak to moderate positive correlations with pH (0.22), TDS (0.27), EC (0.28), and salinity (0.29).

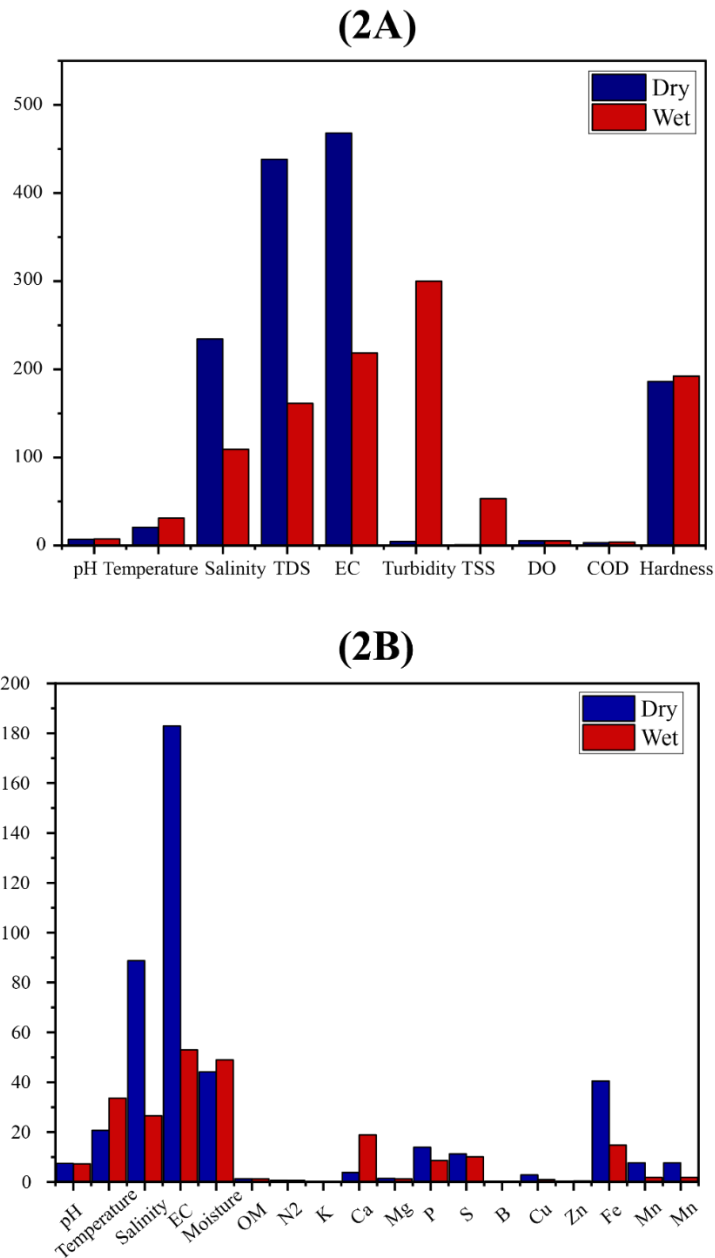


Fig. 2. Comparisons of water (A) and soil (B) quality for both dry and wet season

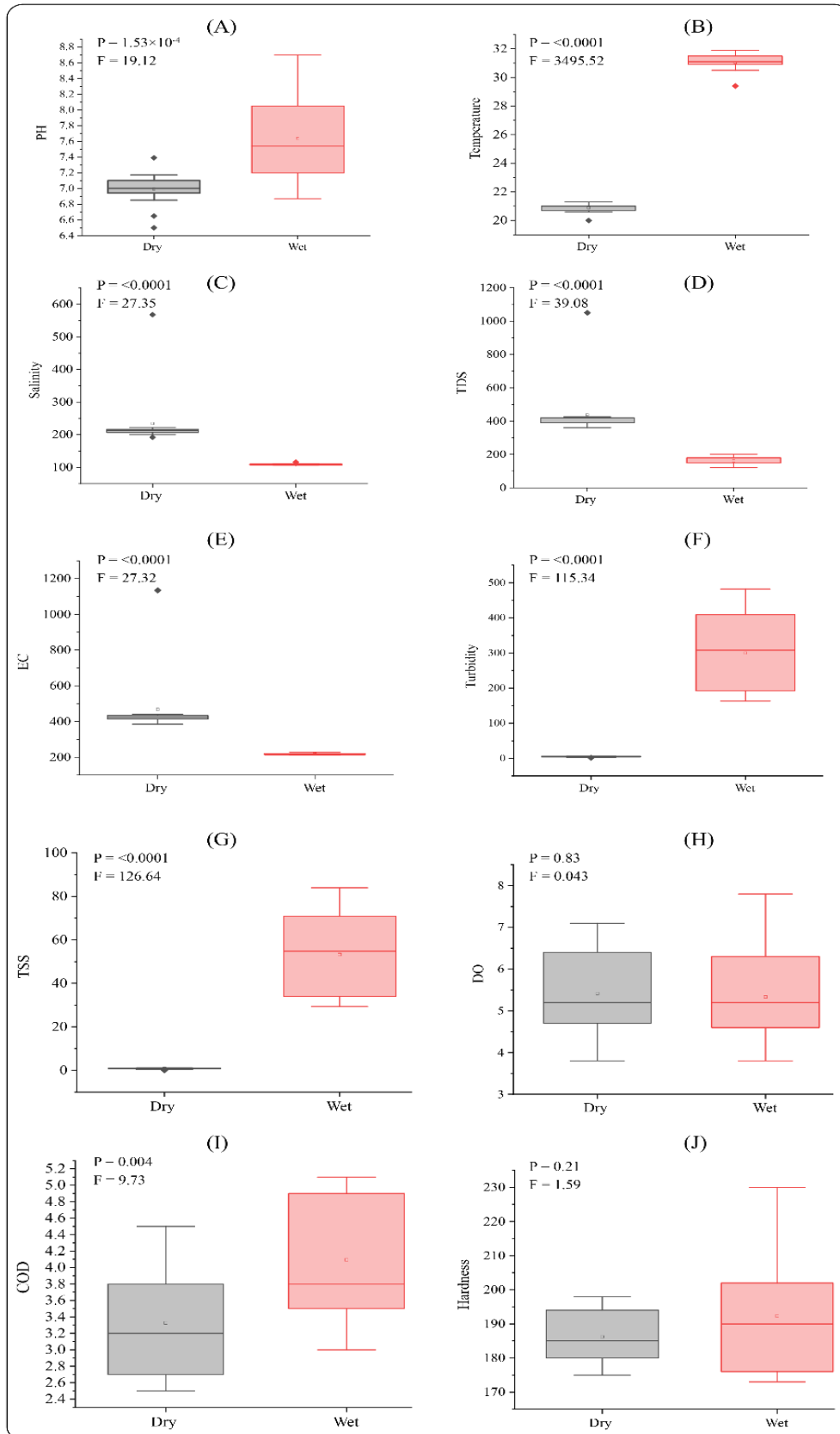


Fig. 3. One-way ANOVA test of water sample between dry and wet season

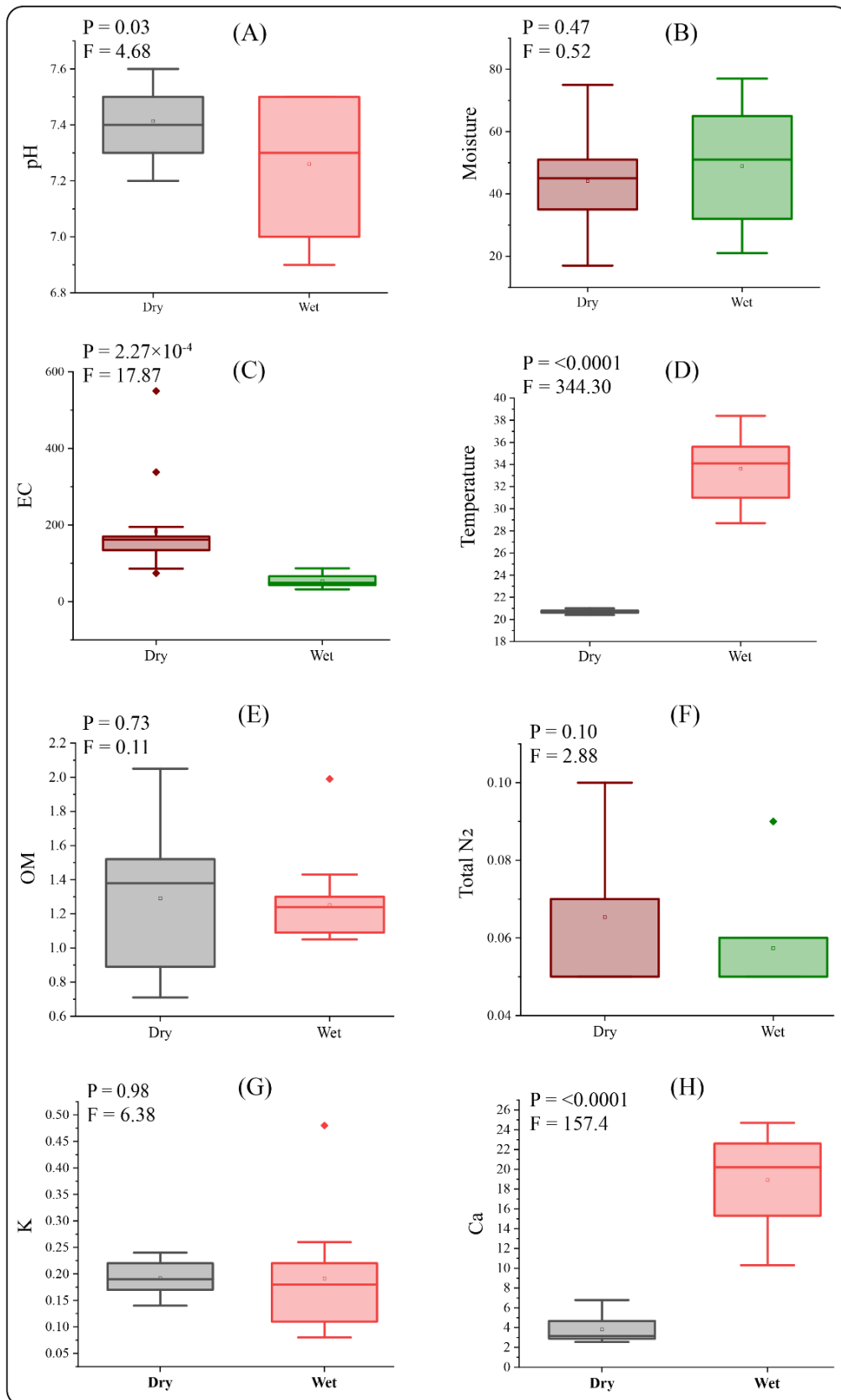


Fig. 4. One-way ANOVA test of soil sample between dry and wet season

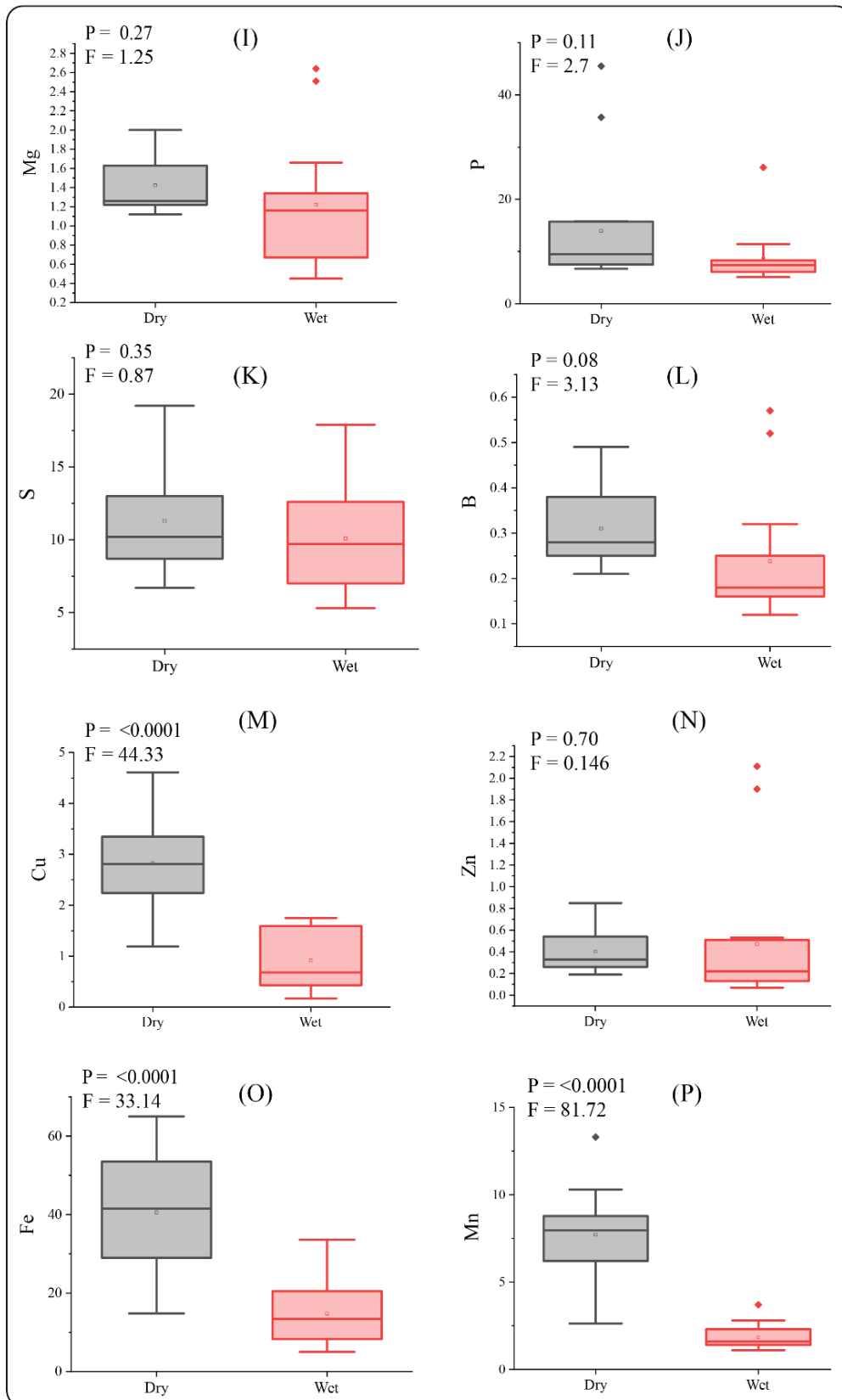


Fig. 4. Cont. One-way ANOVA test of soil sample between dry and wet season

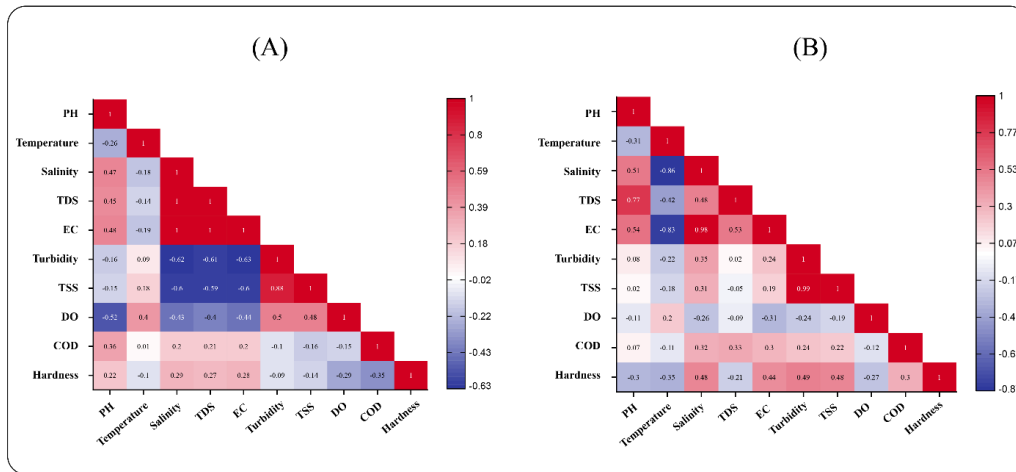


Fig. 5. Pearson correlation among water quality parameters for both dry (A) and wet (B) seasons respectively

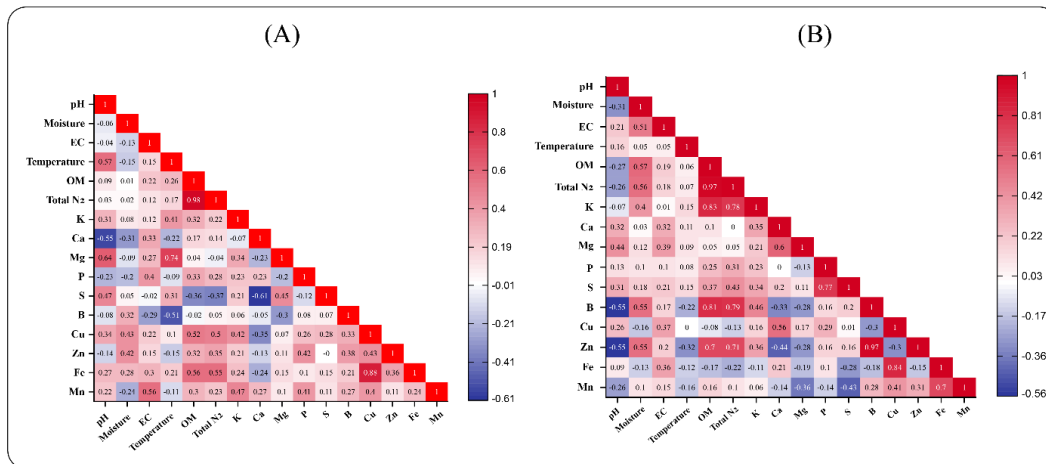


Fig. 6. Pearson correlation among soil quality parameters for both dry (A) and wet (B) seasons respectively

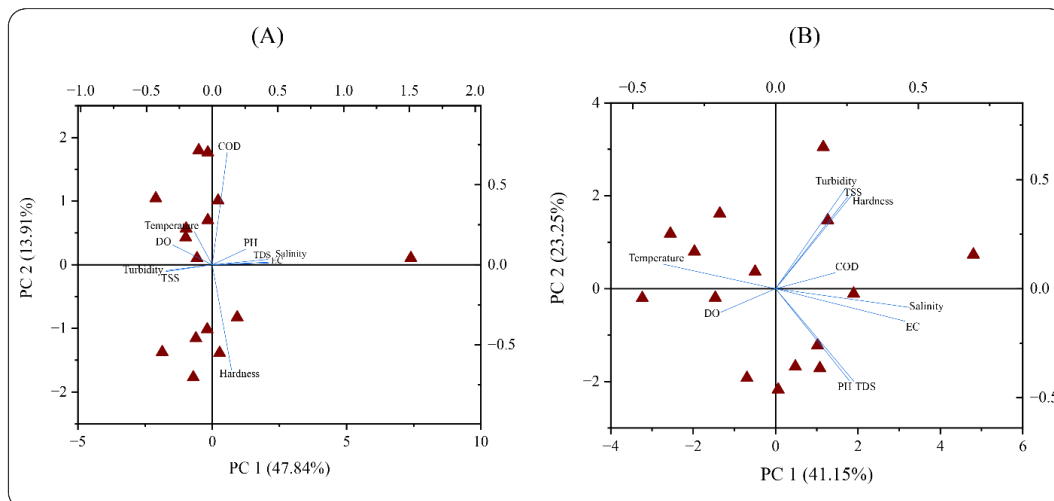


Fig. 7. PCA analysis among water quality parameters for both dry (A) and wet (B) seasons respectively

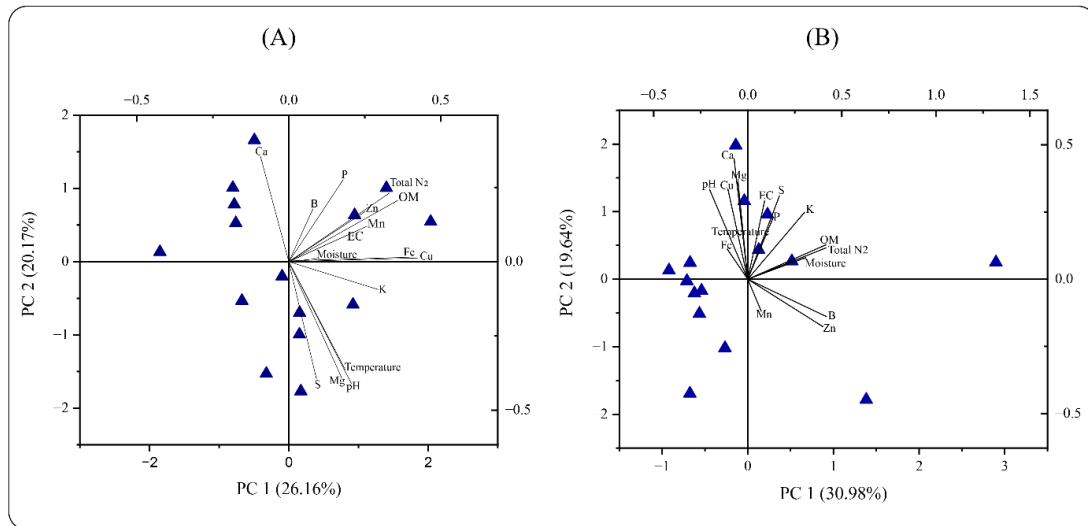


Fig. 8. PCA analysis among soil quality parameters for both dry (A) and wet (B) seasons respectively

Fig. 5B represents the Pearson correlation coefficients among different measured water quality parameters during the wet season. pH shows moderate positive correlations with EC (0.54) and salinity (0.51) and a strong positive correlation with TDS (0.77), suggesting that as pH levels increase, these parameters (EC and salinity) also tend to grow. Conversely, pH exhibits a moderate negative correlation with hardness (-0.3) and temperature (-0.31), indicating that lower temperatures and hardness are associated with higher pH levels. Temperature also shows a moderate negative correlation with TDS (-0.42) and strong negative correlations with EC (-0.83) and salinity (-0.86), signifying that lower salinity, EC, and TDS levels are associated with higher temperatures. Temperature demonstrates a weak negative correlation with hardness (-0.35). A robust positive correlation can be found between salinity and EC (0.98). Salinity also shows weak positive correlations with TSS (0.31) and turbidity (0.35). TDS exhibits moderate positive correlations with salinity (0.48) and EC (0.53), whereas EC has a moderate negative correlation with DO (-0.31). A robust positive correlation remains between turbidity and TSS (0.99), highlighting that higher TSS levels are associated with higher turbidity levels. Turbidity also exerts weak positive correlations with EC (0.24) and salinity (0.35), whereas TSS shows weak positive correlations with EC (0.19) and salinity (0.31). DO shows weak negative correlations with EC (-0.31), hardness (-0.27), turbidity (-0.24), and pH (-0.11), suggesting that lower EC, hardness,

turbidity, and pH levels are associated with higher DO levels. COD displays weak positive correlations with pH (0.07), TSS (0.22), turbidity (0.24), EC (0.3), salinity (0.32), TDS (0.33), and hardness (0.3). Finally, hardness shows a weak positive correlation with EC (0.44), and moderate positive correlations with salinity (0.48), TSS (0.48), and turbidity (0.49). It also indicates weak negative correlations with DO (-0.27) and temperature (-0.35).

3.3.2 Pearson Correlation among soil quality parameters (dry and wet seasons)

Fig. 6A shows the Pearson correlation coefficients among different measured soil quality parameters during the dry season. pH indicates a strong negative correlation with calcium (-0.55), suggesting that higher pH levels are related to lower calcium content, whereas moisture content shows weak correlations with maximal parameters. EC shows a negative correlation with boron (-0.29). Temperature exhibits a moderate positive correlation with magnesium (0.74), signifying that higher magnesium content is associated with higher temperatures. Temperature demonstrates a strong negative correlation with boron (-0.51) and a moderate negative correlation with calcium (-0.22). Organic matter (OM) content reflects a strong positive correlation with total N₂ (0.98), indicating that higher nitrogen levels are associated with higher OM content. Most parameters show weak correlations with potassium (K) contents. Calcium (Ca) highlights a weak positive correlation with phosphorus

(0.23). Phosphorus (P) exhibits moderate positive correlations with EC (0.4), Mn (0.41), and Zn (0.42). Sulfur (S) signifies a strong negative correlation with calcium (-0.61). Boron (B) has moderate negative correlations with EC (-0.29) and Mg (-0.3). It also shows weak positive correlations with Cu (0.33) and Zn (0.38). Cu exerts a strong positive correlation with iron (0.88). Zinc (Zn) shows moderate positive correlations with moisture (0.42), phosphorus (0.42), and copper (0.43). It also exhibits weak positive correlations with EC (0.15) and Mg (0.15). Iron (Fe) shows moderate positive correlations with OM (0.56) and total N₂ (0.24); and a moderate negative correlation with Ca (-0.24). Lastly, Manganese (Mn) has weak positive correlations with magnesium (0.1), sulfur (0.11), and zinc (0.11).

Fig. 6B displays the Pearson correlation coefficients among different measured soil quality parameters during the wet season. Firstly, pH exhibits strong negative correlations with zinc (-0.55) and boron (-0.55). On the contrary, moisture content reflects moderate positive correlations with EC (0.51), zinc (0.55), boron (0.55), total nitrogen (0.56), and OM (0.57). Electrical Conductivity (EC) shows weak positive correlations with most parameters. Temperature highlights weak negative correlations with iron (-0.12), and manganese (-0.16). There is a very strong positive correlation between organic matter (OM) and total nitrogen (0.97) and a weak negative correlation with iron (-0.17). Total Nitrogen (N₂) shows a relatively weak positive correlation with phosphorus (0.31). Potassium (K) signifies strong positive correlations with OM (0.83) and total nitrogen (0.78); and a weak negative correlation with iron (-0.11). Calcium (Ca) shows a moderate positive correlation with magnesium (0.60) and a moderate negative correlation with zinc (-0.44). Magnesium (Mg) exhibits weak positive correlations with OM (0.05), total nitrogen (0.05), temperature (0.09), and moisture (0.12). Phosphorus (P) shows a strong positive correlation with sulfur (0.77), and Sulfur (S) shows a weak negative correlation with iron (-0.28). Boron (B) exhibits strong positive correlations with OM (0.81) and total nitrogen (0.79). It also shows weak negative correlations with iron (-0.18) and temperature (-0.22). Copper (Cu) highlights a strong positive correlation with iron (0.84) and moderate negative correlations with boron (-0.30) and zinc (-0.30). Zinc (Zn) exhibits a very strong positive correlation with boron (0.97). Iron has weak negative correlations with potassium (-0.11), temperature (-0.12),

moisture (-0.13), zinc (-0.15), OM (-0.17), boron (-0.18), magnesium (-0.19), and total nitrogen (-0.22). Manganese (Mn) shows a strong positive correlation with iron (0.70), and a moderate negative correlation with sulfur (-0.43).

3.3.3 Principal component analysis of water quality parameters (dry and wet seasons)

The PCA for the dry season in Fig. 7A demonstrates that the first two principal components interpret the majority of the inconsistency among the water quality parameters. The strong alignment of EC, TDS, and salinity along the same vector suggests that the parameters are positively correlated and, during the dry season, have the most significant impact on water quality. On the other hand, DO and pH are placed in the opposite direction, indicating an inverse relationship with the parameters. The water sample parameters' clustering around these vectors exhibits a homogeneous water quality pattern, primarily driven by salinity-related factors, with some distinct outliers.

In the wet season, the PCA from Fig. 7B highlights a separate water quality parameters' influence pattern. Turbidity, nitrate, and phosphate indicate strong positive correlations, as depicted by their close grouping, and they are significantly responsible for the water quality variability during this season. The aggravated scatter of water samples exerts a greater variability in the water quality, likely because of agricultural areas' increased runoff and nutrient load. The water samples' distinct separation and the divergence of influential parameters, e.g., turbidity and nutrients, signify the seasonal dynamics, where sedimentation and nutrient enrichment highly influence the water quality during the wet season.

3.3.4 Principal component analysis of soil quality parameters (dry and wet season)

According to Fig. 8A, the PCA for the dry season depicts a clustering of soil samples around particular physicochemical and nutrient parameters, highlighting a more homogeneous distribution among soil properties. Parameters such as soil pH, EC, and potassium (K) are revealed to have a significant influence, as displaced by their dominant state along the principal components. These outcomes suggest that soil chemistry during the dry season is largely influenced by these alluded factors, which are likely affected by lower moisture content and

subtle leaching. The tight grouping of soil samples demonstrates that relatively these parameters are uniform across the sampling locations, expressing consistent soil conditions during this season. In addition, OM appears to have less influence, possibly due to decreased microbial activity in the dry season.

In the wet season, the PCA from Fig. 8 illustrates a broader spread of soil samples, revealing greater inconsistency in the soil characteristics compared to the dry season. Parameters such as OM, nitrogen (N), and phosphorus (P) exhibit stronger correlations suggesting that during the wet season, these factors are highly influenced by aggravated rainfall and organic decomposition. The spread of soil samples implies that among soil characteristics, there is a more dynamic variation likely due to changes in water content and availability of nutrients resulting from runoff, leaching, and enhanced biological activity. From the dry to wet season, the shift in dominant parameters highlights how nutrient dynamics and soil fertility are more variable and subjected to moisture during the rainy season.

4. DISCUSSION

The water samples' pH for both dry and wet seasons are obtained at 6.99 and 7.6 respectively, falling within the acceptable limit for industrial and domestic use [39], and irrigated agriculture [37,40]. Albeit, pH does not exceed the optimum value but in the dry season, the Gorai River's water is slightly acidic. In addition, the temperature's mean values are 20.88 and 31.04 for dry and wet seasons respectively, and it does not exceed the WHO standard value. The water samples' temperature for both seasons showed no extreme changes and was suitable for irrigation purposes, and domestic and industrial uses [37, 39, 41]. During the dry season, the Gorai River's water salinity is comparatively higher than the wet season but values remain below the permissible limit. In water, mean values of total dissolved solids (TDS) are found at 438.3 and 161.3 respectively for both dry and wet seasons and these values do not exceed the DoE and WHO standard limits which means the Gorai River water does not hold metals over the allowable limit [27]. For the dry and wet seasons, electrical conductivity (EC) values are 468.06 and 218.6 respectively, and do not surpass the WHO standard value. High EC values indicate many ionic substances in water [42]. Turbidity in Gorai River water for dry and wet seasons are obtained at 4.73 and 300

respectively, and the mean values' variation between the two seasons is huge exceeding the WHO and DoE standard limits. TSS for both the dry and wet seasons are 0.79 and 53.25 respectively, and do not surpass the WHO standard value with a huge difference between these two periods. COD values for both seasons are found at 3.32 (dry) and 4.09 (wet) respectively falling within the WHO and DoE limits where the value is slightly higher during the wet season. Lastly, the mean values of DO and hardness do not exceed the acceptable limits of WHO and DoE. However, the study area's ambient temperature was colder during the dry season compared to the wet season, which in the colder climate may influence the dissolving of more oxygen than the warmer ones [39]. Thus, it can be seen that measured values of physicochemical parameters do not exceed the WHO and DoE standards. Nevertheless, the results highlighted a huge difference between these two seasons (dry and wet) suggesting the Gorai River water quality's seasonal dynamics.

Soil physicochemical parameters' mean values have significant variations in pH, electrical conductivity, Ca, Cu, Fe, and Mn, identified from the ANOVA test in this study for both dry and wet seasons. pH values are respectively 7.41 and 7.26 during both dry and wet seasons representing neutral but exceeding the standard value. Soil pH relies on the sorts of parent materials or basic rock, and soil acidity can be increased by rainfall [43]. Therefore, it can be said that in the dry season, the mean value of pH is greater because of low rainfall than in the wet season. EC mean values depict a huge difference during both dry and wet seasons and further state that the salinity level can be determined by measuring EC. In the present study, salinity concentration is higher (88.73) in the dry season. Ca values are respectively 3.81 and 18.92 suggesting that Ca remains in a smaller quantity in the dry season than the standard value; and exists in a huge amount in the wet season exceeding the standard value. Cu mean values are 2.82 and 0.92 respectively, exceeding the standard value in both seasons, and the value is greater during the dry season compared to the wet season. Fe values are 40.53 and 14.75 respectively in both dry and wet seasons, and surpasses the standard value for upland and wetland. Mn mean values are 7.70 and 1.83 respectively signifying a huge difference between these seasons and it exceeds the optimum value in the dry season for both upland and wetland. Lastly, during dry and

wet seasons, the variation in mean values is not found in moisture, organic matter, total nitrogen, K, Mg, P, S, B, and Zn.

The correlation among water quality parameters of the Gorai River demonstrates that salinity has a strong positive correlation during both seasons (dry and wet) with TDS and EC. In water samples, higher TDS results in greater EC, making EC a feasible indicator of TDS levels. In the Pashur River, TDS and EC are strongly correlated [44]. There has been a strong positive correlation between turbidity and TSS in both dry and wet seasons. Daphne et al. [45], highlighted that turbidity levels effectively portend TSS concentration in rivers because of their strong positive correlation, resulting in turbidity as a cost-effective approach for estimating TSS. Dissolved oxygen (DO) exhibits moderate positive correlations with TSS and turbidity in the dry season but shows a weak negative correlation in the wet season. Suspended particles can support the photosynthetic bacteria's growth, generating oxygen and increasing DO levels, and DO maintains favourable relationships with both TSS and turbidity. Furthermore, turbulent water can uplift the oxygen transfer from the atmosphere into water and is often linked to greater TSS and turbidity. During the dry season, hardness exhibits weak to moderate correlations with the pH, TDS, EC, and salinity; during the wet season, it has moderate positive correlations with EC, salinity, TSS, and turbidity. In contrast, during the dry season, pH exhibits a moderate negative correlation with dissolved oxygen (DO) and a weak negative correlation during the wet season. Therefore, between pH and DO, simply by the chemical equilibrium, pH can generally show a positive linear relationship with DO [46]. This relationship can be changed by aggregation of factors, e.g., algal photosynthesis, water temperature, aquatic respiration, and the organic matter's oxidative decomposition, which may result in an inverse correlation trend. During the dry season, EC and TDS display strong negative correlations with turbidity; and COD displays weak negative relationships with DO and TSS. Hardness signifies a moderate to weak negative correlation with temperature during both dry and wet seasons, and a moderate correlation with DO.

The correlation among Gorai Riverbank's soil quality parameters shows that organic matter has a strong positive correlation with total nitrogen in both dry and wet seasons. Therefore, higher OM

generally indicates higher N₂ in the soil. This relationship is important for maintaining soil fertility and supporting healthy plant growth, especially in environments like riverbanks, where soil composition can significantly impact the surrounding ecosystem. A moderate negative correlation was found between pH and nitrogen (N₂). There was a significant correlation between pH and organic matter (OM) in soil samples from the coastal region of Bangladesh [47]. However, the organic matter present in the soil influences the major proportion of nitrogen in the soil [48]. Soil organic matter (SOM) and total nitrogen are not only important components of wetland soils but also the ecological factors of wetland ecosystems that greatly influence the productivity of wetland ecosystems [49]. Potassium and phosphorous have a weak positive correlation in both seasons. This correlation means that as one level increases slightly, the other tends to increase as well. This suggests a mild interaction between these two nutrients in the soil environment. Mandal and Ghosh [50] also discovered a significant correlation between potassium, nitrogen, and available phosphorus. A positive correlation exists in this study between Cu and Fe during both seasons. A positive relationship between copper and iron in soil samples [51], while Singh et al. [52] reported a strong positive relationship in soil samples due to their similar geochemical behaviour and tendency to co-occur in mineral deposits and organic matter. Irrigation using low-quality water without taking into account the permitted levels has detrimental effects on the surrounding ecosystem, including nearby soil, drain sediment, and humans [53]. It is advised to conduct regular assessments, smaller-scale household waste treatment, and centralized industrial waste treatment to limit pollution, which can lessen the detrimental effects on water quality [54].

5. CONCLUSION

The study attempted to evaluate the seasonal dynamics of water and embanked soil quality in the Gorai River, Kushtia. The results of one-way ANOVA demonstrated significant seasonal variations in several water quality parameters, including turbidity, TSS, EC, COD, and pH except for DO and hardness. Moreover, the Pearson correlation revealed a strong correlation between EC and TDS and turbidity and TSS in water samples from both the dry and wet seasons. Conversely, the soil samples showed significant differences in EC, Ca, Cu, Fe, and Mn, indicating a robust correlation between

organic matter and total nitrogen. Additionally, both seasons demonstrated a positive correlation between Cu and Fe. The Principal Component Analysis (PCA) signified that salinity-related parameters, specifically EC and TDS, exert the most significant impact on water quality during the dry season. However, in the wet season, there is more variation in nitrogen, phosphorus, and organic matter, playing important roles because of increased moisture and changes in nutrient levels in the soil samples. Water quality was better in the dry season (July- August) compared to the wet season (January-February), where pollution levels were significantly higher. This study demonstrates that while soil and water quality are currently within safe limits, the quality of the analyzed parameters is deteriorating at an alarming rate. The findings of this study will provide valuable insights to researchers, policymakers, and investigators, developing strategies to enhance their endeavours in managing soil and water quality sustainably.

However, variability in land use practices along the river and potential anthropogenic influences like agricultural runoff and industrial pollution were not accounted in detail, which could affect the overall conclusions. Furthermore, this study only used a specific set of chemical parameters, excluding biological and microbial assessments, which could provide a more holistic view of water and soil health. Future research should be conducted in this river, including biological indicators, such as microbial contamination and aquatic biodiversity, giving a more comprehensive understanding of ecosystem health and agricultural productivity.

HIGHLIGHTS:

- Though the seasonal dynamics of turbidity, TSS, TDS, COD, and EC seem significantly varied in water samples, DO and hardness are consistent over the seasons.
- The pH, EC, Ca, Cu, Fe, and Mn differences between dry and wet seasons represent seasonal soil fertility variations.
- Throughout the year, EC and TDS, turbidity and TSS (from water samples); OM and N₂, and Cu and Fe (from soil samples) strongly correlate with each other.
- According to PCA results, salinity is the most dominant factor in the dry season's water quality; parallelly, nutrient dynamics

play a vital role in soil quality in the wet season.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

SUPPLEMENTARY MATERIALS

Supplementary materials available in this link: <https://journaljgeesi.com/index.php/JGEESI/libraryFiles/downloadPublic/18>

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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