Original Research Article

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

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 exceptdissolved 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 (N_2), 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 N_2, 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 important, and inevitable for the sustenance of life [1]. Around 40% of the world's food supply, today 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, and groundwater and surface water quality [4]. Besides water and air quality, soil quality is one of the 3 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 Gangas-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, furthermore it 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] 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]. To assess the surface water quality’s seasonal variation in different periods considering river toxicity, water quality parameters, and physicochemical properties, multivariate statistical techniques have been used by numerous researchers [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 management sustainably 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 the agricultural productions 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 23.94^0 and 23.88^0 north latitudes, and between 89.11^0 and 89.18^0 east longitudes [27]. The Gorai River is the Padma River's only and largest perennial distributary 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 including 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% HNO_3 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 HNO_3 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 1-4**.

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**.

Table 1: Methods and equipment used in laboratory analysis

Parameters	Materials/Equipment	Unit
Temperature	Portable Glass Mercury Thermometer	(^{0}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

2.3.2 Soil Sample Analysis

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

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 Kurt’z 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

2.4 Statistical Analysis

To assess the seasonal dynamics of the Gorai River’s water quality and embankment soil quality, a comprehensive statistical analysis has been conducted. The statistical analyses namely statistical calculations 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 parameters were normally distributed separately for each season (Prob. < 0.05) and presented in **Table 3-4**

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 metricis 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 illustrate the interrelationships between the soil and water physicochemical 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 thekey indicator variables and convert these into independent principal components [33]. A Principal Component identifies the most significant variables in a dataset, aidingin data reduction while conserving as much of the main information as possible [34]. Assessing the water quality of anentire 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)

Table3 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 rangedbetween 6.5 and 7.39 in the dry season, and in the wet season from 6.87 to 8.7, with average values of 6.99 and 7.6 respectively, both falling within the acceptable limit of 6.5 to 8.5.

Measuredtemperatureshowedupward 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, exceedingthe 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 µS/cm) in the dry season in comparison to the wet season values (average 218.6 µS/cm), both falling below the standard limit of 700-3000 µS/cm.

Table 3: Descriptive statistics of measured water quality parameters (dry and wetseasons)

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

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 ± 0.16°C to in the wet season 33.62 ± 2.68°C, though no specific optimum limits are provided for temperature. Salinity levels 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 μS/cm) than the wet season (53 ± 14.35 μS/cm), both surpass the optimum limit of <4 μS/cm. During the dry season, moisture content was 44.13 ± 17.02% (average) and slightly onward to 48.93 ± 19.35% during the wet season. However, organic Matter (OM) extent was relatively stable throughout seasons, averaging 1.29 ± 0.40% (dry season) and 1.24 ± 0.23% (wet season). Nitrogen (N2) content was also consistent across seasons; in the dry season (averaging 0.06 ± 0.01%) and in the wet season (averaging 0.057 ± 0.01%), both remained below the optimum values of 0.27-0.36%.

Table 4: Descriptive statistics of measured soil quality parameters (dry and wetseasons)

Parameters	**Unit**	**Number of Samples**	**Minimum**		**Maximum**		**Average ±SD**		**Optimum value [38]**	
			Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Upland**	**Wetland**
pH	--	15	7.2	6.9	7.6	7.5	7.41 ± 0.14	7.26 ± .23	6-7	6-7
Temperature	(^0C)	15	20.4	28.7	21	38.4	20.71 ± .16	33.62 ± 2.68	--	--
Salinity	ppm	15	36	17	271	43	88.73 ± 59.4	26.6 ± 7.01	--	--
TDS	ppm	15	80	200	520	700	168 ± 110.33	473.33 ± 116.29	--	--
Electrical Conductivity	µs/cm	15	74	32	550	87	182.93 ± 118.14	53 ± 14.35	<4000	<4000
Moisture	(%)	15	17	21	75	77	44.13 ± 17.02	48.93 ± 19.35	--	--
Organic Matter	(%)	15	.71	28.7	2.05	38.4	1.29 ± .40	1.24 ± .23	--	--
Total N_2	(%)	15	.05	.05	0.1	.09	0.06 ± .01	.057 ± .01	0.27 - 0.36	0.27-0.36
Potassium (K)	meq/100g soil	15	.14	.08	.24	.48	0.192 ± .03	.19 ± .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 ± 1.31	18.92 ± 4.47	4.51 - 6	4.51-6.0
Magnesium (Mg)	meq/100g soil	15	1.12	.45	2	2.64	1.42 ± .27	1.22 ± .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 ± 11.35	8.64 ± 5.11	22.51 - 30	18.1-24
Sulfur (S)	ppm	15	6.7	5.3	19.2	17.9	11.3 ± 3.62	10.09 ± 3.42	22.51-30	27.1-36
Boron (B)	ppm	15	.21	.12	.49	.57	.31 ± .08	0.238 ± .134	0.451-0.6	0.45-0.6
Copper (Cu)	ppm	15	1.19	.17	4.61	1.75	2.82 ± .95	0.92 ± .56	0.451-0.6	0.45-0.6
Zinc (Zn)	ppm	15	.19	.07	.85	2.11	.4 ± .2	0.47 ± .64	1.351-1.8	1.35-1.8
Iron (Fe)	ppm	15	14.8	5	65	33.6	40.53 ± 15.45	14.75 ± 7.84	9.1-12	9.1-12
Manganese (Mn)	ppm	15	2.63	1.1	13.3	3.7	7.70 ± 2.41	1.83 ± .72	2.256-3	2.25-3.0

Potassium (K) levels ranged averaging 0.192 ± 0.03% (dry season) and 0.19 ± 0.09% (wet season), lower than the optimum limits of 0.27-0.36%. Calcium (Ca) content significantly increased from 3.81 ± 1.31% (dry season) to 18.92 ± 4.47% (wet season), exceeding the optimum values of 4.51-6%. Magnesium (Mg) levels in the dry season averaged 1.42 ± 0.27% and in the wet season averaged 1.22 ± 0.64%, falling within the optimum range (1.126-1.5%).Phosphorus (P) content reduced from 13.92 ± 11.35% (dry season) to 8.64 ± 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 ± 3.62% in the dry season and 10.09 ± 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 ± 0.08% (dry season) and 0.238 ± 0.134% (wet season), within the optimum values of 0.451-0.6%.Copper (Cu) levels werecontrarily higher during the dry season, (averaging 2.82 ± 0.95%) than 0.92 ± 0.56% during the wet season, both exceeding the optimum limits(0.451-0.6%). Zinc (Zn) levels averaged 0.4 ± 0.2% (dry season) and 0.47 ± 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 ± 15.45%in the dry season, compared to 14.75 ± 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 ± 2.41%) in comparison to the wet season (averaging 1.83 ± 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-wayANOVAtest results show that there were statistically significant variations among mean values (pvalue< 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 resultsin **Fig. 4**depict that there is astatistically significantdissimilation 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 N_2, 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. 5Aillustrates the Pearson correlation coefficients among differentmeasured water quality parameters during the dry season. pH exhibits a moderate positive correlation with EC suggesting that the parameter tends to riseif 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 expectedconferredtheir 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), anda strong positive correlation with turbidity (0.88).DO exhibitsa moderate positive correlation with TSS turbidity (0.5), and moderate negative correlations with TDS (-0.40), salinity (-0.43), EC (-0.44), and pH (-0.52) suggesting thatlower 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. 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 be increased. Conversely, pH exhibits a moderate negative correlation with hardness (-0.3) andtemperature (-0.31), indicating that lower temperatures and hardness are associated with higher pH levels.Temperature also showsa moderate negative correlation with TDS (-0.42), and strong negative correlations with EC (-0.83) and salinity (-0.86) signifying that lower salinity, EC, andTDS levels are associated with higher temperatures. Temperature demonstratesa weak negative correlation with hardness (-0.35). A strong 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 strong 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 pHlevels 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) andtemperature (-0.35).

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

Fig. 6Ashows 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 relatedto lower calcium content whereas moisture content shows weak correlations with maximalparameters.EC showsa negative correlationwith boron (-0.29). Temperatureexhibits a moderate positive correlation with magnesium (0.74), signifying that higher magnesium content is associated with higher temperatures. Temperature demonstratesa 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 N_2 (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 withphosphorus (0.23). Phosphorus (P) exhibits moderate positive correlations with EC (0.4), Mn (0.41), and Zn (0.42). Sulfur (S) signifiesa strong negative correlation with calcium (-0.61). Boron (B) has moderate negative correlations with EC (-0.29) and Mg (-0.3). It alsoshows 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 N_2 (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. 6Bdisplays the Pearson correlation coefficients among different measured soil quality parameters during the dry 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 (N_2) 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) showsa strong positive correlation with sulfur (0.77), and Sulfur (S) shows a weak negative correlation with iron (-0.28). Boron (B) exhibits strongpositive 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); andmoderatenegative 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 theparameters 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, primarilydriven 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 ofagricultural 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 qualityduring 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 areuniform 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 asOM, 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 dynamicsand 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 favorable 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 (N_2). 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 behavior 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 attemptedtoevaluate 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 endeavors 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 variated 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 N_2, 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.

References

1. Suthar S, Sharma J, Chabukdhara M, Nema AK. Water quality assessment of river Hindon at Ghaziabad, India: impact of industrial and urban wastewater. Environmental monitoring and assessment. 2010 Jun;165:103-12. Available:https://doi.org/10.1007/s10661-009-0930-9
2. Islam SM, Karim Z. World's demand for food and water: The consequences of climate change. Desalination-challenges and opportunities. 2019 Aug 8;2019. Available:https://doi.org/10.5772/intechopen.85919
3. Ahmed AS, Sánchez CP, Candela ME. Evaluation of induction of systemic resistance in pepper plants (Capsicum annuum) to Phytophthora capsici using Trichoderma harzianum and its relation with capsidiol accumulation. European Journal of Plant Pathology. 2000 Nov;106:817-24. Available:https://doi.org/10.1023/A:1008780022925
4. Suravi S, Islam MS, Ali MA, Meghla NT, Nargis Sultana NS. Seasonal variations of physicochemical parameters of water in the Pungli River, Tangail, Bangladesh. 2013.
5. Andrews SS, Karlen DL, Mitchell JP. A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agriculture, ecosystems &

environment. 2002 Jun 1;90(1):25-45. Available:https://doi.org/10.1016/S0167-8809(01)00174-8

6. Miah MY, Kamal MZ, Salam MA, Islam MS. Impact of salinity intrusion on agriculture of Southwest Bangladesh-A review. International Journal of Agricultural Policy and Research. 2020 Apr. Available:https://doi.org/10.15739/IJAPR.20.005
7. Lam Y, Winch PJ, Nizame FA, Broaddus-Shea ET, Harun MG, Surkan PJ. Salinity and food security in southwest coastal Bangladesh: impacts on household food production and strategies for adaptation. Food Security. 2022 Feb 1:1-20. Available:https://doi.org/10.1007/s12571-021-01177-5
8. Guimbeau A, Ji X, Menon N, Long Z. An extra grain of salt: The effect of salinity exposure on early life health outcomes in coastal Bangladesh. 2022. Available:http://dx.doi.org/10.22004/ag.econ.322076
9. Ahmed MF, Haider MZ. Impact of salinity on rice production in the south-west region of Bangladesh. Environ Sci. 2014;9:135-41.
10. Coleman JM. Brahmaputra River: channel processes and sedimentation. Sedimentary geology. 1969 Aug 1;3(2-3):129-239. Available:https://doi.org/10.1016/0037-0738(69)90010-4
11. Rahman AA, Huq S, Conway GR. Environmental aspects of surface water systems of Bangladesh. 1990.
12. Rahman AA, Huq S, Reddy A, Alam M, Kabir SA. Bangladesh: State of the Environment 2001. United Nations Environmental Programme (UNEP).2001.
13. Bunn SE, Arthington AH. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental management. 2002 Oct;30:492-507. Available:https://doi.org/10.1007/s00267-002-2737-0
14. Magilligan FJ, Nislow KH. Changes in hydrologic regime by dams. Geomorphology. 2005 Oct 1;71(1-2):61-78. Available:https://doi.org/10.1016/j.geomorph.2004.08.017
15. DoE (Department of Environment). Annual Report. Dhaka, Bangladesh. 1993;25.
16. Hossain A. Evaluation of Surface water Quality: A case study on Surma River. Sc. Engineering Thesis, Civil and Environmental Engineering Department, Shahjalal University, Bangladesh. 2001.
17. Ahmed MK, Das M, Islam MM, Akter MS, Islam S, Al-Mansur MA. Physico-chemical properties of tannery and textile effluents and surface water of River Buriganga and Karnatoli, Bangladesh. World Applied Sciences Journal. 2011 Jun 22;12(2):152-9.
18. Rahman AK, Islam M, Hossain MZ, Ahsan MA. Study of the seasonal variations in Turag river water quality parameters. African Journal of pure and applied Chemistry. 2012 May 30;6(10):144-8. Available:https://dx.doi.org/10.5897/AJPAC12.023
19. Islam MS, Kabir MH, Sifat SA, Meghla NT, Tusher TR. Status of water quality from the Padma river at Bheramara point of Kushtia in Bangladesh. Bangladesh Journal of Environmental Science. 2014;27:110-5.

20. Barakat A, El Baghdadi M, Rais J, Aghezzaf B, Slassi M. Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. International soil and water conservation research. 2016 Dec 1;4(4):284-92. Available:https://doi.org/10.1016/j.iswcr.2016.11.002
21. Tahmina B, Sujan D, Karabi R, Hena MK, Amin KR, Sharmin S. Assessment of surface water quality of the Turag River in Bangladesh. Research Journal of Chemistry and Environment. 2018 Feb;22(2):49-56.
22. Machender G, Dhakate R, Narsimha Reddy M, Panduranga Reddy I. Hydrogeochemical characteristics of surface water (SW) and groundwater (GW) of the Chinnaeru River basin, northern part of Nalgonda District, Andhra Pradesh, India. Environmental earth sciences. 2014 Mar;71:2885-910. Available:https://doi.org/10.1007/s12665-013-2665-8
23. Hafizur RM, Nuralam HM, Rumainul IM. Investigation of physicochemical parameter, heavy metal in Turag river water and adjacent industrial effluent in Bangladesh. Journal of science, technology and environment informatics. 2017;5(1):347-60. Available:https://doi.org/10.18801/jstei.050117.37
24. Jolly YN, Rana S, Akter S, Kabir J, Rahman MS, Rahman MM, Sultana MS. APPRAISAL OF METAL POLLUTION IN THE AQUATIC ENVIRONMENT OF SHITALAKHYA RIVER, BANGLADESH AND ITS ECOLOGICAL RISK ASSESSMENT. Journal of Nature Science & Sustainable Technology. 2018 Oct 1;12(4).
25. BWDB (Bangladesh Water Development Board). Environmental and Social Impact Assessment of Gorai River Restoration Project. Environmental and GIS Support Project for Water Sector Planning. Ministry of Water Resources, Govt. of Bangladesh, Dhaka.2001.
26. EGIS (Environmental and Geographical Information System). Environmental baseline of Gorai River restoration project, EGIS-II. Bangladesh Water Development Board, Ministry of Water Resources, Government of Bangladesh, 2000, 150.
27. Nahar N, Lanon MA, Sah B, Shaibur MR. Assessment of physico-chemical properties of water of Gorai river at Kushtia town in 2014: a case study. J. Sci. Technol. Environ. Inform. 2016;2(2):51-60. Available:http://dx.doi.org/10.18801/jstei.020216.16
28. Rogerson PA. Statistical methods for geography: A student's guide. 2019. Available:http://digital.casalini.it/9781529700237
29. Kitsiou D, Karydis M. Coastal marine eutrophication assessment: a review on data analysis. Environment international. 2011 May 1;37(4):778-801. Available:https://doi.org/10.1016/j.envint.2011.02.004
30. Mustapha A, Aris AZ, Yusoff FM, Zakaria MP, Ramli MF, Abdullah AM, Kura NU, Narany TS. Statistical approach in determining the spatial changes of surface water quality at the upper course of Kano River, Nigeria. Water Quality, Exposure and Health. 2014 Sep;6:127-42. Available:https://doi.org/10.1007/s12403-014-0117-7
31. Yang Q, Kang Q, Huang Q, Cui Z, Bai Y, Wei H. Linear correlation analysis of ammunition storage environment based on Pearson correlation analysis. InJournal of physics: Conference

series 2021 Jun 1 (Vol. 1948, No. 1, p. 012064). IOP Publishing. Available:https://doi.org/10.1088/1742-6596/1948/1/012064

32. Roy M, Shamim F, Chatterjee S. Evaluation of physicochemical and Biological parameters on the water quality of ShilabatiRiver, West Bengal, India. Water Science. 2021 Jan 1;35(1):71-81. Available:https://doi.org/10.1080/23570008.2021.1928902
33. Arslan O. Spatially weighted principal component analysis (PCA) method for water quality analysis. Water Resources. 2013 May;40:315-24. Available:https://doi.org/10.1134/S0097807813030111
34. Shrestha S, Kazama F. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environmental Modelling & Software. 2007 Apr 1;22(4):464-75. Available:https://doi.org/10.1016/j.envsoft.2006.02.001
35. Canobbio S, Azzellino A, Cabrini R, Mezzanotte V. A multivariate approach to assess habitat integrity in urban streams using benthic macroinvertebrate metrics. Water science and technology. 2013 Jun 1;67(12):2832-7. Available:https://doi.org/10.2166/wst.2013.166
36. WHO (World Health Organization). Guidelines for drinking-water quality. World Health Organization. 1998.
37. DoE (Department of Environment). The environment conservation rules 1997. Government of the people’s republic of Bangladesh, Dhaka.1997.
38. BARC (Bangladesh Agricultural Research Council). Fertilizer recommendation guide-2018. 2018. Available:http://www.barc.gov.bd
39. Peavy HS, Matthews DR, Tchobanoglous G. Environmental engineering. 1985.
40. UCCC (University of California Committee of Consultants). Guidelines for interpretations of water quality for irrigation.1974.
41. Gupta SK, Gupta RC, Gupta AB, Seth AK, Bassin JK, Gupta A. Recurrent acute respiratory tract infections in areas with high nitrate concentrations in drinking water. Environmental health perspectives. 2000 Apr;108(4):363-6. Available:https://doi.org/10.1289/ehp.00108363
42. Kabir ES, Kabir M, Islam SM, Mia CM, Begum N, Chowdhury DA, Sultana SM, Rahman SM. Assessment of effluent quality of Dhaka export processing zone with special emphasis to the textile and dying industries. Jahangirnagar University Journal of Science. 2002;25:137-8.
43. Jerin IJ, Islam MK, Bhuyan MI, Majumder MS, Ferdous M, Islam MM. Physicochemical Properties and Nutrient Status of Agricultural Soils in Kuakata, Patuakhali. Journal of Experimental Biosciences. 2021;12(1):59-68.
44. Kabir MA, Hossain MK, Hossain MA, Molla MO, Khatun MS, Jamal MA. Impact of Water and Soil Salinity on Coastal Agriculture in Bangladesh: Insights and Mitigation Strategies. American Journal of Multidisciplinary Research and Innovation. 2024 Jul 2;3(4):36-48. Available:https://doi.org/10.54536/ajmri.v3i4.2927
45. Daphne LH, Utomo HD, Kenneth LZ. Correlation between turbidity and total suspended solids in Singapore rivers. Journal of Water Sustainability. 2011 Dec;1(3):313-22.

46. Zang C, Huang S, Wu M, Du S, Scholz M, Gao F, Lin C, Guo Y, Dong Y. Comparison of relationships between pH, dissolved oxygen and chlorophyll a for aquaculture and non-aquaculture waters. Water, Air, & Soil Pollution. 2011 Jul;219:157-74.Available:https://doi.org/10.1007/s11270-010-069
47. Ghode MK, Vaidya PH, Nawkhare AD, Ingole AJ. Relationship between soil Physico-chemical properties, available macro and micronutrients and yield in cotton growing soils of Nanded district of Maharashtra. Journal of Pharmacognosy and Phytochemistry. 2020;9(3):2062-5.
48. Baruah TC, Borthakur HP. Soil Chemistry. Baruah, TC, Borthakur, HP, A textbook of soil analysis. Vikas Publishing House Pvt. Ltd., New Delhi. 1997:118-32.
49. Mitsch WJ, Gosselink JG. The value of wetlands: importance of scale and landscape setting. Ecological economics. 2000 Oct 1;35(1):25-33.
50. Mandal S, Ghosh GK. Depthwise distribution of macronutrients (N, P, K, S) and their correlation with soil properties in selected soil profiles of Birbhum district of West Bengal, India. International Journal of Chemical Studies. 2021;9(1):2801-9. Available:https://doi.org/10.22271/chemi.2021.v9.i1am.11651
51. Sen A, Zaidi SF, Kumar S. Status of available macro and micro nutrients and their correlation in soils of Eastern Plain Zone (Uttar Pradesh). Journal of Pharmacognosy and Phytochemistry. 2017;6(6S):270-3.
52. Singh YV, Kant S, Singh SK, Sharma PK, Jat LK, Kumar M, Shahi SK, Jatav HS, Yadav RN. Assessment of physico-chemical characteristics of the soil of Lahar block in Bhind district of Madhya Pradesh (India). International Journal of Current Microbiology and Applied Sciences. 2017;6(2):511-9. Available:http://dx.doi.org/10.20546/ijcmas.2017.602.058
53. Mansour H, Ahmed SA, Zaghloul A, Kabary H, Nassar HF. Seasonal variation effect on water quality and sediments criteria and its influence on soil pollution: Fayoum Governorate, Egypt. Environmental Sciences Europe. 2024 Jul 18;36(1):132.Available:https://doi.org/10.1186/s12302-024-00953-2
54. Bukit NT. Water quality conservation for the Citarum River in West Java. Water Science and Technology. 1995 Jan 1;31(9):1-0.Available:https://doi.org/10.1016/0273-1223(95)00400-H

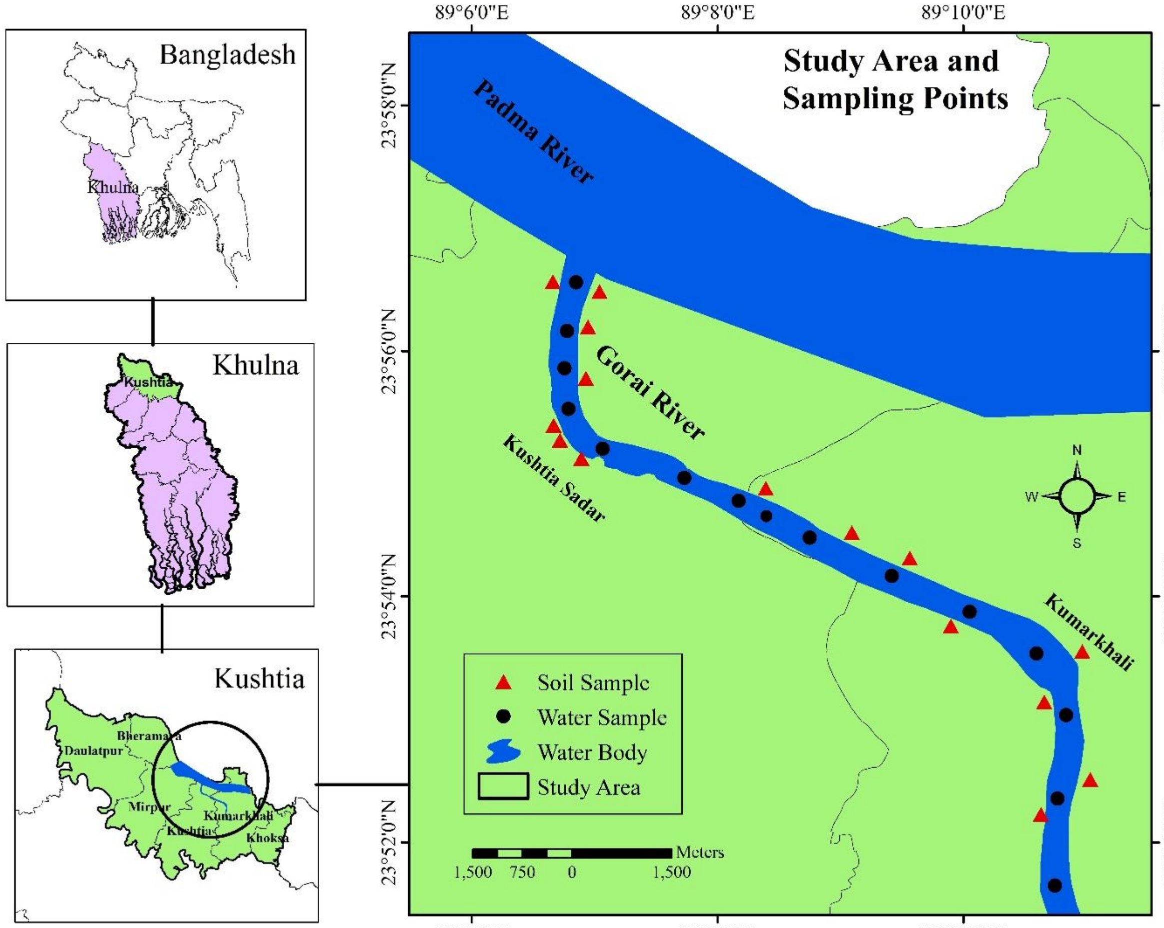

Fig. 1: Study area – The Gorai River and distribution of sampling points

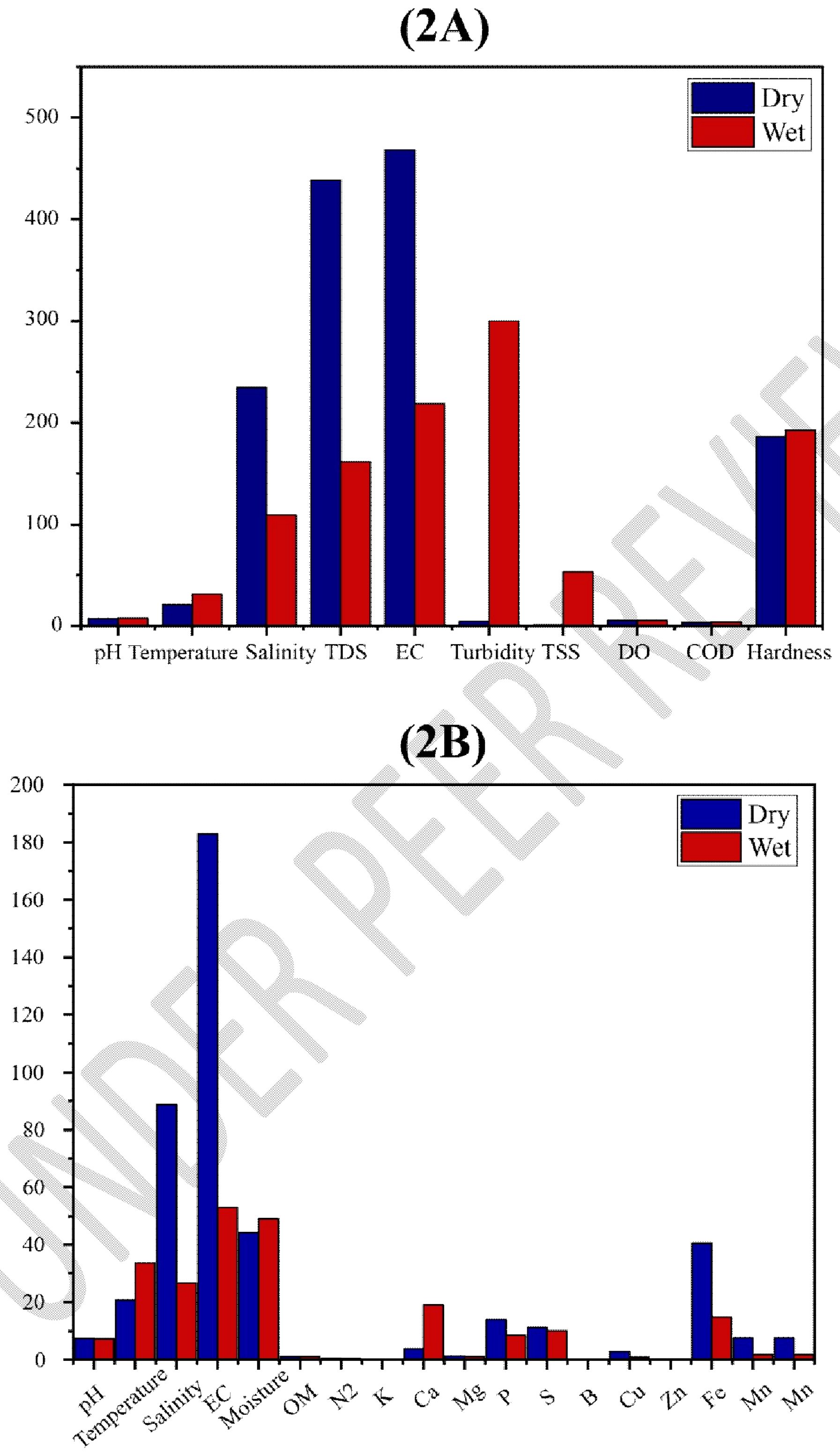

Fig. 2: Comparisons of water (A) and soil (B) quality for both dry and wet season

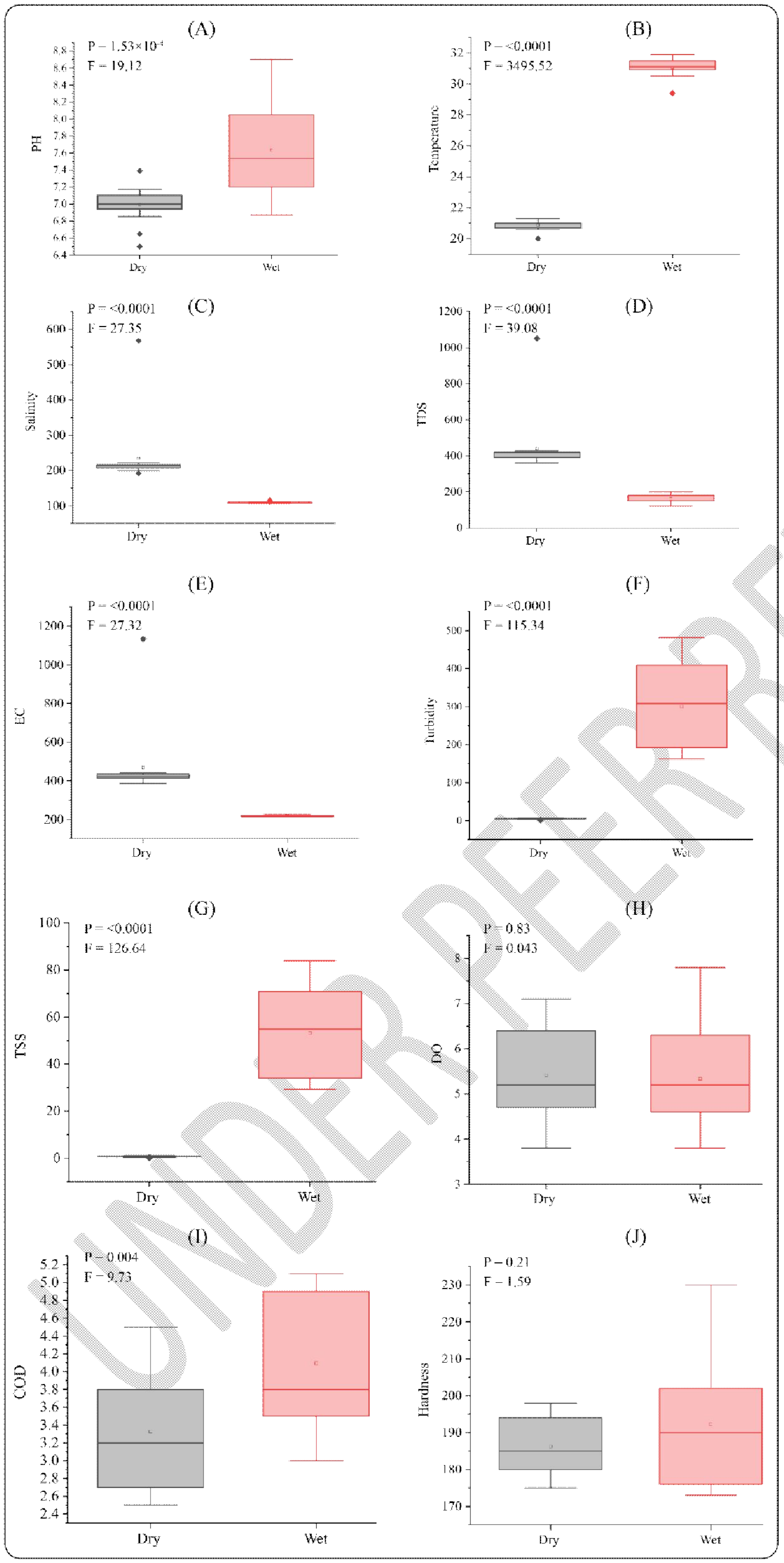

Fig.3: One-way ANOVA test of water sample between dry and wet season

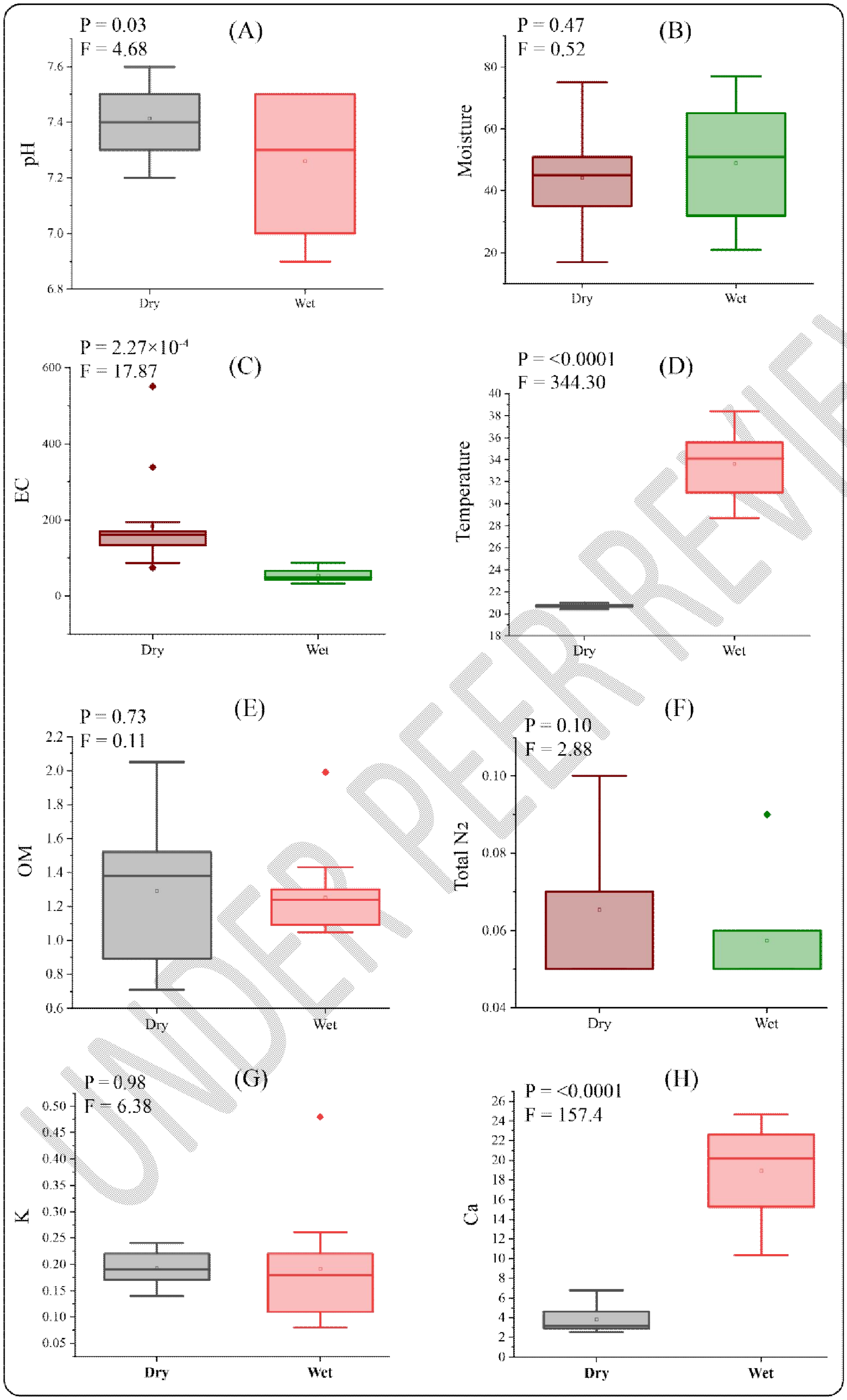
P = 0.03
F = 4.68
(A)
pH
7.6
7.4
7.2
7.0
6.8
Dry
Wet
P = 0.47
F = 0.52
(B)
Moisture
80
60
40
20
Dry
Wet
P = 2.27×10^{-4}
F = 17.87
(C)
EC
600
400
200
0
Dry
Wet
P = <0.0001
F = 344.30
(D)
Temperature
40
38
36
34
32
30
28
26
24
22
20
18
Dry
Wet
P = 0.73
F = 0.11
(E)
OM
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
Dry
Wet
P = 0.10
F = 2.88
(F)
Total N2
0.10
0.08
0.06
0.04
Dry
Wet
P = 0.98
F = 6.38
(G)
K
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
Dry
Wet
P = <0.0001
F = 157.4
(H)
Ca
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Dry
Wet

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

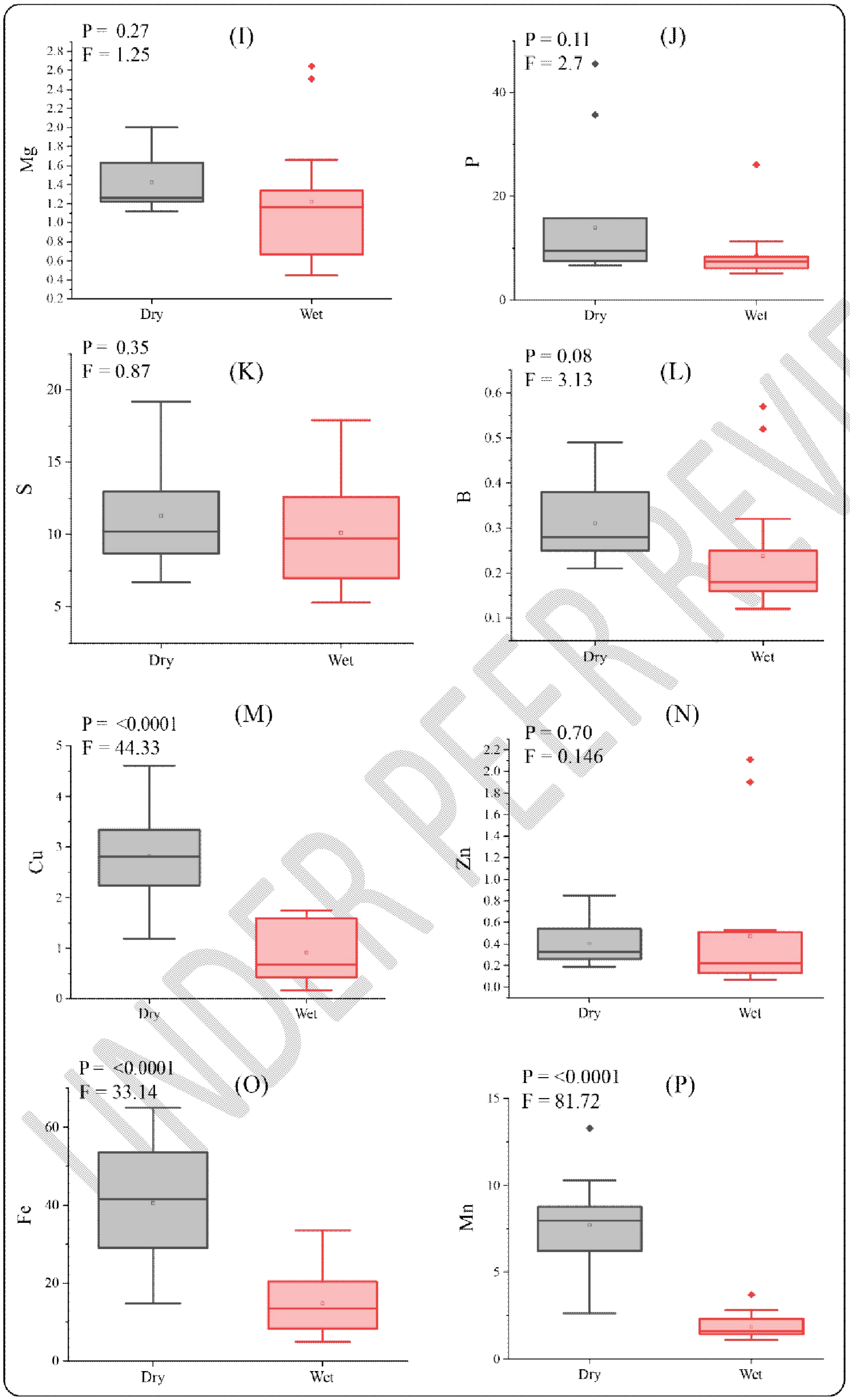

Fig. 4. Cont.…. One-way ANOVA test of soil sample between dry and wet season

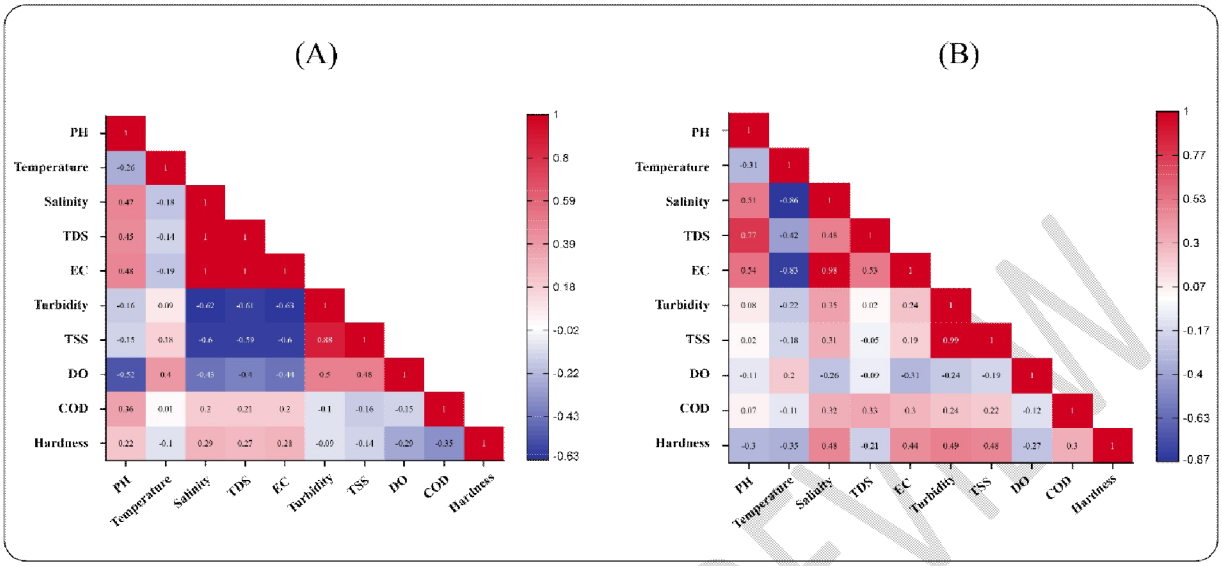

Fig. 5: Pearson correlation among water quality parameters for both dry (A) and wet (B) seasons respectively

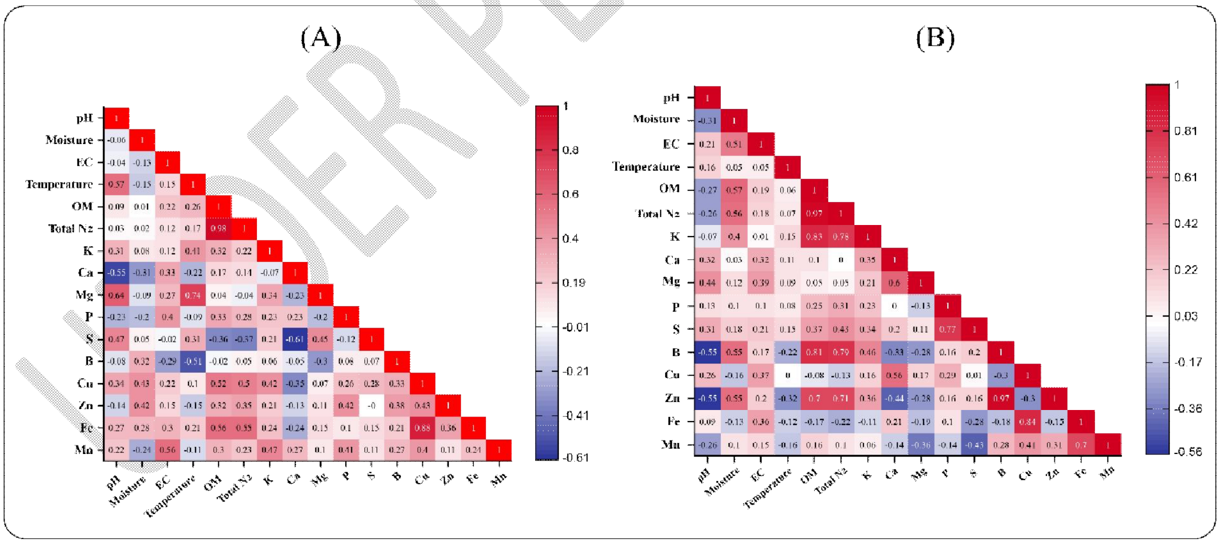

Fig. 6: Pearson correlation among soil quality parameters for both dry (A) and wet (B) seasons respectively

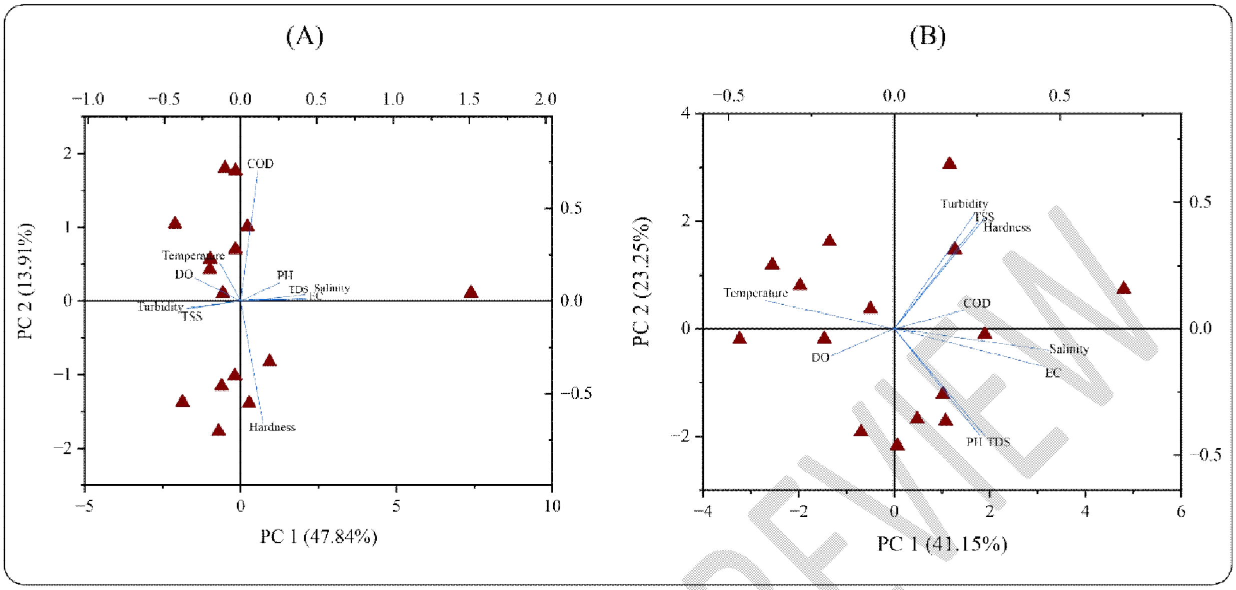

Fig. 7: PCA analysis among water quality parameters for both dry (A) and wet (B) seasons respectively

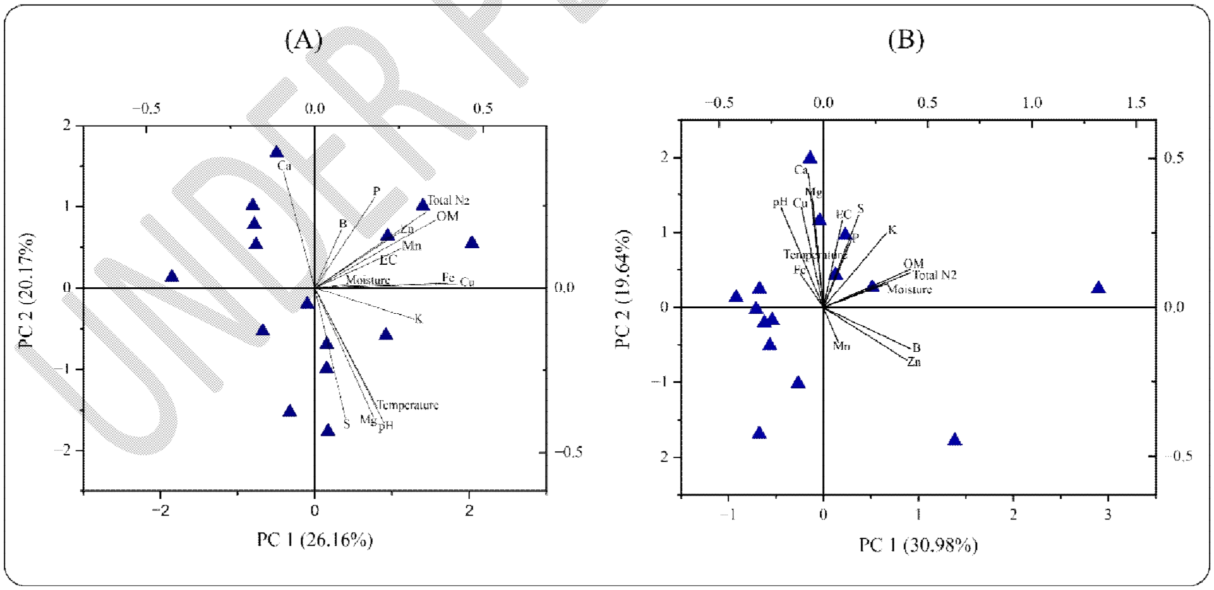

Fig. 8: PCA analysis among soil quality parameters for both dry (A) and wet (B) seasons respectively