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Irrigation Channel Water Quality Monitoring by Multivariate Statistical Methods in the Interior Coastal District of Bangladesh

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Abstract: *Multivariate statistical techniques including cluster analysis (CA), principle component analysis (PCA), and factor analysis (FA) was applied to the water analyses data of the irrigation channel located in Gopalganj, which is one of the interior coastal districts of Bangladesh. The intention of the study was to identify factors controlling water quality in dry (December to February) and pre-monsoon (March to May) season. Total seventy water samples were collected from ten sampling stations in seven sampling phases; twenty water samples were collected in the dry season in two sampling phases, and fifty water samples were collected in the pre-monsoon season in five sampling phases. Twelve water quality parameters namely pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Sodium (Na^+), Potassium (K^+), Calcium (Ca^{++}), Magnesium (Mg^{++}), Bicarbonate (HCO_3^-), Chloride (Cl^-), Phosphate (PO_4^{2-}), Sulfate (SO_4^{2-}), and Nitrate (NO_3^-) were analyzed in the Environmental Quality Laboratory of Khulna University by following standard methods. HCA was applied on the channel water analyses dataset that clustered the parameters into three groups which were distinctive for the two seasons. PCA was conducted to ensure how many factors to be extracted by Factor Analysis (FA). FA analysis revealed that three latent factors namely "salinity-water hardness factor", "biological activity factor", and "anthropogenic pollution factor" controlled the water quality of the dry season with 52.6%, 18.9%, and 18.2% of the total variance, respectively. However, the water of the pre-monsoon season was controlled by "salinity factor" and "organic pollution factor" with 62.9% and 22% of the total variance, respectively. Irrigation with this salinity affected water might reduce agricultural production. Proper initiative such as storing freshwater before saline water intrusion might be excellent solution. Hence, multivariate statistical methods are found to be significant to assess the water quality controlling factors for short time duration, even within a season. These are worthy for water resources managing authorities to observe intricate nature of water quality issues and, operate and maintain the water flow controlling structures, such as sluice gates on water courses, thereby keep water suitable for agriculture and other uses. Storing of rain and freshwater in this irrigation channel before salinity intrusion might be an excellent solution to the inhabitants of the newly salinized interior coast of Bangladesh like Gopalganj district.*

Keywords: *Water Quality, Interior Coast, Gopalganj, Irrigation Channel, Principle Component Analysis, Factor Analysis.*

I. Introduction

Gopalganj is one of the interior coastal districts of Bangladesh [1], which is well defined newly salinized areas of the coastal zone of Bangladesh [2]. It is an agro-ecologically disadvantaged province. The irrigation channel under present study originated from the Ghagar River, and flows over the Kotalipara and Gopalganj Sadar Upazila of Gopalganj District. Most significant feature of hydrology in relation to agricultural development is the seasonal shallow flooding (up to 90 cm) in Gopalganj which affects about 64% of the total area [3].

In Gopalganj Sadar Upazila, 10000 hectre of land is cultivated by using various irrigation equipments in the dry and pre-monsoon season. Because 85% of the annual rainfall occurs in monsoon period between June and September in Bangladesh. But the dry period between November and March usually remains rainless [4], when irrigation is required for growing crop. In Gopalganj Boro rice is the main crop in the dry to pre-monsoon season that requires irrigation. Asaduzzaman et al. also stated that Boro grown at present under irrigated conditions during the largely dry period from February/March to April/May [5]. Groundwater in beel area under organic soil is not suitable for irrigation. Irrigation management in a planned way is expected in this region [6].

The pressure for salinity intrusion is occurred due to reduction in the monsoon water discharges, decrease in the fresh water flow from the rivers during lean months. Consequently water and soil salinity is increasing and the salinity fronts are changing in the coastal districts which is causing reduction in the agricultural productivity, reduction in yield and changes in the cropping patterns viz. Aus and Rabi [7][8].

Deterioration of irrigated soil quality is now common concern for sustainable agriculture and environment in these interior coastal upazilas. The yield reduction of irrigated rice is now an alarming signal for rethinking the way of taking adaptation strategies for ensuring food security in the study area [2]. The live and livelihood of most of the peoples in the area directly depends on traditional irrigated agricultural practices [2]. Sustainable management of river and channel water requires knowing the sources of pollution and thereby adopting appropriate strategy. Consequently, the intention of the study was to identify factors controlling water quality in dry (December to February) and pre-monsoon (March to May) season by applying multivariate statistical techniques.

II. Materials And Methods

2.1 Study Area

Gopalganj District is encompassing an area of 1489.92 sq. km. having total 110951 hectares of cultivable land and 36697 hectares of fallow land. Cropping pattern is single crop 37%, double crop 49.96% and treble crop land 13.04%. Main source of income is agriculture and main crop is rice and paddy. The average maximum temperature of Gopalganj district is 35.8°C and minimum 12.6°C, with average total rainfall of 2105 mm [9]. The study area occupies extensive low-lying areas between the Ganges river floodplain and the Ganges tidal floodplain [10]. The study area is under tropical monsoon climate and three seasons are dominant. Rainy season stretches from May to October and it showers 86% of the total rainfall [6]. In rainy season, medium low land is inundated for 5-6 months and maximum depth of inundation is 90-180 cm. Lowlands are inundated for 6-7 months and maximum depth of inundation is 180-275 cm. Flood water is not drained prior to the month of mid-November [6]. The map of the study area with sampling stations is provided in Fig. 1.

Figure 1: Google Earth image of the study area with sampling stations (Inset: Location of the Gopalganj District in Bangladesh Map)

The irrigation channel originated from the Ghagar River near Ghagar Bridge, and it was formerly a tributary of Madumati River; but due to the sluice gate across the channel near Kati Bazar, water flow to the Madumati is restricted. It is the main source of irrigation water for the people of Hiran and Kushla Union of Kotalipara Upazila, and Kajulia, Kati, and Majhigati Union of Gopalganj Sadar Upazila.

2.2 Methods of the Study

Water sample were collected and analyzed in the dry season (December to February) and the pre-monsoon season (March to May). Total seventy water samples were collected from ten sampling stations in seven sampling phases. Twenty water samples were collected in the dry season in two sampling phases, and fifty water samples were collected in the pre-monsoon season in five sampling phases.

pH, EC, and TDS were measured by microprocessor pH meter, and multi range conductivity meter [11], respectively. Na^+ and K^+ concentration were determined by flame photometric method [11]. Argentometric titration method was used for Cl^- and EDTA titrimetric method was used to analyze Ca^{2+} and Mg^{2+} concentration [11]. In addition, titrimetric method was used to evaluate HCO_3^- content of water samples [11]. NO_3^-, PO_4^{3-} and SO_4^{2-} were measured by using spectrophotometric method [12]. To verify the analytical error of analyzed ion concentration, electroneutrality (ionic balance) was computed by following equation (1):

$$EN=\frac{\sum \text{Cation} - \sum \text{Anion}}{\sum \text{Cation} + \sum \text{Anion}} X100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where the sum of major cations and anions are expressed in meq/L and EN is the error percent in cationic and anionic balance. The ionic balances for the analyses were within ±10% that is acceptable [13].

Multivariate methods are used to reveal differences, similarities or relationship between individuals [14]. CA, PCA, and FA were conducted by Minitab-16 software. CA and FA have been used for long days for surface and groundwater assessment and monitoring. These statistical techniques were proved to be largely advantageous to interpret large sets of water quality data, because these methods allow deriving hidden information [15]. CA is an exploratory data analysis tool that is used to sort cases, i.e. degree of association is strong between members of the same cluster and weak between members of different clusters [16]. CA was conducted based on the similarity of water quality characteristics. For this analysis, ward linkage and correlation coefficient distance was used.

PCA is widely used because it reduce dimension, modeling and suitable display method. This method reduces redundant information and attains a small number of variables that make it easier to use other multivariate statistical techniques [17]. PCA sometimes produces very interesting and exciting results [14]. The principle component can be expressed as the following equation (2) [18]:

$$z_{ij}= a_{i1}x_{1j}+a_{i2}x_{2j}+a_{i3}x_{3j}+\cdots+a_{im}x_{mj}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where z is the component score, a is the component loading, x is the measured value of variable, i is the component number, j is the sample number, and m is total number of variables.

Factor analysis explains the correlations between the variables in terms of the principal factors that normally remain hidden. Observations that are highly correlated (either positively or negatively) are likely influenced by the same factors, while those that are relatively uncorrelated are likely influenced by different factors [15]. FA can be explained by the following equation (3) [18]:

$$Z_{ij}=a_{f1}f_{1i}+a_{f2}f_{2i}+a_{f3}f_{3i}+\cdots+a_{fm}f_{mi}+e_{fi}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where z is the measured variable, a is the factor loading, f is the factor score, e is the residual term accounting for errors or other source of variation, i is the sample number, and m is the total number of factors.

III. Results And Discussion

3.1 Descriptive Statistics

The descriptive statistics of the dry and pre-monsoon water quality data such as mean, standard error of mean, standard deviation, minimum, and maximum values are provided in the following Table-1. All the water quality parameters showed increasing trend except NO_3^-.

Table 1: Descriptive statistics of the dry and pre-monsoon season water quality data

Parameter	Unit	Dry Season (December to February)					Pre-monsoon Season (March to May)				
		Mean	Std. Error of Mean	Std. Deviation	Min.	Max.	Mean	Std. Error of Mean	Std. Deviation	Min.	Max.
pH		6.44	0.025	0.1128	6.27	6.68	6.56	0.022	0.157	6.22	6.93
EC	μS/cm	480.4	19	85	383	618	1522	143	1012	538	3770
TDS	ppm	335.3	13.6	60.8	262	433	1127	101	713	376	2630
Na^+	mg/l	44.94	3.85	17.22	24.85	70.37	377.5	36.8	260.3	67.9	829.3
K^+	mg/l	9.88	0.515	2.30	7.31	14.51	12.51	0.627	4.431	4.38	22.99
Ca^{++}	mg/l	22.70	0.598	2.68	18.99	25.99	28.16	0.678	4.795	20	40
Mg^{++}	mg/l	6.99	0.146	0.253	6.005	8.4	17.58	1.36	9.58	7.20	39
HCO_3^-	mg/l	197.88	1.92	8.57	187.9	213.5	202.2	4.90	34.63	115.9	268.4
Cl^-	mg/l	30.31	5.11	22.83	7.20	69.73	494.5	51.9	367.1	54.3	1213.1
SO_4^{2-}	mg/l	7.73	0.413	1.85	5.38	11.43	43.70	3.95	27.92	7.40	94.33
NO_3^-	mg/l	4.03	0.246	1.10	2.53	5.52	2.62	0.114	0.805	1.364	4.898
PO_4^{3-}	mg/l	0.089	0.0098	0.044	0.041	0.189	0.112	0.0106	0.075	0.044	0.415

3.2 Cluster analysis

Cluster analysis of the variables provides an idea about how the single water quality parameters are related to one another and how they should be compared [19]. Dendrogram of the analyzed parameters of water in the dry season and pre-monsoon season is provided in the following Fig. 2 and 3, respectively. The dendrograms represent two main clusters, which are further subdivided in to sub-clusters as follows:

Figure 2: Dendrogram of water quality parameters of the dry

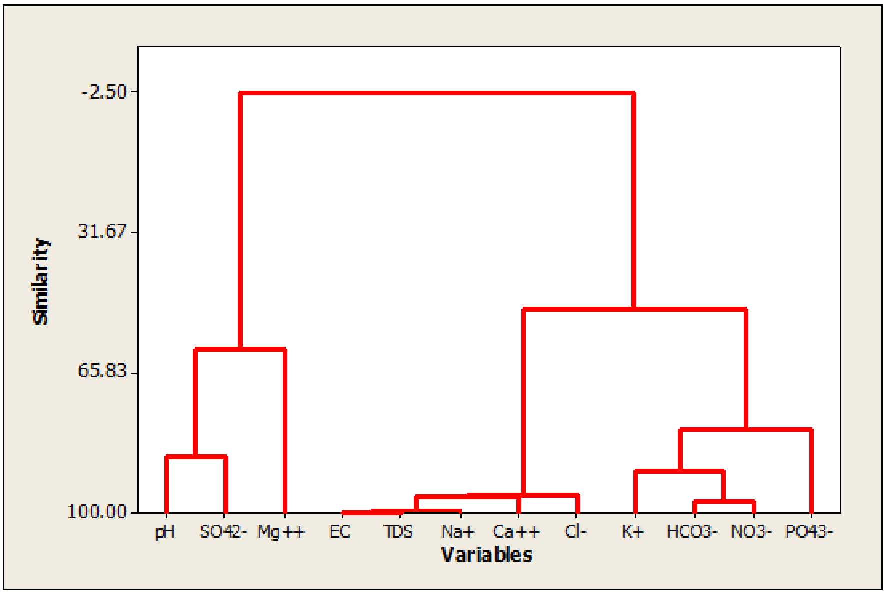
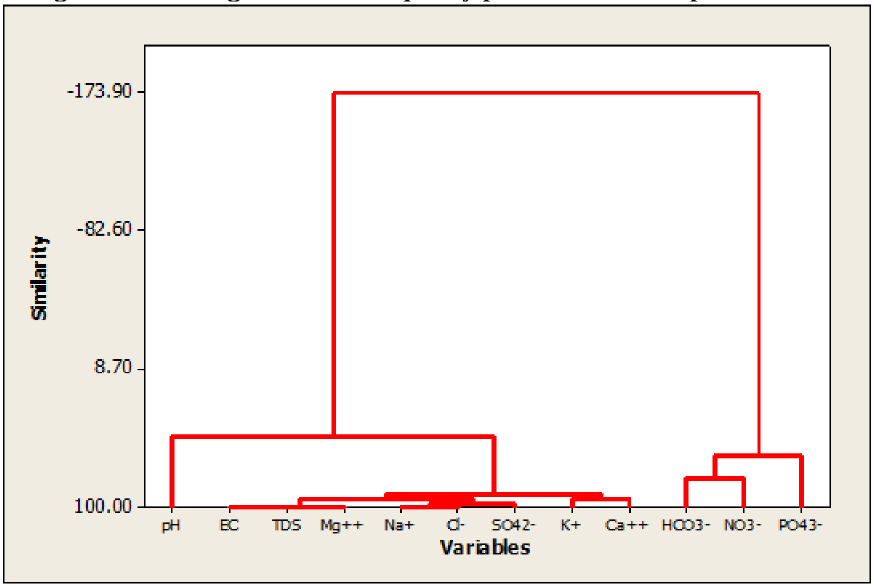


Figure 3: Dendrogram of water quality parameters of the pre-monsoon



	Dry Season (December to February)	**Pre-monsoon Season** (March to May)
Cluster 1	pH, SO_4^{2-}, Mg^{++}	pH, EC, TDS, Mg^{++}, Na^+, Cl^-, SO_4^{2-}, K^+, Ca^{++}
	Subcluster 1.1: pH, SO_4^{2-}	Subcluster 1.1: pH
	Subcluster 1.2: Mg^{++}	Subcluster 1.2: EC, TDS, Mg^{++}, Na^+, Cl^-, SO_4^{2-}, K^+, Ca^{++}
Cluster 2	EC, TDS, Na^+, Ca^{++}, Cl^-, K^+, HCO_3^-, NO_3^-, PO_4^{3-}	HCO_3^-, NO_3^-, PO_4^{3-}
	Subcluster 1.1: EC, TDS, Na^+, Ca^{++}, Cl^-	Subcluster 1.1: HCO_3^-, NO_3^-
	Subcluster 1.2: K^+, HCO_3^-, NO_3^-, PO_4^{3-}	Subcluster 1.2: PO_4^{3-}

Careful observation of the two dendrograms had provided distinctive clustering patterns. Dendrogram of the dry season (December to February) demonstrated small clusters, such as pH, SO_4^{2-} group; Mg^{++} group; EC, TDS, Na^+, Ca^{++}, Cl^- group; and K^+, HCO_3^-, NO_3^-, PO_4^{3-} group. Conversely, the dendrogram of the pre-monsoon season (March to May) depicted clusters like pH group; EC, TDS, Mg^{++}, Na^+, Cl^-, SO_4^{2-}, K^+, Ca^{++} group; HCO_3^-, NO_3^- group; and PO_4^{3-} group. Clustering variables are conducted to looking the patterns in the data that are useful in interpreting the factors affecting water quality.

3.3 Data structure determination and source identification

Multivariate analysis reduces the number of components and recognizes the relationship among variables. As clustering does not provide any cause and effect relationship among variables, it only depicts similarity; therefore PCA was conducted to identify the relationship among variables. Varimax rotation was used to maximize variation explained by the components. Absolute loading values of >0.75, 0.75-0.5 and 0.5-0.3 was termed as strong, moderate, and weak loading, respectively; when applied to factor loadings [19][20][21]. PCA was applied to recognize the number of factors to be extracted by FA. Only the verifactors (VFs) with eigenvalues >1 was considered essential [19]. FA was used to the water analyses dataset to identify the factors that control the quality of water in the irrigation channel in the dry and pre-monsoon season. The output of the principle component factor analysis is provided in following **Table- 2** and **3** for dry and pre-monsoon season, respectively; containing factor loading, eigenvalues, and variance (%).

Table 2: Principal Component Factor Analysis (Varimax rotation) of Dry Season Water

Variable	Factor 1	Factor 2	Factor 3
pH	0.117	**0.865**	-0.197
EC	**0.916**	0.291	-0.215
TDS	**0.915**	0.296	-0.221
Na^+	**0.931**	0.240	-0.222
K^+	**0.850**	-0.327	-0.279
Ca^{++}	**0.948**	0.200	-0.098
Mg^{++}	0.058	0.482	**-0.741**
HCO_3^-	**0.713**	-0.069	**-0.579**
Cl^-	**0.891**	0.279	-0.136
SO_4^{2-}	0.268	**0.888**	0.201
NO_3^-	**0.765**	-0.030	**-0.590**
PO_4^{3-}	0.410	-0.195	**-0.788**
Variance	**6.311**	**2.268**	**2.184**
% Var	**0.526**	**0.189**	**0.182**
Eigenvalue	**7.559**	**2.058**	**1.146**
Cumulative	**0.630**	**0.801**	**0.897**

FA analysis of the water of the dry season revealed that three factors explained 89.7% of the total variance. Factor-1 explained 52.6% of the total variance with strong loadings of EC, TDS, Na^+, K^+, Ca^{++}, NO_3^- and Cl^-; and moderate loading of HCO_3^-. This loading category could be termed as "salinity-water hardness" factor [19] [22]. Moderate positive loading on NO_3^- is possibly due to agricultural runoff [23] [24]. Utilization of fertilizer in the agricultural land endures nitrification process and rivers receive NO_3^- through groundwater leaching [18].

The second factor (18.9% of the total variance) contained strong positive loading of two parameters (pH and SO_4^{2-}). When atmospheric CO_2 dissolves in water, it creates H_2CO_3, which further dissociates into H^+ and HCO_3^-. The irrigation channel is occupied with many rooted and floating aquatic plants and algae that require dissolved CO_2 for food production. Photosynthesis by aquatic organisms takes up dissolved carbon dioxide during daylight [13]. This process will liberate OH^-, and an increase in OH^- concentration will cause the pH to increase. Sulfur is essential plant nutrient for production of protein, enzyme, and vitamins [25]. Biodegradation of aquatic organisms might release SO_4^{2-} in water. Therefore this factor could be described as "biological activity" factor.

The third factor, accounting for 18.2% of the total variance, consisted of strong negative loading of PO_4^{3-}, with moderate negative loading of Mg^{++}, HCO_3^-, and NO_3^-; which indicates the non-point pollution from anthropogenic pollution input from the adjacent localities.

Table 3: Principal Component Factor Analysis (Varimax rotation) of Pre-monsoon Season Water

Variable	Factor 1	Factor 2
pH	0.309	0.642
EC	**0.939**	0.301
TDS	**0.943**	0.316
Na^+	**0.917**	0.344
K^+	**0.942**	0.104

Ca^{++}	**0.963**	0.087
Mg^{++}	**0.925**	0.348
HCO_3^-	-0.642	-0.661
Cl^-	**0.934**	0.328
SO_4^{2-}	**0.913**	0.327
NO_3^-	-0.236	**-0.759**
PO_4^{3-}	-0.021	-0.740
Variance	**7.550**	**2.636**
% Var	**0.629**	**0.220**
Eigenvalue	**8.834**	**1.352**
Cumulative	**0.736**	**0.849**

Conversely, FA analyses of the pre-monsoon season water demonstrated that only two latent factors explained 84.9% of the total variance (Table-2). Factor-1, which explained 62.9% of the total variance, had strong positive loading of EC, TDS, Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, and SO_4^{2-}. Liu et al. suggested that the association of EC, TDS, Cl^-, SO_4^{2-}, Na^+, K^+, and Mg^{++} reflects the influence of seawater intrusion and can thus be termed as “the sea water salinization factor” [21]; because Cl^-, SO_4^{2-}, Na^+, K^+, and $Mg^{++}$are the solutes in sea water. Bahar and Reza also opined that Mg^{2+}, K^+, and Cl^- along with EC indicate the saltwater signature [26]. Therefore, the first latent factor in pre-monsoon season could be stated as “salinity factor”. Simeonov et al. had also described high level of correlation of conductivity, Cl^-, SO_4^{2-}, Mg^{++}, Ca^{++}, Na^+, andK^+ as “salt” factor [17]. Factor-2 had only strong negative loading on NO_3^- with 22% of the total variance and it could be described as “organic pollution” factor [22].

The study area occupies extensive low-lying areas in the Gopalganj-Khulna beel region. Land remains inundated 6-7 months in Gopalganj Sadar Upazila and 2-3 months in Kotalipara Upazila at a time. Flood water is not drained prior to the month of November. In rainy season, cultivation of crop is dependent on rain water but in dry season, pumping equipments are used. Groundwater in beel region under organic soil is not suitable for irrigation [6] [27]. Therefore, water from this channel is used by the residents of Gopalganj Sadar and Kotalipara Upazila for irrigation.

Multivariate statistical analysis revealed that water quality of the dry season was controlled by hardness-salinity, biological activity, and anthropogenic pollution factor. However, water of the pre-monsoon season was influenced by salinity factor and organic pollution factor. As the first latent factor of water in the both season is correlated with salinity, therefore utilization of this channel water might cause reduction in the crop reduction. Prior to the water is contaminated with saline water, fresh water storing in this channel could be good solution for the inhabitants in Gopalganj Sadar and Kotalipara Upazila. For this reason, continuous monitoring of the channel water is required.

IV. Conclusion

The channel water is used extensively for irrigation and other purposes in the study area. Cluster analysis revealed the pattern of correlation among water quality variables. Principle component factor analysis revealed that water quality of the dry season was controlled by hardness-salinity, biological activity, and anthropogenic pollution factor. However, water of the pre-monsoon season was influenced by salinity factor and organic pollution factor. The results are effective in improving the channel water quality, because proper initiative to the management of these factors/sources of pollution would improve the quality of water.

The application of different multivariate statistical techniques, such as CA, PCA, and FA helped in the reduction of twelve water quality parameters into three possible factors/sources for dry season and two for pre-monsoon season that influenced water systems. These methods are proved to be precious to the water management authority; because it identifies the pollution sources based on which proper initiative could be taken. Lastly, it could be said that storing of rain and freshwater in this irrigation channel before salinity intrusion might be an excellent solution to the inhabitants of the newly salinized interior coast of Bangladesh like Gopalganj district.

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