Asian Journal of Water, Environment and Pollution, Vol. 21, No. 6 (2024), pp. 91-100.
DOI 10.3233/AJW240076

Characterisation of Power Plant Disposal Water from Two Distinct Regions in Bangladesh: A Comparative Assessment of Irrigation Feasibility

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Received May 9, 2024; revised and accepted July 3, 2024

Abstract: This study assesses the feasibility of using power plant disposal water for irrigation in Bangladesh, focussing on water from the Ashuganj and Ghorashal power plants. Addressing the need for sustainable water management in agriculture, particularly in water-scarce areas, the research explores the reuse of industrial disposal water. Thirty water samples from irrigation canals influenced by these plants were analysed for pH, electrical conductivity (EC), total dissolved solids, major ionic concentrations, and water quality indices, including a comprehensive irrigation water quality index (IWQI). Findings show pH levels of 6.1 to 7.7 at Ghorashal and 5.2 to 7.1 at Ashuganj, with Ghorashal displaying higher salinity (EC, 289.3 to 356.9 µS cm^{-1}) compared to Ashuganj (123.4 to 179 µS cm^{-1}). Calcium levels were significantly higher at Ghorashal (157-201 mg L^{-1}) than at Ashuganj (60.98-97.12 mg L^{-1}). Both sites demonstrated chemical suitability for irrigation, with IWQI values classifying their water as "excellent" for agricultural use. Ghorashal's higher salinity and sodium levels require careful management to prevent soil degradation, while Ashuganj's water shows lower risks of soil alkalization or acidification. The study underscores the need for region-specific water management strategies and contributes empirical data supporting sustainable agricultural practices and informed policy-making.

Key words: Irrigation feasibility, water quality indices, power plant disposal water, sustainable agriculture.

Introduction

Water quality is critical for plant growth and sustainable agriculture. Globally, agriculture consumes about 70% of all water, mainly through irrigation (Boretti & Rosa, 2019). In Bangladesh, the extensive use of surface and groundwater for irrigation underlines the need for sustainable water management, particularly due to the rapid depletion of groundwater, which threatens food security and water availability (Akhter et al., 2019; Das et al., 2019). The Northwest region of Bangladesh is particularly vulnerable, facing recurrent water crises during winter due to meteorological droughts (Islam et al., 2022).

Exploring alternative irrigation sources like wastewater from industrial and power plants is important. However, the viability of these non-traditional sources hinges on their quality, essential for maintaining high agricultural yields (Dotaniya et al., 2023; Islam et al., 2015, 2017; Kumari, 2017). Bangladesh's challenge is exacerbated by seasonal low water levels, making traditional irrigation methods ineffective from December to April (Yasmin et al., 2019). Remarkably, 6.3% of Bangladesh is at very high risk and 19.1% is

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at high risk of water scarcity, impacting agriculture (Ahammed et al., 2018). In the Northwest, reliance on groundwater through deep tube wells has increased since the 1970s, irrigating 78% of the land. However, climate change and geographic factors are intensifying water crises, thus reducing agricultural yields (Akhter et al., 2019; Deng & Wheatley, 2016; Hasan et al., 2016).

The Bangladesh Agricultural Development Board initiated the Ashuganj-Palash Agro Irrigation Project to address water shortages in northern Bangladesh. This project uses wastewater from Ghorashal and Ashuganj power plants for irrigation during the Boro season. While this conserves water and enhances productivity, it necessitates rigorous water quality assessments due to potential thermal and chemical pollutants (Padhan & Sahu, 2012; Rao & Rao, 2013). Assessing irrigation water quality is complex but crucial, involving the evaluation of salinity risks, sodium hazards, toxic ions, and other factors affecting soil pH and crop health. In Bangladesh, salinity and sodium severely affect soil structure and plant vitality.

Our study aims to fill the research gap by systematically evaluating water quality from operational power plants in Bangladesh for irrigation. We conducted detailed chemical analyses, assessing parameters like calcium, magnesium, potassium, sodium, and chloride, and indices such as sodium adsorption ratio (SAR), soluble sodium percentage SSP, residual sodium carbonate (RSC), permeability index (PI), magnesium adsorption ratio (MAR), Kelly's ratio (KR), potential salinity (PS), and total hardness (TH). This comprehensive approach helps develop an irrigation water quality index (IWQI), providing data to support sustainable practices and informed policy-making.

Materials and Methods

Study Area and Disposal Water Sampling

The study took place in the Ashuganj-Palash Agro-Irrigation Project area in Bangladesh, established in 1992, located at 24º 5' N, 91º 2' E near the Meghna River. This area heavily relies on the Ashuganj Power Station, positioned at 23º 98' N and 90º 63' E near the Shitalakshya River, alongside the Ghorashal Power Station, crucial for irrigation (Figure 1). During the dry season, Narsingdi, Palash, and Shibpur in Narsingdi district depend on Ghorashal, while Brahmanbaria, Sarail, Ashuganj, and Nabinagar in Brahmanbaria district utilise water from Ashuganj for irrigation. Both plants draw water from the Shitalakshya and Meghna Rivers, respectively, supporting vital irrigation from December to April. On March 22, 2021, prior to harvest season, water samples were gathered from main, secondary, and tertiary canals at key sites, with five samples from each type. These samples, stored in 500 mL bottles pre-rinsed with dilute hydrochloric acid and distilled water, underwent filtration to reduce turbidity. For preservation, 0.5% nitric acid was added, totaling 2.5 mL of HNO_3 per sample, while other samples remained non-acidified for carbonate and bicarbonate analysis and were sealed to minimise air exposure.

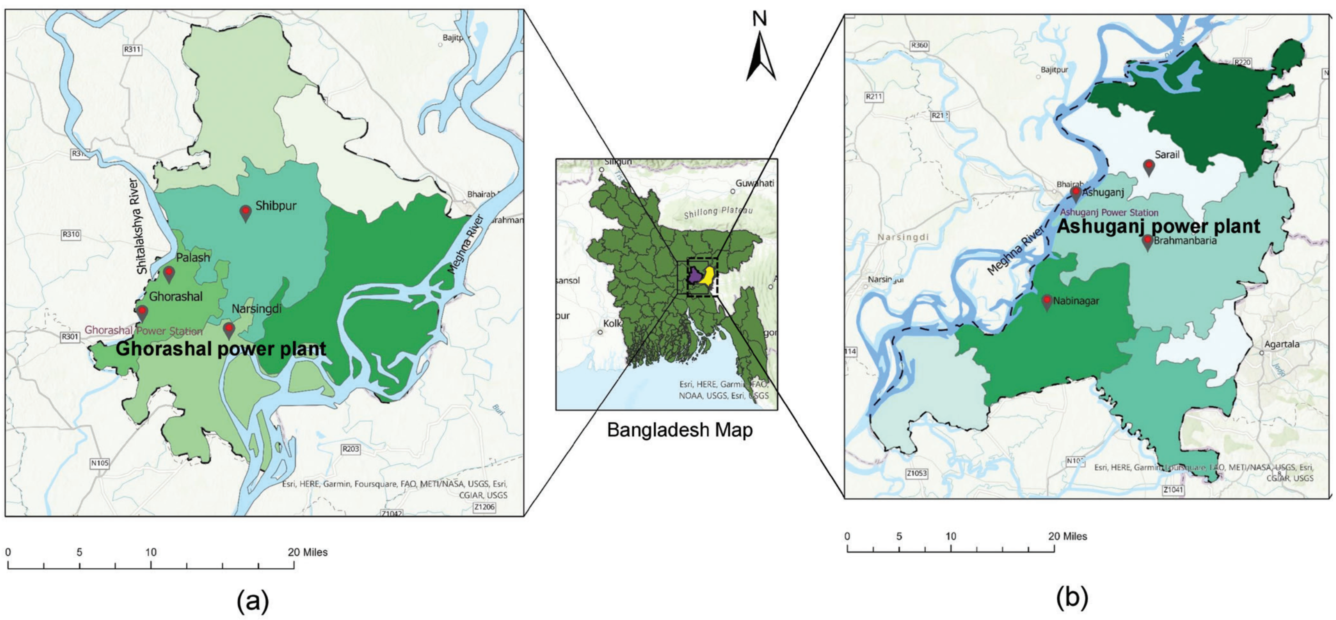

Figure 1: Map of the irrigated areas covered by the (a) Ghorashal and (b) Ashuganj power plants in Bangladesh.

Laboratory Analysis of Sampled Disposal Water
Total dissolved solids (TDS), electrical conductivity (EC), and pH of the samples were measured at Bangladesh Agricultural University (BAU)'s central laboratory using a combined electrode. Ionic concentrations were analysed in the postgraduate research laboratory, Department of Agricultural Chemistry, BAU, where calcium (Ca^{2+}) and magnesium (Mg^{2+}) levels were determined by the EDTA titrimetric method. Sodium (Na^{+}) and potassium (K^{+}) were measured through flame photometry, while chloride (Cl^{-}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^{-}) levels were quantified titrimetrically. Sulphate (SO_4^{2-}) concentrations were assessed turbidimetrically. Crucial water quality indices like SAR, SSP, MAR, RSC, TH, KR, PI, and PS were calculated to evaluate the suitability of power plant disposal water for agricultural use.

Irrigation Water Quality Index (IWQI) Estimation
The IWQI was calculated with the weighted arithmetic index method, developed by Brown et al. (1970), to simplify complex water quality data into a single, clear indicator of water quality. The calculation involves three primary steps:

Step 1: Calculation of unit weight factors (W_n) for each parameter using the following equation:

$$W_n = \frac{K}{S_n} \quad (1)$$

Where $$K = \frac{1}{\frac{1}{S_1}+\frac{1}{S_2}+\frac{1}{S3}+\ldots\frac{1}{Sn}} = \frac{1}{\Sigma S_n} \quad (2)$$

and S_n denotes the standard desirable value of the nth parameter, following the Bureau of Indian Standards for values such as pH, EC, TDS, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-}, and TH. Summing the unit weights for all selected parameters gives $W_n = 1$ (unity).

Step 2: Calculation of the sub-index (Q_n) for each parameter using the following equation:

$$Q_n = \frac{[(V_n - V_0)]}{[(S_n - V_0)]} \times 100$$

Where, V_n is the mean concentration of the nth parameter and V_0 represents the baseline or actual values of the parameters in pure water, typically zero for all parameters except pH.

Step 3: Calculation of the overall IWQI using the formula given below:

This step combines the weighted sub-indices calculated in Step 2 to yield a comprehensive index value representing the overall quality of the irrigation water.

Statistical Analyses
To quantitatively assess physicochemical properties, the mean and standard deviation for each attribute across primary, secondary, and tertiary canals were calculated. The relationships among hydrochemical indicators were explored using linear regression, gauging relationship strength via the coefficient of determination (R^2). Cluster analysis, utilising Ward's method and Euclidean distances, categorised water quality at two irrigation sites, with dendrograms illustrating similarities (Warsito et al., 2021). Z-score standardization in IBM SPSS software aided in hierarchical clustering, visually represented by dendrograms. In addition, correlation analyses using Pearson's method examined linearity between parameters, depicted through a colour gradient from red (inverse) to green (direct), indicating relationship strength.

Results and Discussion

Water Quality Parameters
This study compared water quality at the disposal sites of two Bangladeshi power plants—Ghorashal and Ashuganj (Table 1)—with FAO irrigation standards. Ghorashal exhibited pH levels of 6.1–7.7, indicating near-neutral to slightly basic conditions, while Ashuganj showed pH values of 5.2–7.1, suggesting slight acidity. Ghorashal's electrical conductivity (EC) (289.3–356.9 $\mu S\ cm^{-1}$) indicated higher salinity than Ashuganj's (123.4–179 $\mu S\ cm^{-1}$). Ghorashal also had significantly higher calcium (157–201 $mg\ L^{-1}$) and magnesium levels (14.58–43.75 $mg\ L^{-1}$) than Ashuganj (60.98–97.12 $mg\ L^{-1}$ and 2.92–19.44 $mg\ L^{-1}$, respectively). Sodium, potassium, chloride, sulphate, carbonate, and bicarbonate concentrations also varied between the sites. Despite these variations, the water quality generally adhered to FAO standards, suggesting the disposal of water from both plants is suitable for irrigation. This aligns with the findings by Rana et al. (2019) and supports using power plant disposal water in agriculture, with necessary quality management and monitoring as endorsed by Jeong et al. (2016).

Water Quality Indices and the Changes over Different Diversion Canals
Water quality indices and parameters were assessed

Table 1: Power plant disposal water quality parameters values (range) compared to the standard limit

Parameter	*Ghorashal District*	*Ashuganj District*	*FAO Standard Limit*
pH	6.1-7.7	5.2-7.1	6.5-8.4
EC (μS cm^{-1})	289.3-356.9	123.4-179	3000
TDS (mg L^{-1})	157-201	60.98-97.12	450
Ca^{2+} (mg L^{-1})	35.27-76.95	12.83-65.73	400
Mg^{2+} (mg L^{-1})	14.58-43.75	2.92-19.44	60
Na^{+} (mg L^{-1})	25.95-34.49	9.27-12.12	620
K^{+} (mg L^{-1})	2.30-18.07	0.08-0.86	78
Cl^{-} (mg L^{-1})	23.99-43.99	25.99-55.98	1065
SO_4^{2-} (mg L^{-1})	10.89-12.61	3.46-4.58	960
CO_3^{2-} (mg L^{-1})	0-2.9	0-2.7	3
HCO_3^{-} (mg L^{-1})	75.06-128.16	67.73-115.32	610

*FAO, Food and Agricultural Organization

in primary, secondary, and tertiary canals at two experimental sites, revealing significant differences between water from Ghorashal and Ashuganj power plants (Figure 2). Ghorashal water showed elevated pH, EC, TDS, SAR, SSP, TH, KR, and PS levels, posing irrigation risks. A decrease in pH from primary to tertiary canals indicated increased acidity, crucial for soil management. In contrast, higher EC, TDS, MAR, and TH in tertiary canals indicated more dissolved solids and hardness, necessitating soil degradation prevention measures (Marathe et al., 2021). Conversely, at Ashuganj, parameters like KR, PI, PS, RSC, MAR, SSP, SAR, and TDS decreased from primary to tertiary canals, suggesting reduced alkalization or acidification risks and confirming irrigation suitability (Djaani, 2020). Both sites maintained water quality within acceptable irrigation limits (Table 2).

Irrigation Water Quality Index (IWQI)

The IWQI, defined by Brown et al. (1970) and further refined by Ramakrishnaiah et al. (2009), is a crucial tool for assessing water suitability for agricultural use. It categorises scores below 50 as "excellent," indicating optimal conditions for irrigation. Conversely, scores between 100 and 200 are considered "poor," highlighting potential risks to crops and soil. In our study, the IWQI scores for Ghorashal and Ashuganj power plant disposal waters were 33.48 and 44.24, respectively, both classifying as "excellent" (Table 3). This confirms their suitability for irrigation and suggests minimal industrial or environmental impact at these sites. Our comparative analysis further reveals regional variations in water quality, which emphasises the importance of region-specific water management strategies to enhance agricultural productivity, especially in arid and semi-arid areas (Mainardis et al., 2022).

Alkalinity Hazards

Our study, employing the Wilcox diagram, assesses the risks of sodium alkalinity in the irrigation water of Ghorashal and Ashuganj, affirming its suitability. The data from both locations consistently depict water quality ranging from "excellent" to "good" (Figure 3), aligning with Bhat et al.'s (2016) findings in South-West Kashmir. Their research underscores the benefits of low sodium and salinity levels for soil health and plant growth. Aboukarima et al. (2018) further support these parameters, noting their positive impact on soil infiltration and nutrient retention, crucial for sustainable agriculture. Moreover, Al Hadidi and Al Hadidi (2021) highlight the relevance of such water quality in irrigating sensitive crops in semi-arid regions, suggesting broader implications for agricultural productivity through strategic resource management.

Interrelationship Among Key Water Quality Parameters

In this comparative study, we analysed significant chemical parameters in the disposal of water from two distinct power plants in Bangladesh to investigate

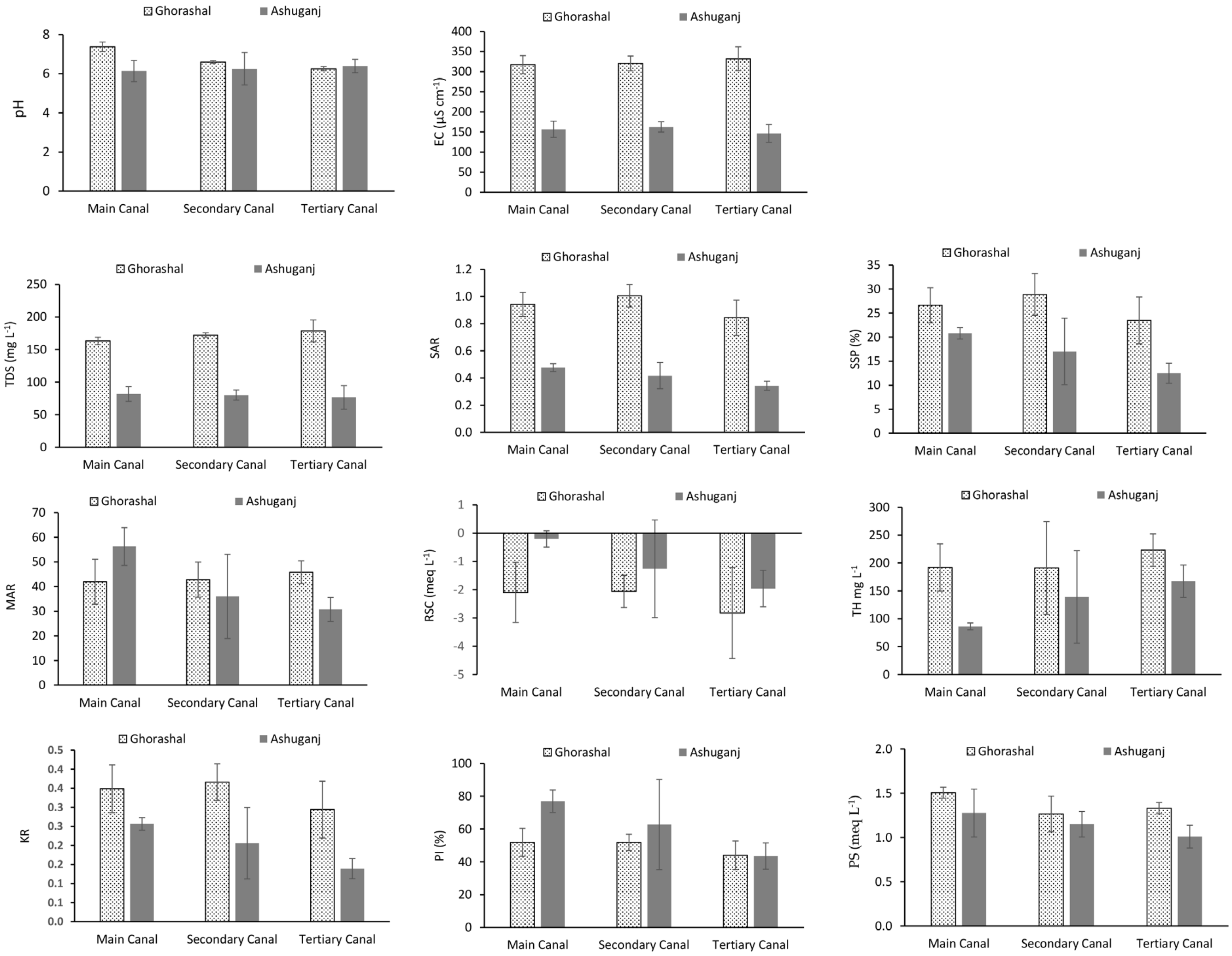

Figure 2: Comparative assessment between Ghorashal and Ashuganj power plant disposal water quality parameters and indices for main canal, secondary canal, and tertiary canal.

their interrelationships (Figure 4). The R^2 values for all targeted parameters did not exceed 0.4, indicating generally weak correlations. However, positive relationships were noted at the Ghorashal site, particularly between Mg^{2+} and Ca^{2+}, and K^+ and Na^+. These show unique site-specific interactions affecting water chemistry at Ghorashal. In contrast, the Ashuganj site displayed broader positive correlations, including EC and pH, TDS and pH, Mg^{2+} and Ca^{2+}, and Cl^- and SO_4^{2-}, except for CO_3^{2-} and HCO_3^-. This pattern indicates a more predictable chemical interaction, potentially facilitating the application of linear regression models for water quality assessment at Ashuganj. The contrasting findings between the two sites highlight the complexity at Ghorashal and the necessity for site-specific water quality management approaches, aligning with Haldar et al. (2020), which emphasised regional variations in water quality.

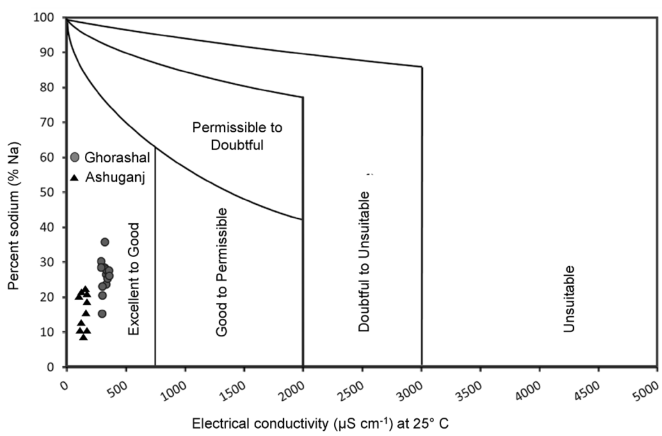

Figure 3: Wilcox Diagram for the classification of power plants disposal water.

Table 2: Classification of power plant deposed water samples for irrigation purposes based on some key selected quality indicators

Water class with its developer	*Ranges of parameter*	*% of the sample (Ghorashal)*	*% of the sample (Ashuganj)*
EC (**µS** cm^{-1})	Wilcox (1955)		
Excellent	<250	100	100
Good	250-750	-	-
Doubtful	750-2250	-	-
Unsuitable	>2250	-	-
SAR	Regional Salinity Laboratory (US) (1954)		
Excellent	<10	100	100
Good	10-18	-	-
Doubtful	18-26	-	-
Unsuitable	>26	-	-
SSP	Wilcox (1955)		
Excellent	<20	6.67	53.33
Good	20-40	93.33	46.67
Permissible	40-60	-	-
Doubtful	60-80	-	-
Unsafe	>80	-	-
RSC (meq L^{-1})	World Health Organization (WHO) (1989)		
Safe	<1.25	100	100
Marginal	1.25-2.50	-	-
Unsuitable	>2.50	-	-
TH (mg L^{-1})	Sawyer and McCarty (1967)		
Soft	0-75	-	46.67
Moderately Hard	75-150	93.33	53.33
Hard	150-300	6.67	-
Very Hard	>300	-	-

Table 3: Summary of irrigation water quality index (IWQI) of Ghorashal and Ashuganj study areas

Chemical parameters	*Mean concentration (V_n)*	*BIS standard (S_n)*	*Unit weight (W_n)*	*Sub-index (Q_n) (Ghorashal)*	*Ghorashal: W_n*Q_n*	*Sub-index (Q_n) (Ashuganj)*	*Ashuganj: W_n*Q_n*
pH	6.75	8.5	0.65	16.66	10.77	48.8	31.55
EC	323.23	300	0.02	107.74	1.97	51.69	0.95
TDS	171.33	500	0.01	34.27	0.38	15.89	0.17
Ca^{2+}	45.50	75	0.07	60.67	4.44	44.03	3.23
Mg^{2+}	21.32	30	0.18	71.08	13.02	39.32	7.20
Cl^-	35.46	250	0.02	14.18	0.31	14.50	0.32
HCO_3^-	97.93	200	0.03	48.97	1.35	0.73	0.02
TH	202.05	300	0.02	67.35	1.23	43.64	0.79
Sum			1		33.48		44.24

Ghorashal, IWQI: 33.48/1 =33.48; Ashuganj, IWQI: 44.24/1= 44.24

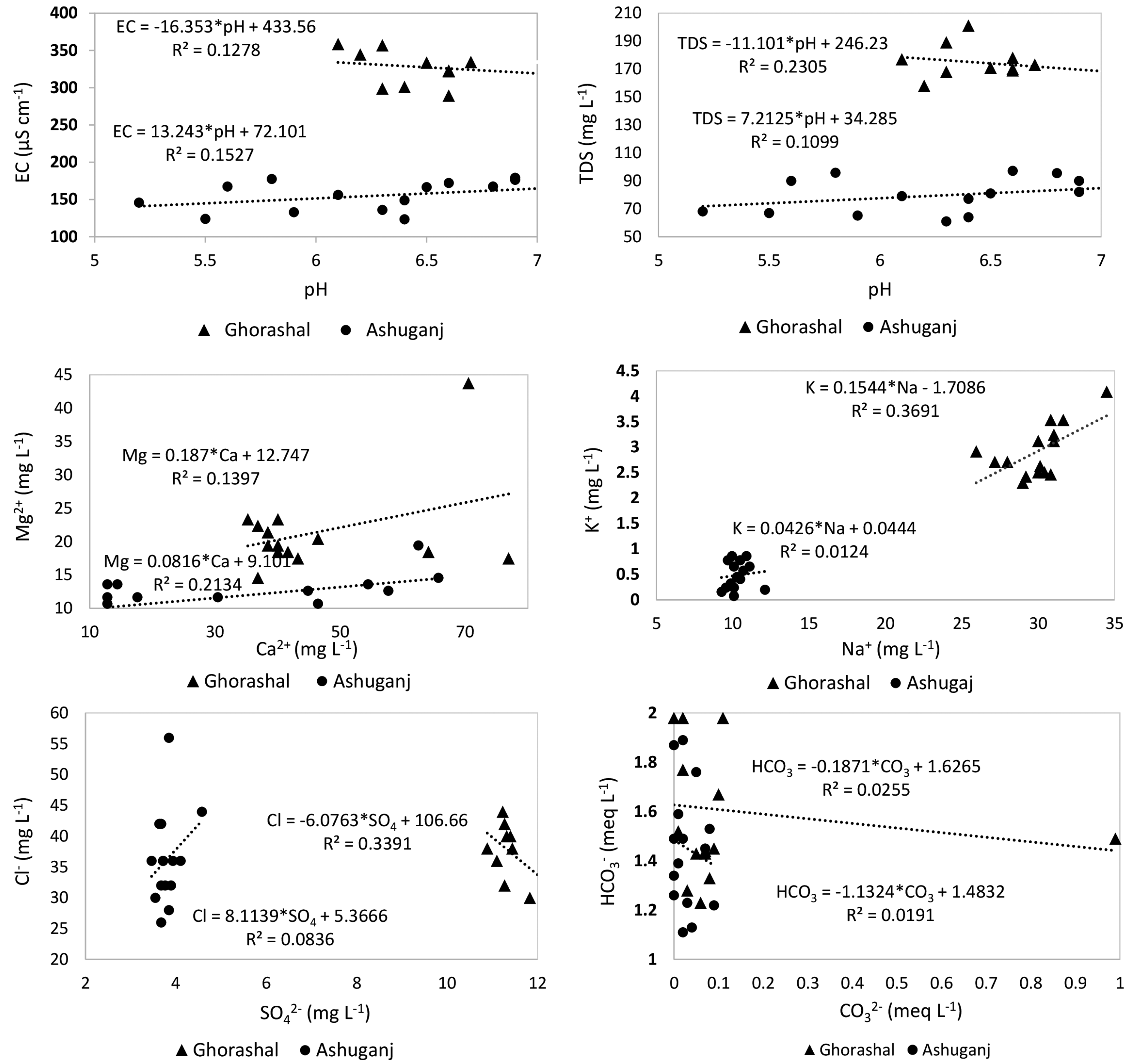

Figure 4: Relationship between major chemical parameters of Ghorashal and Ashuganj power plants disposal water.

Cluster Analysis

In this study, we applied cluster analysis, a multivariate statistical technique, to categorise entities based on similarity (Figure 5). At Ghorashal, Cluster 1 included K, S, and Na; Cluster 2 featured Ca, Mg, TDS, CO_3, and EC; Cluster 3 emphasised pH, Cl, and HCO_3. Conversely, at Ashuganj, Cluster 1 comprised EC, TDS, HCO_3, and Cl, while Cluster 2 mainly included S and K, and Cluster 3 focused on Ca, Mg, and CO_3. Both sites showed significant overlap in EC, TDS, Ca, Mg, Cl, and HCO_3, enhancing irrigation suitability and potentially reducing the need for fertilisers. However, monitoring EC and TDS is essential to prevent salinization, impacting water quality and soil health. Variability in K, S, and HCO_3 highlights the need for site-specific management, as high Cl and HCO_3 levels may require mitigation strategies to protect soil and plant health (Alnaimy et al., 2021).

Correlation Analysis

The correlation coefficient matrix (*r*) was utilised to analyse relationships among water quality parameters (Figure 6). "*r*" values near zero imply weak associations, whereas values closer to 1 indicate strong correlations;

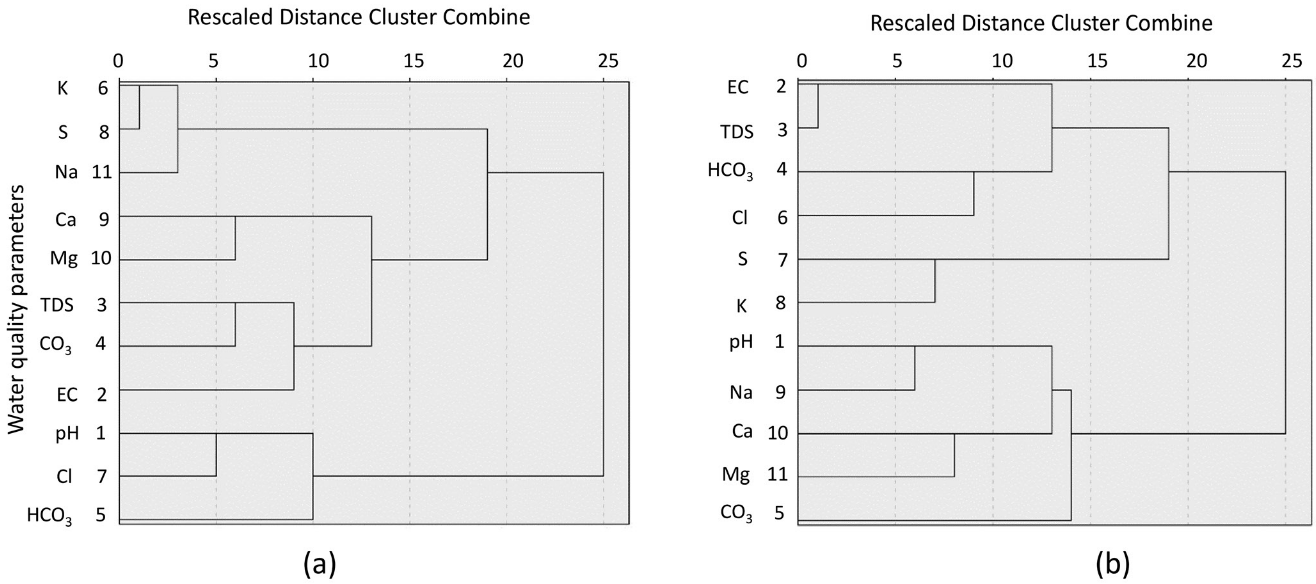

Figure 5: Dendrogram of cluster analyses for (a) Ghorashal and (b) Ashuganj power plants disposal water.

Correlation matrix of the chemical parameters (Ghorashal)

Variables	EC	pH	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	CO_3^{2-}	HCO_3^{-}
EC	1.00										
pH	0.55	1.00									
TDS	0.91	0.50	1.00								
Ca^{2+}	-0.07	0.27	-0.06	1.00							
Mg^{2+}	0.20	0.41	0.31	0.60	1.00						
Na^{+}	0.26	0.70	0.25	0.55	0.71	1.00					
K^{+}	0.28	0.39	0.17	0.21	0.05	0.37	1.00				
Cl^{-}	0.59	0.20	0.52	-0.01	0.32	0.24	0.35	1.00			
SO_4^{2-}	0.35	0.39	0.34	0.06	0.41	0.47	0.62	0.57	1.00		
CO_3^{2-}	0.35	0.42	0.40	0.09	0.32	0.33	0.17	0.16	0.18	1.00	
HCO_3^{-}	0.43	0.48	0.50	0.12	0.17	0.32	0.25	0.54	0.21	0.15	1.00

Correlation matrix of the irrigation water quality indices (Ghorashal)

Variables	EC	pH	TDS	SAR	SSP	RSC	MAR	KR	PI	PS
EC	1.00									
Ph	-0.36	1.00								
TDS	0.13	-0.48	1.00							
SAR	0.20	0.20	-0.09	1.00						
SSP	0.17	0.15	-0.03	0.98	1.00					
RSC	0.31	0.13	-0.07	0.84	0.82	1.00				
MAR	0.26	-0.37	-0.12	0.06	0.10	0.20	1.00			
KR	0.17	0.22	-0.10	0.98	0.97	0.89	0.13	1.00		
PI	0.15	0.27	-0.19	0.90	0.88	0.95	0.20	0.95	1.00	
PS	0.07	0.46	-0.38	0.19	0.25	0.09	0.23	0.22	0.18	1.00

(a)

Correlation matrix of the chemical parameters (Ashuganj)

Variables	EC	pH	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	CO_3^{2-}	HCO_3^{-}
EC	1.00										
pH	0.39	1.00									
TDS	0.89	0.33	1.00								
Ca^{2+}	-0.36	0.06	-0.35	1.00							
Mg^{2+}	-0.17	0.08	-0.01	0.46	1.00						
Na^{+}	-0.02	0.58	-0.05	0.38	0.54	1.00					
K^{+}	0.07	0.18	-0.08	0.00	-0.41	0.12	1.00				
Cl^{-}	0.44	-0.17	0.33	-0.40	-0.11	-0.22	0.12	1.00			
SO_4^{2-}	0.11	0.13	0.07	-0.33	0.05	0.13	0.49	0.29	1.00		
CO_3^{2-}	0.17	0.24	0.22	-0.19	0.01	0.02	-0.08	-0.23	-0.22	1.00	
HCO_3^{-}	0.25	0.29	0.33	-0.14	-0.25	0.01	0.01	0.34	-0.16	-0.14	1.00

Correlation matrix of the irrigation water quality indices (Ashuganj)

Variables	EC	pH	TDS	SAR	SSP	RSC	MAR	KR	PI	PS
EC	1.00									
pH	0.39	1.00								
TDS	0.89	0.33	1.00							
SAR	0.39	0.09	0.31	1.00						
SSP	0.39	0.00	0.31	0.99	1.00					
RSC	0.38	0.00	0.36	0.93	0.96	1.00				
MAR	0.25	-0.11	0.35	0.66	0.64	0.56	1.00			
KR	0.38	-0.02	0.30	0.98	1.00	0.95	0.66	1.00		
PI	0.38	-0.06	0.33	0.93	0.97	0.98	0.56	0.96	1.00	
PS	0.46	-0.15	0.34	0.36	0.39	0.44	0.37	0.38	0.46	1.00

(b)

Figure 6: Correlation analyses for (a) Ghorashal and (b) Ashuganj power plants disposal water quality parameters and water quality indices.

values above 0.7 are considered robust, and those between 0.5 and 0.7, moderate (Islam et al., 2023). Negative "*r*" values indicate inverse correlations (Jahan et al., 2020). Positive correlations in Ghorashal disposal water pH with CO_3^{2-} and K^+ suggest potential for acidity neutralization (Rana et al., 2010). Ashuganj showed similar trends with Na+, Ca^{2+}, and Mg^{2+}. In Ghorashal, positive correlations between EC and Mg^{2+}, Na^+, K^+, SO_4^{2-}, and HCO_3^- indicate their contribution to salinization. Significant correlations in Ghorashal between PI and SSP, SAR, RSC reflect trends in Ashuganj, highlighting sodium's impact on PI, essential for agricultural productivity.

Conclusion

The study offers a comparative analysis of irrigation water quality sourced from power plant disposal in Bangladesh's Ghorashal and Ashuganj regions, addressing local water scarcity challenges. Employing chemical analysis and multivariate statistical methods, we evaluated key water quality parameters. Results indicate chemically suitable water for irrigation at both sites, with noteworthy differences favoring Ashuganj. Ashuganj exhibited superior sodium-related soil permeability (SAR: 2.8) compared to Ghorashal (SAR: 4.2), alongside lower SSP (Ashuganj: 45%, Ghorashal: 60%) and RSC levels (Ashuganj: 1.5 meq L^{-1}, Ghorashal: 2.7 meq L^{-1}), crucial for soil and crop health. Both locations demonstrated favorable IWQI values. Nevertheless, tailored management approaches are essential due to regional disparities, emphasising continual monitoring and adaptive strategies to optimise benefits and mitigate risks. Implementation of such measures could significantly alleviate water scarcity and boost agricultural output in these parched regions.

Acknowledgements

The research work described in this paper received financial support from the University Grants Commission (UGC) of Bangladesh under a specific research project grant (ID - 2019_Crop_10). The authors extend their gratitude to the Bangladesh Agricultural University Research System (BAURES) for its exemplary management of the project.

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