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Suitability of powerplant disposed water for irrigation of Ashuganj agro-irrigation project in Bangladesh

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Abstract

A study was conducted to analyze the quality of power plant disposed water for irrigation and its impact on the soil of Ashuganj agro-irrigation project in Bangladesh. Water samples were collected during the irrigation period and chemically analyzed for the assessment of their quality based on pH, electrical conductivity (EC), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium bicarbonate (RSBC), Kelley‘s ratio (KR), total hardness (TH), magnesium absorption ratio (MAR) and permeability index (PI). Most of the water samples were basically excellent in case of EC and SAR, satisfactory in respect of RSBC and good based on SSP and PI for irrigation use. The relationships between the pairs of KR-SAR, KR-SSP, and SSP-SAR of the water samples were very strong with correlation coefficient around 1. Moreover, the values of pH, EC, Na, K, Ca, Mg and organic carbon of the soil samples were in the suitable range before and after crop cultivation. Therefore, it can be inferred that the power plant disposed water of the agro-irrigation project is suitable for irrigation as well as crop cultivation without any hazard of soil health.

Key words: Disposed water, physico-chemical properties, irrigation, soil health

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Introduction

The success of irrigated agriculture greatly depends on the supply of sufficient water with standard quality that is suitable for producing safe harvests. Good quality irrigation water has the latent ability to produce maximum crop yield under proper soil and water management practices. In Bangladesh context, a few years ago, the quality of irrigation water had been neglected because the supply of good quality water was abundant. But this condition is changing now, and the irrigated agriculture in this country has already begun showing difficulties concerning water quality (Barkat *et al.,* 2007). Whilst moving through underground geologic formation, water may have various salts and minerals dissolved in it. The concentration of salts and minerals relies on the movement and source of the groundwater (Moses *et al.,* 2016). The irrigation water of poor quality negatively affects crop growth and also hampers the composition of irrigated soil by assembling harmful and toxic components in the soil, which eventually lowers crop productivity (Talukder *et al.,* 1989).

The quality of irrigation water can be defined by exploring physical, chemical and biological properties of water. Conceptually, the quality of water indicates the characteristics of a water source that have an effect on its suitability for a specific use, that is, how efficiently the water covers the demand of users (Ayers and Westcot, 1985). Suitability of water has been judged based on the prospective problems that may be anticipated to form in case of long-term utilization. The standard of water quality may be expressed as a qualitative statement of a desired quality of water for a specific purpose. Standards are developed to control environmental problems or adverse effects on the product or health. Many environmental problems may only become apparent long after occurring an activity or environmental stress. Water quality standards may differ in space and/or time; one approach is to relate them to the bearing capacity of the receiving environment on which environmental stress is exerted. The standard for different parameters of the water quality is not necessarily of equal weight. In establishing standards, the benefits of good environmental quality have to be weighed against the socio-economic cost of imposing such standards. The assessment of water quality is highly related to the prospective problems of soil, which are interrelated to the problems of salinity, toxicity, and water infiltration rate. The quality of water used for irrigation is assessed by its potential to create problems, which will hamper crop yields unless proper management practices are taken to obtain probable higher production (Finkel, 1982).

During the dry season (December–April), surface water irrigation is not feasible for most of the areas of Bangladesh because of limited amount of surface water in rivers and other detention water bodies (e.g. wetlands, ponds, oxbow lakes). Therefore, groundwater has been a reliable source of water supply for winter crop cultivation since the revolution of deep tube well (DTW) technology in the 1970s. If the groundwater is contaminated by arsenic or any ionic composition, crop production would be hampered. Bangladesh has made enormous improvement towards obtaining its target of crop grain self-sustenance. A considerable increase in irrigated area and use of modern varieties of rice has led to the speedy extension of production in Bangladesh in the last few years. In Bangladesh, the total cultivable under irrigation is about 3.83 million ha and its 71% has been irrigated by utilizing the source of groundwater (Quasem, 2011).

In Bangladesh, Ashuganj power station is one of the largest power stations to generate electricity. The water of the Meghna River is used for cooling the power plants and subsequently the used water disposed off to the river. This disposed water of the power plant is one of the important water sources of irrigation for the Ashuganj agro-irrigation project, which was established under the Bangladesh Agricultural Development Corporation (BADC) in 1990. The power plant disposed water covers 11,740 ha of land for irrigation in the dry season (BADC, 2013). The soil productivity has been reduced, and its physical and chemical properties may be changed due to the irrigation with poor quality water (Talukder *et al.,* 1989). It is unknown to the farmers that the use of irrigation water of poor quality undoubtedly hampers the productivity of soil, which has a negative effect on crop yield. In addition to irrigation purpose, quality of water needs to be evaluated for the purposes of drinking, domestic and agro-based industries (Jinwal and Dixit, 2008). Testing of irrigation water quality is necessary for the determination of the percentage of different salts, ions and other pollutants, which may negatively affect the public health and crop production. In Bangladesh, especially for Ashuganj agro-irrigation project, specific research work relating the quality of power plant disposed water on irrigation to soil health has not been conducted yet. For this reason, an attempt was taken to assess the quality of power plant disposed water of the Ashuganj agro-irrigation project, Bangladesh for irrigation purpose considering the soil health for crop cultivation covering the entire study area and also to evaluate the correlations among various irrigation water and soil quality parameters.

Materials and Methods

***Study location*:** Ashuganj power station is located at a latitude of 24.05º N and longitude of 91.02º E, on the bank of the river Meghna and is about 100 km North-East of Dhaka, Bangladesh (Figure 1). Disposed water of this power plant is used for irrigation over eleven thousand hectares of land. This study was carried out at Ashuganj agro-irrigation project of Brahmanbaria, Bangladesh, during the period from December 2013 through May 2014, to investigate the quality of power plant disposed water for irrigation purpose considering its impact on soil health for crop production. Aus, jute, broadcast *aman*, wheat, mustard, tomato are normally grown in the area as non-irrigated crops. Mainly *Boro* (*Oryza sativa* L.) is grown in the area as an irrigated crop. Power plant disposed water of this project is extensively needed for *Boro* cultivation. In a few cases, wheat and tomatoes are grown by irrigation using this disposed water.

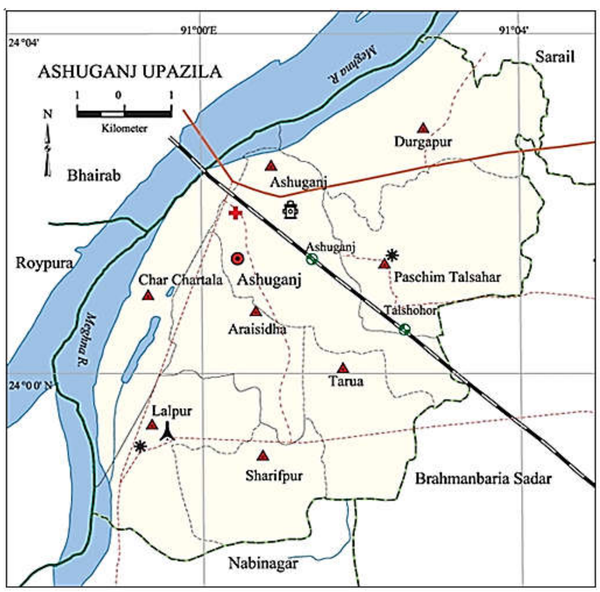

Figure 1. Location of the study area (Banglapedia, 2015)

Data collection**:** At first, soil samples were randomly collected from six plots of the study area up to a depth of 15 cm. Thereafter when irrigation was applied in the rice field with power plant disposed water, six samples of water from the same plot and four samples of water from the canal were collected. After harvesting of the crop, eight soil samples were collected again. All of the collected samples were analyzed in a laboratory of the Department of Agricultural Chemistry, and Humbolt Soil Testing Laboratory of the Department of Soil Science, Bangladesh Agricultural University, Bangladesh. Soil samples were analyzed for pH, EC, Na, K, Ca, S, P, total-N (%) and OC (%), and the collected disposed water samples were also analyzed for obtaining the value of pH, EC, Na, K, Ca, Fe, Mg, Zn, Cu, HCO_3, NH_4-N and NO_3 to evaluate their quality.

Water quality parameters**:** For irrigation purposes, the collected disposed water was classified based on a number of important quality parameters, *viz.* sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium bicarbonate (RSBC), total hardness (TH), magnesium adsorption ratio (MAR), Kelly's ratio (KR) and permeability index (PI).

A ratio of soil extracts and irrigation water used to define the relative activity of sodium ions in an exchange reaction with soil is called SAR. It was estimated by the following equation (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where all the ions are expressed in meq/l or epm (equivalents per million).

Soluble sodium percentage (SSP) is a term used in concentration with soil extract and irrigation water to express the proportion of sodium ions in soil solution in relation to the concentration of total cation. It was estimated by the following equation (Todd, 1980):

$$SSP = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100 \quad \ldots\ldots\ldots(2)$$

where all ionic concentrations are expressed in epm.

Residual sodium bicarbonate (RSBC) is an important factor of evaluating the quality of water for irrigation purpose on the basis of HCO_3 ion concentration, estimated by using the following equation (S. Gupta, 1983):

$$RSBC = HCO_3^- - Ca^{2+} \quad \text{.....................................(3)}$$

where all ionic concentrations are expressed in epm.

A standard has been developed based on the salts solubility and the reaction happening in the soil solution for assessing the quality of water for irrigation purpose (S. K. Gupta and Gupta, 1997). The permeability index (PI) is defined based on the concentration of Na, Ca, Mg and HCO_3 ions present in water, estimated by the following equation (Raghunath, 1987):

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \quad \text{..................(4)}$$

where all ionic concentrations are expressed in epm.

Doneen (1964) classified waters quality characteristics and developed a standard for evaluating the suitability of water for irrigation purpose based on the PI and total ions concentration. The classification was mainly made on the basis of the concentration of Na, Ca, Mg and HCO_3 ions present in water. Based on the Doneen's chart (Figure 2), Class I and II waters are generally classified as good and suitable for irrigation, and in contrast, class III water is unsuitable for irrigation.

Total hardness, a standard for water quality assessment, is the hardness of the minerals present in water that is immutable by boiling. It is the sum of calcium and magnesium hardness, calculated by the following equation (Raghunath, 1987):

$$TH = (Ca^{2+} + Mg^{2+}) \times 50 \quad \text{...............................(5)}$$

where TH is expressed in ppm (parts per million) and the concentration of the constituents are expressed in epm.

Magnesium adsorption ratio (MAR) is an irrigation water quality parameter used in the management of magnesium-affected soils. It is the ratio of the Mg concentration to the Ca + Mg concentration present in the water samples, calculated using equation 6 (Szabolcs and Darab, 1968).

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad \text{..........................(6)}$$

where all the ions are expressed in epm.

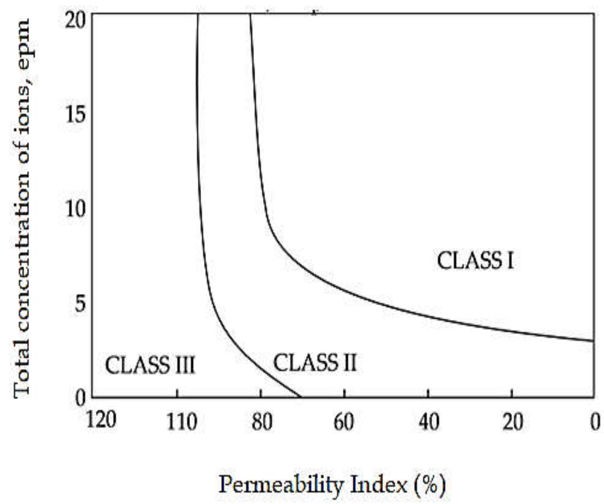

Figure 2. Doneen's chart for water quality assessment base on PI.

The concentration of Na ion measured against the concentration of Ca and Mg ion is considered to estimate Kelley's ratio (KR). The value of KR of more than one represents excessive Na present in water indicating unsuitable for irrigation, while water with the value of KR of less than one is suitable for irrigation purpose. The KR was calculated using equation 7 (Kelley, 1963).

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad \text{.....................................(7)}$$

where all the ions are expressed in epm.

Results and Discussion

***Chemical composition and quality parameters of power plant disposed water*:** The chemical properties and quality parameters of power plant disposed water samples of the Ashuganj agro-irrigation project, Bangladesh are presented in Tables 1 and 2, respectively. According to the FAO standard, the values of pH, EC, K, Na, Ca, Mg, HCO_3 and Total–N are within the recommended limit. The relationship among different chemical properties and quality parameters of the disposed water samples is shown in Figures 3 and 4, respectively.

Table 1. Chemical properties of power plant disposed water samples.

Chemical properties	Range (Minimum-Maximum)	Average	Standard deviation	Recommended Limit (FAO standard)
pH	5.78 - 6.54	6.28	0.27	6 – 8.5
EC (μS/cm)	133.6 - 171.7	144.92	14.12	< 3000
K (epm)	0.05 - 0.156	0.0859	0.04	0 - 2
Na (epm)	0.443 - 0.716	0.53	0.11	0 - 40
Ca (epm)	0.3 - 0.8	0.54	0.15	0 - 20
Mg (epm)	0.7 - 1.2	0.96	0.14	0 - 5
HCO_3 (epm)	1.3 - 1.8	1.54	0.16	1 - 10
Total – N (ppm)	1.4 - 4.3	2.95	1.05	0 - 10
P (ppm)	0.04 - 0.706	0.13	0.20	-
S (ppm)	2.41 - 5.33	3.49	0.96	-

The power plant disposed water samples were classified for irrigation purpose in accordance with different quality parameters as presented in Table 3.

Table 2. Quality parameters of power plant disposed water for irrigation.

Quality parameters	Range (Minimum-Maximum)	Average	Standard deviation
SAR	0.53 - 0.88	0.62	0.13
SSP (%)	20.26 - 41.49	28.53	5.67
RSBC (epm)	0.8 - 1.3	1.00	0.16
KR	0.31 - 0.6	0.36	0.09
TH (ppm)	85 - 150	131.50	24.50
MAR	57.1 - 76.9	64.29	6.55
PI (%)	75.8 - 111.6	88.07	9.55

The EC values ranged from 133.6 – 171.7 μS/cm with an average value of 144.92 μS/cm in the study area (Table 1). According to the EC values (Wilcox, 1955), 100% of the disposed water samples were found as excellent for irrigation purposes (Table 3). Based on pH values, 50% of the water samples were in the categories of slightly acidic and rests were practically neutral for irrigation purpose according to Ayers and Westcot (1985), as presented in Table 3. Biswas and Khan (1976) found that the use of waters having a pH value of 7.69 to 8.33 did not pose any problems to irrigation water. The observed values of pH of all of the disposed water samples were less than 8.33, indicating their suitability for irrigation in crop production.

According to the recommended values of SAR (Richards, 1954), all of the observed values of SAR of the study area are within the excellent limit for the irrigation. Considering the recommended values of SSP (Wilcox, 1955), the suitability of the power plant disposed water for irrigation purpose varied from good to permissible limit (Table 3). The observed values of RSBC of the study area meet the water quality for irrigation purpose where all values are < 5 epm indicating the satisfactory level (S. Gupta, 1983), where it represents the excess concentration of HCO_3^- over the concentration of Ca^{2+} (Hussain and Hussain, 2004). The values of TH of the water samples are varied from 85 to 150 ppm with an average value of 131.50 ppm (Table 2), which are classified as moderately hard (Sawyer and McCarty, 1967). The PI of all of the water samples was found to be good (Raghunath, 1987) having PI values ranged from 75.8 to 111.6 % (Table 2), and it also revealed that the water would not make any problems related to permeability. The values of MAR of the water samples were varied from 57.1 to 76.9, and the KR values varied from 0.31 to 0.60 (Table 2). Kelley (1963) suggested that the value of this ratio should not be more than one for irrigation water.

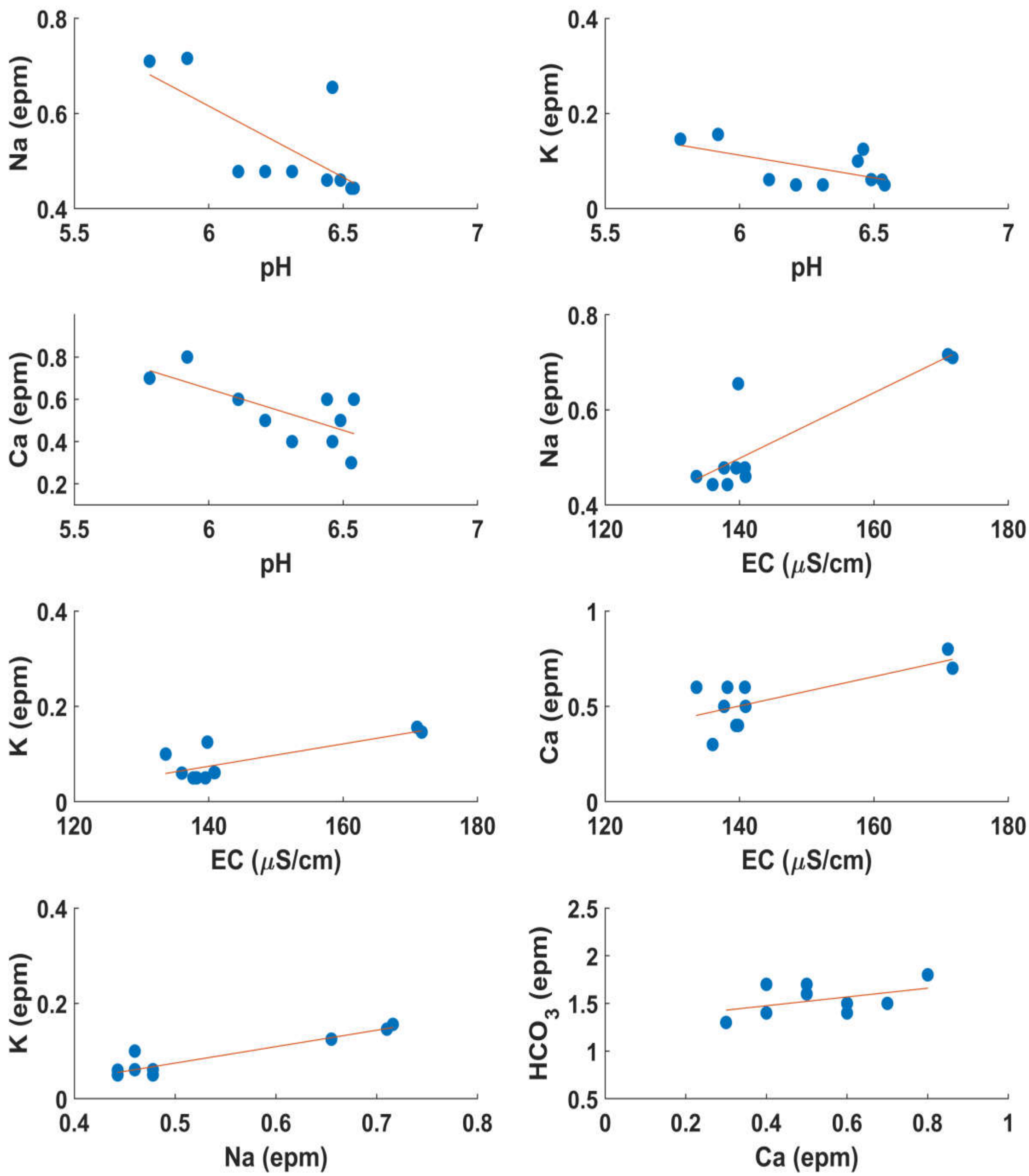

Figure 3. Relationship among different chemical properties of the disposed water samples.

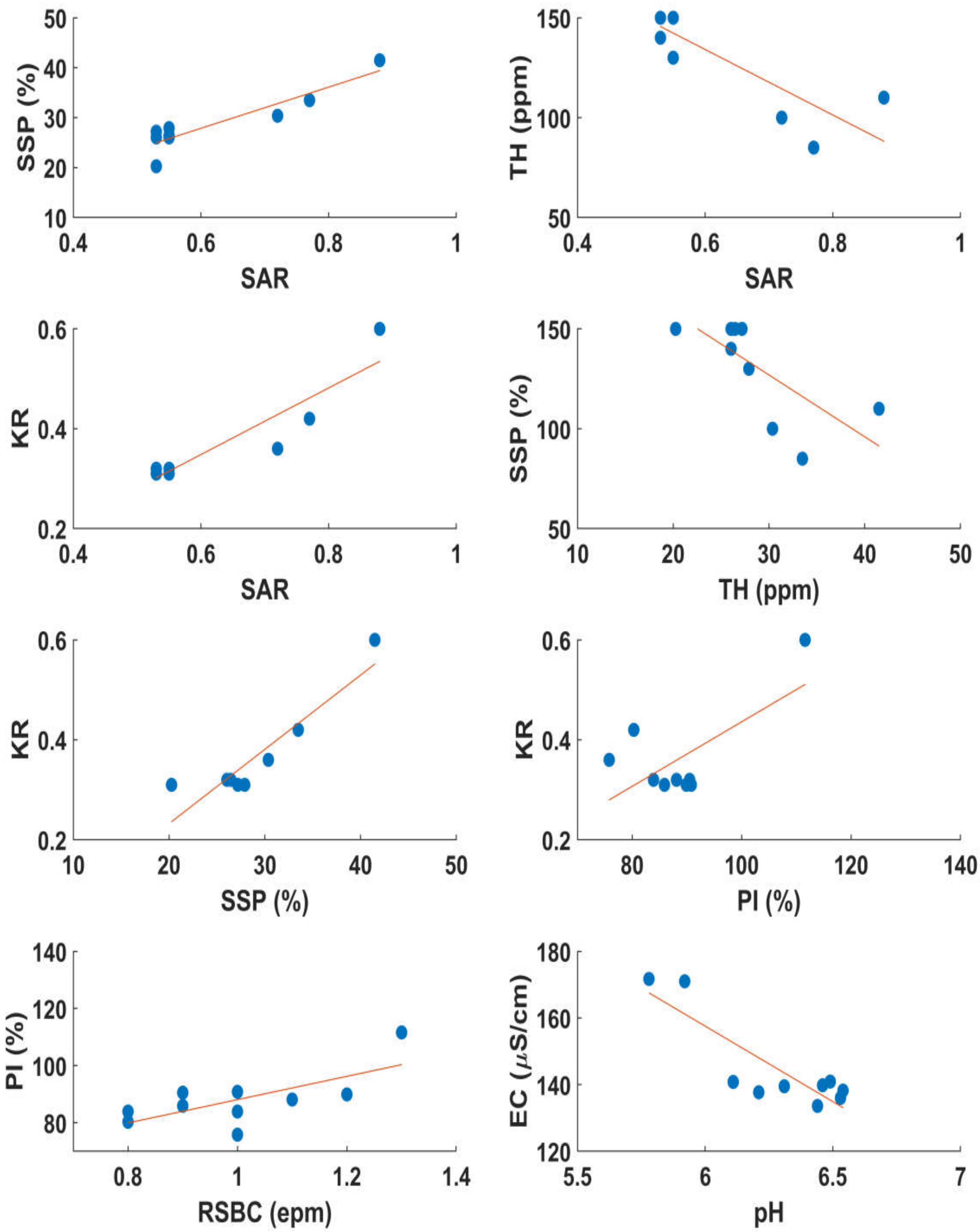

Figure 4. Relationship among different quality parameters of the water samples for irrigation.

Table 3. Classification of powerplant disposed water samples based on different parameters.

Range of Parameter	Water class with its developer	% of the sample
EC (µS/cm)	**Wilcox 1955**	
< 250	Excellent	100
250-750	Good	
750-2250	Doubtful	-
> 2250	Unsuitable	-
pH	**Ayers and Westcot 1985**	
< 5.5	Acidic	-
5.6 - 6.4	Slightly acidic	50
6.5 -7.5	Practically neutral	50
7.6 -8.0	Slightly alkaline	-
SAR	**Richards 1954**	
< 10	Excellent	100
10-18	Good	-
18-26	Doubtful	-
> 26	Unsuitable	-
SSP (%)	**Wilcox 1955**	
< 20	Excellent	-
20-40	Good	90
40-60	Permissible	10
60-80	Doubtful	-
RSBC (epm)	**Gupta 1983**	
< 5	Satisfactory	100
5 - 10	Marginal	-
> 10	Unsatisfactory	-
TH (ppm)	**Sawyer and McCarty 1967**	
0-75	Soft	-
75-150	Moderately Hard	100
150-300	Hard	-
> 300	Very Hard	-

***Chemical composition of soil before cultivation and after harvesting of rice*:** The chemical composition of the soil before crop cultivation and after harvesting of rice is listed in Table 4. The relationship among some important chemical properties of the soil and power plant disposed water samples is shown in Figure 5. The soil pH before crop cultivation or irrigation by disposed water ranged from 5.68 to 6.00, classified as acidic to slightly acidic, whereas after harvesting of rice, the pH value ranged from 5.5 to 6.95 with an average value of 5.99, slightly increased from its value of before crop cultivation condition. In this study, the EC values varied from 250 to 536 µS/cm in case of before crop cultivation, and its values ranged from 210 to 272 µS/cm after crop harvesting, indicating a slight reduction in EC after using disposed water. Before crop cultivation, the organic carbon (OC) of the soil varied from 0.1 to 1.84 %, categorized as very low to low (BARC, 1997), whereas the OC of soil after crop harvesting ranged from 0.12 to 1.61 %, which was almost same as before of the crop cultivation condition. The total nitrogen content of the soil samples collected before the cultivation of crops ranging from 0.035 to 0.168 %, and after rice harvesting, it ranged from 0.033 to 0.152 %, nearly same as before crop cultivation. Before cultivation, the values of Na, Ca, P and S content of the soil ranged from 60.21 to 150.29, 0.95 to 1.25, 3.32 to 3.96 and 42 to 124.7 ppm, respectively, whereas after harvesting, their values varied from 60.2 to 93.24, 0.7 to 1.15, 3.4 to 4.72 and 18.2 to 25.6 ppm, respectively, where the all contents except S were almost the same as its previous conditions. The magnesium content after harvesting ranged from 1.00 to 1.50 ppm, which showed a satisfactory limit, but in case of K content, its value after harvesting ranged from 35 to 45 ppm, which revealed that the value decreased from its initial value in case of before cultivation. However, the values of the chemical properties of the observed soil samples in the study area were in considerable level for crop yield and also within the range of data as well observed by SRDI (1990) and Sadat (2000) reported for different soil types in Bangladesh.

***Interrelationship among different chemical composition and water quality parameters*:** The correlation for chemical composition and quality parameters of the power plant disposed water samples for irrigation purpose was done by bivariate technique, presented in Tables 5 and 6, respectively. Pearson's correlation coefficient (*r*) was estimated to explore the interrelationship among different chemical composition and water quality parameters. The value of *r* indicates that the correlation between the parameters, and its value ranges between −1 and 1.

Table 4. Major chemical properties of soil before cultivation (BC) and after harvesting (AH) of rice.

Chemical properties with field condition		Range (Minimum-Maximum)	Average	Standard deviation
pH	BC	5.68 - 6	5.88	0.12
	AH	5.5 - 6.95	5.99	0.45
EC (µS/cm)	BC	220 - 536	295	122.25
	AH	210 - 272	235	19.74
K (ppm)	BC	40 - 86	60.17	20.12
	AH	35 - 45	39.63	3.38
Na (ppm)	BC	60.21 - 150.29	97.59	36.82
	AH	60.2 - 93.24	78.09	12.30
Ca (ppm)	BC	0.95 - 1.25	1.11	0.12
	AH	0.7 - 1.15	0.99	0.15
Mg (ppm)	BC	1.15 - 1.7	1.41	0.21
	AH	1.0 - 1.5	1.29	0.15
Total – N (%)	BC	0.035 - 0.168	0.127	0.05
	AH	0.033 - 0.152	0.12	0.04
OC (%)	BC	0.1 - 1.84	1.32	0.63
	AH	0.12 - 1.61	1.25	0.50
P (ppm)	BC	3.32 - 3.96	3.62	0.22
	AH	3.4 - 4.72	3.96	0.51
S (ppm)	BC	42 - 124.7	64.96	30.94
	AH	18.2 - 25.6	21.2	2.36

Table 5. Correlation matrix of chemical composition of the disposed water.

	pH	**EC**	**Na**	**K**	**Ca**	**Mg**	**HCO_3**
pH	1.00						
EC	0.860	1.00					
Na	0.710	0.857	1.00				
K	0.602	0.785	0.927	1.00			
Ca	0.698	0.722	0.522	0.581	1.00		
Mg	0.505	0.500	0.170	0.126	0.288	1.00	
HCO_3	0.200	0.400	0.550	0.526	0.733	0.077	1.00

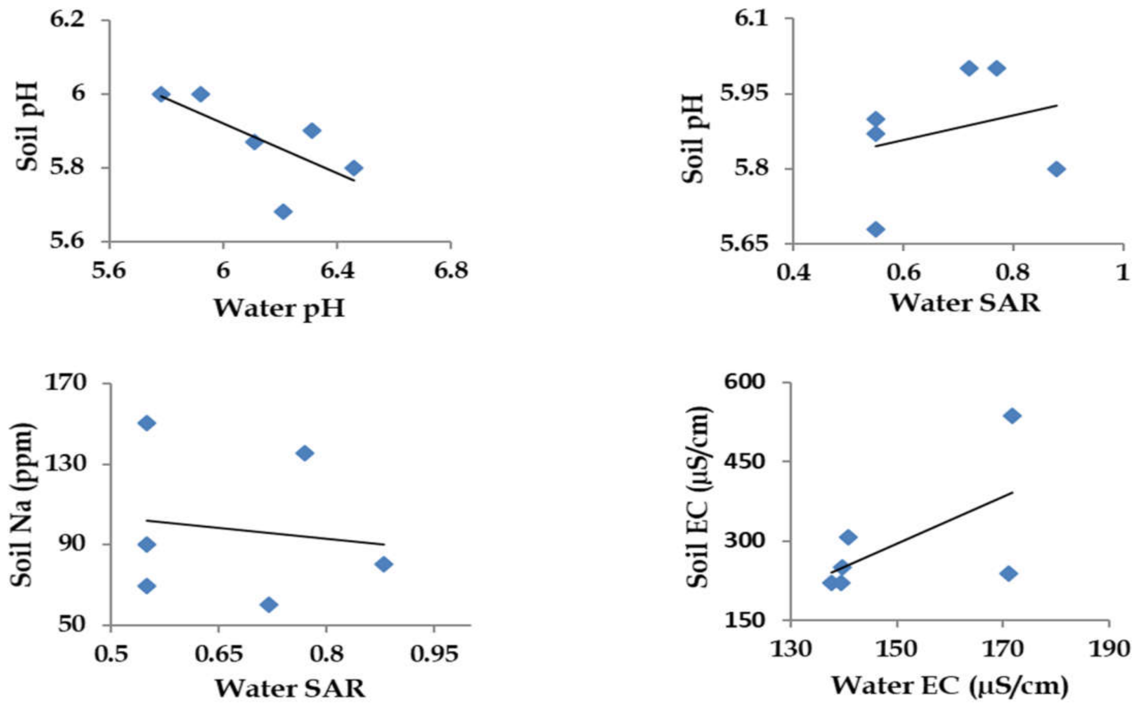

Figure 5. Relationship among some important chemical properties of the soil and water sample.

Table 6. Correlation matrix of quality parameters of the disposed water.

	SAR	SSP	PI	RSBC	TH	MAR	KR
SAR	1.00						
SSP	0.918	1.00					
PI	0.361	0.498	1.00				
RSBC	0.295	0.214	0.697	1.00			
TH	0.846	0.716	0.044	0.055	1.00		
MAR	0.265	0.197	0.158	0.371	0.288	1.00	
KR	0.922	0.922	0.675	0.470	0.610	0.187	1.00

The value of r around zero represents no relationship between the parameters (Srivastava and Ramanathan, 2008), whereas its value around 1 indicates a very strong correlation between the parameters. If the value of r is higher than 0.7, it is considered as strongly correlated, and if its value varies from 0.5 to 0.7, the parameters are moderately correlated. Its negative value shows that the value of one parameter is dropping with the increase in another parameter (Giridharan *et al.,* 2008).

In case of the chemical composition of the power plant disposed water samples, there exists very strong correlation (r = 0.927) between K and Na, a strong correlation between HCO_3 and Ca (*r* = 0.733), and between Na and pH (*r* = 0.71). In this study, Na, K and Ca also showed a strong correlation with EC. The pairs of K-pH, Ca-pH, Mg-pH, Mg-EC, Ca-Na, HCO_3-Na, Ca-K, and HCO_3-K were moderately correlated with a correlation coefficient ranged from 0.5 to 0.7, and other pairs of the chemical composition had a weak correlation with a correlation coefficient less than 0.5 as presented in Table 5.

In case of water quality parameters for irrigation purpose, very strong correlation exists between the pairs of KR-SAR (*r* = 0.922), KR-SSP (*r* = 0.922) and SSP-SAR (*r* = 0.918), a strong correlation was also found between TH-SAR (*r* = 0.846), and TH-SSP (*r* = 0.716) as demonstrated in Table 6. Moreover, the pairs of RSBC-PI, KR-PI, and KR-TH were moderately correlated with a coefficient (*r*) varied from 0.5 to 0.7, and other pairs of the water quality parameters had a weak correlation with a correlation coefficient less than 0.5.

Conclusions

Analyzed disposed water samples of the study area were basically excellent in case of EC and SAR, satisfactory in respect of RSBC and good based on PI. The KR of the disposed water showed full satisfaction, the SSP was in good and permissible limit, and the MAR was within the acceptable limit for irrigation use. The presence of Na, K, Mg and Ca content in the water samples was within the acceptable limit. In the case of water quality parameters, besides a very strong correlation in the pairs of KR-SAR, KR-SSP, and SSP-SAR, a strong correlation was also found between TH-SAR and TH-SSP. The study also revealed that the disposed water contributed various important nutrients and organic matter to the soil health for the better crop yield. Soil pH, Na, K, Ca, Mg, Total–N and % of OC were almost the same as before and after irrigation by disposed water. Therefore, it may be concluded that the power plant disposed water has enough potential to be utilized as a source of irrigation in the crop field without any soil health hazards.

Acknowledgments

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Conflicts of Interest

The authors declare no conflict of interest.

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