Aquifer Salinity and its Suitability for Irrigation in the Southwest Coastal Region of Bangladesh

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KEYWORDS

Saline Aquifer, Non-saline Aquifer, Agriculture, Suitability, Coastal region

ABSTRACT

In coastal regions of Bangladesh, sources of irrigation water are rainfall, surface, and groundwater. Due to rainfall anomaly and saline contamination, it is important to identify saline and non-saline aquifer domain that is usable for irrigation. In a coastal region and the regions where the fresh water aquifer domain is overlain or underlain by the saline water domain, the availability of usable water is limited due to the presence of salinity. Therefore, knowledge of the extent of saline aquifer domains and the evaluation of degree of salinity is essential to determine the potential for, and sustainability of groundwater resources for irrigated agriculture, domestic water supplies, and industrial uses. The current study focuses the saline and non-saline aquifer domains identification and evaluation of the degree of salinity in the identified aquifer domains including the irrigation suitability. The aquifer hydraulic potential is found to be favorable for future increased water withdrawal from the southwest coastal aquifer. The investigation of saline and fresh aquifer domains is based on literature, field investigation, and the laboratory analysis. The field investigation is carried out with participatory rural appraisal (PRA) method and in-situ soil and water sample analysis. The Key Informant Interview (KII) of PRA method is followed in the current study. For soil sample analysis, the primary bore logged materials from an exploratory drilling at the two locations are analyzed. The confirmation of the findings of KII and the in-situ soil sample analysis is also made by supplementing with the water sample analysis. In this regard, two monitoring wells at the two locations in the southwest region are installed in the saline and non-saline aquifer depths. Water samples are collected from these observation wells monthly and analyzed them in terms of EC, pH, and SAR. Common problems for poor irrigation water quality are cited and the water quality parameter indices are precisely evaluated and interpreted. In the first location, the non-saline aquifer domain is overlain by saline aquifer domain and the salinity (EC, dS/m) varies from 0.88 dS/m to 1.54 dS/m in the non-saline aquifer domain and from 3.31 dS/m to 5.15 dS/m in the saline aquifer domain. In the second location, the non-saline aquifer domain is underlain by saline aquifer domain and the salinity varies from 0.83 dS/m to 1.22 dS/m in the non-saline aquifer domain and from 3.4 dS/m to 5.38 dS/m in the saline aquifer. In both locations, the salinity in the saline aquifer domain is significantly higher than the salinity limits recommended for agriculture in the region. So, the salinity in the saline aquifer domains in both the location exceeds the irrigation water quality limit and the salinity concentration in the non-saline aquifer domains far below the acceptable limit for irrigation. At both locations, the pH and the SAR values are found good to be excellent for crop production. So, it is concluded that the southwest coastal aquifer is found potential from hydraulic point of view and the water quality consideration except the salinity hazard in the saline aquifer domain.

1. Introduction

In a coastal region and the regions where the fresh water aquifer domain is overlain or underlain by the saline water domain and the availability of usable water is limited due to the presence of salinity, knowledge of the extent of saline aquifer domains and the evaluation of degree of salinity is essential to determine the potential for, and sustainability of groundwater resources for irrigated agriculture, domestic water supplies, and industrial uses. Due to the presence of salinity in the aquifer system , the boreholes drilled in this areas is being limited. So, there is an increasing concern for maintaining suitable groundwater quality in this region. Therefore agricultural water supply in the coastal region of Bangladesh has been a major problem (Islam and Hoque, 2009). Irrigation is largely dependent on groundwater in these areas. Rice cultivation demands large quantities of water during January to April which coincides with the dry season locally (Karim, 2006). Availability of adequate good quality water is one of the most important inputs in successful crop production. The knowledge of irrigation water quality is also critical to understand what management changes are necessary for long-term and short term productivity particularly for crops that are sensitive to changes in quality. Therefore, the current study focuses on the saline and non-saline aquifer domain identification and evaluation of the degree of salinity in the identified aquifer domains including the irrigation suitability.

2. Study Area

The study area is geographically located at between latitude $23^0 15'$N and $22^0 55'$N and longitude $89^0 24'$E and $89^0 36'$E in Narail district in Bangladesh. Maximum air temperature varies from 25.8^0C to 35.8^0C. The highest temperatures are experienced during the pre-monsoon period (April-May). Mean annual rainfall is 1781mm. Almost 90% of the rainfall occurs during the wet season. Input to the aquifer system occurs mainly as natural recharge from rainfall and irrigation. The southern reaches of the area, there are inter tidal floodplains that are generally inundated twice diurnally. The region is located in the coastal zone, and is significantly influenced by tidal effects. According to available statistics on Coastal Zone, majority of the land is within 1 m from mean sea level, a significant proportion of which again falls below high tide level (Islam, 2005).

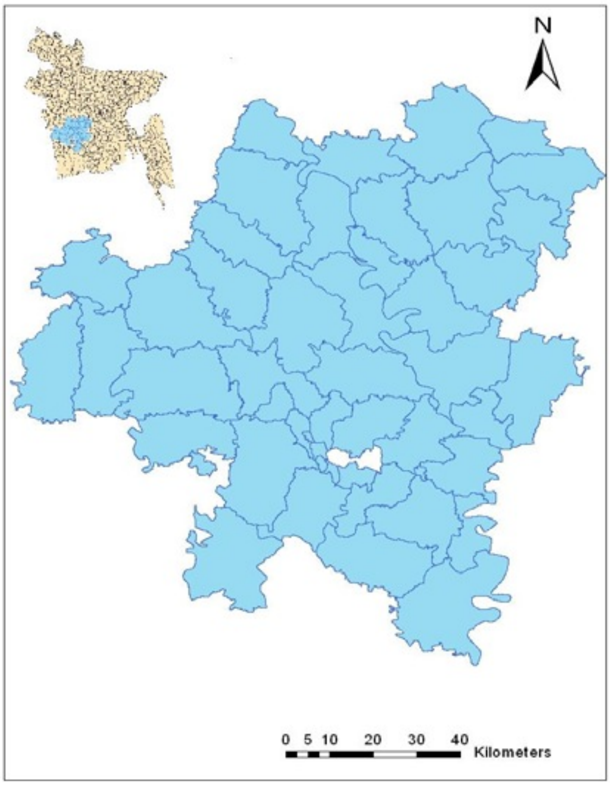


Figure 1. Study area

3. Materials and Methods

The main objective of this study is to investigate the saline and fresh aquifer domains and the suitability of groundwater for irrigation. The study is based on literature and the analysis of secondary and as well as the primary data. Previous hydrogeological investigation through exploratory drillings and the electric loggings (Woobaidullah, 1998; DPHE-JICA, 2007; Sarker, 2005) provides scattered information about groundwater quality in terms of salinity in the study area. This information is not sufficient to identify the extent and the degree of salinity in the region. To derive the required information field investigation was carried out with participatory rural appraisal (PRA) method (Neogi and Babul, 2004) and the in-situ soil and water sample analysis. The Key Informant Interview (KII) of PRA method was followed in the current study. For soil sample analysis the primary bore logged materials were analyzed. The confirmation of the findings of KII and the in-situ soil sample analysis would be made by supplementing with the in-situ water sample analysis. For primary data the two sets of observation well in the two locations of the study area. In this study, salinity is consider as salt content of groundwater which determined by the Electrical Conductivity. EC is recorded is micro Siemens per centimeter (µS/cm) at 25^{o}C. Because the suitability of saline water for irrigation and other application is so dependent upon the conditions of use, including crop, climate, soil, irrigation method and management practices, water quality classifications are not advised for assessing water suitability for these purpose. So water salinity range is classified according to potential uses. Such a classification is given in Table in terms of SAR and EC.

Table 1. Rating groundwater quality for irrigation.

Category	EC(dS/m)	SAR	Sustainability for irrigation
I	<0.75	<10	Excellent
II	0.75-1.5	10-18	Good
III	1.5-3.0	18-26	Fair
IV	>3.0	>26	Poor

Source: FAO (1989) guidelines

According to Rahman and Ravenscroft (2003) and BARI (1991), the guidelines presented in Table 2 for irrigation water should be used in Bangladesh.

Table 2. Irrigation water limit for Bangladesh.

EC (µS/cm)	Recommendation for irrigation
<1000	Unrestricted use
1000-2000	Restriction for irrigation of vegetables
2000-3000	Wheat irrigation only
>3000	Not recommended for irrigation

Source: Rahman and Ravenscroft (2003) and BARI (1991)

4. RESULTS AND DISCUSSION

4.1 Geological and Hydrogeological Setting

The hydrogeological cross-sections were prepared for the study using the data obtained from software Rockworks 15 (www.rockware.com, 2010) is shown in Figure 2. The two-dimensional picture clearly indicates the complex geo-hydrological settings. The aquifer thickness ranges from less than 160 m in the West to a maximum of 220 m in the East. But in the southern part the aquifer thickness is 20-50m, however the aquifer composition is very good. The water source of the aquifer is the adjacent geologic units and the river system. This provides a hydraulic connection between the aquifer and surface water system. The regional ground water flow direction is from the northwest to the southeast, except where ground water converges toward the center of a large cone of depression due to intensive localized pumping. The hydraulic gradient is consistent with the topography, steep in the northwest, and gentle in the east. The aquifer is confined by the thick clay unit.

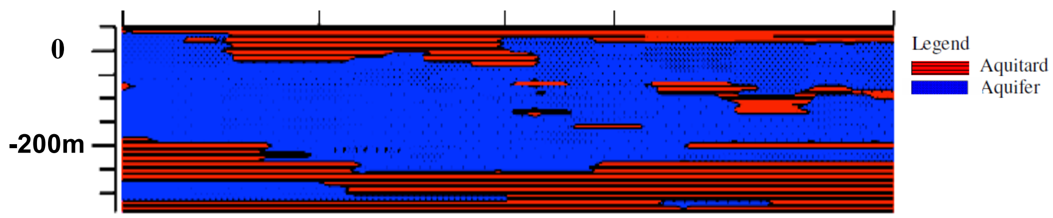


Figure 2. Geo-structural stratification and configuration

4.2 Saline and Non-saline Aquifer Domain Identification

The salinity can be quantified by total concentration of soluble inorganic salts present in a sample, or more accurately in terms of Electrical Conductivity (EC) of a solution, as the two are more closely related. Saline water is generally defined as water containing more than 1 to 1.5 g salts per liter which corresponds with an electrical conductivity of 1.5 to 2.3 dS/m. The saline and the non-saline aquifer domains are identified with the salinity concentration level at the different aquifer depths. Therefore, the aquifer where water contains the concentration of ≤2 dS/m is considered as a non-saline aquifer and when it exceeds 2 dS/m, the aquifer is considered as the saline aquifer. The saline and non-saline aquifer domain is identified with the following way.

4.2.1 Key Informant Interview

The KII was conducted to get the information on the presence of salinity in the aquifer system of the selected study area. The derived information by KII was used to select the locations for drilling well logs. The locations for well log drilling were based on aquifer condition and the presence of salinity with depths of the aquifer. The KII was conducted within the different classes of participants i.e., relevant local officials, public representative, local well drillers, and the selected villagers of the area. The officials include the local official of BADC, BWDB, and the LGED.

Qualitative results were summarized based on the discussion with the different classes of interviewees. It is revealed from the discussion with interviewees that salinity problem has been prevalent in the study area for years. Generally, salinity is found at shallow aquifer depth (100 m) whereas the deeper aquifer (> 300 m) is free from salinity and other water quality elements like Fe, As etc. The local people identified the level of salinity in different months by testing with mouth, observing the plant color etc.

4.2.2 Soil sample analysis

Based on the information from available literature (DPHE-JICA, 2007) and the findings of the KII two sites for exploratory drilling, one at Kalia and the other one at Tularampur as marked in Figure 3.1 in the area have been selected for further investigation on the identification of saline and non-saline aquifer domains and the extent of salinity. The selected sites, Kalia and Tularampur are located at a distance of about 40 km apart. Exploratory drilling has been done at both the locations up to a depth of 300 m.

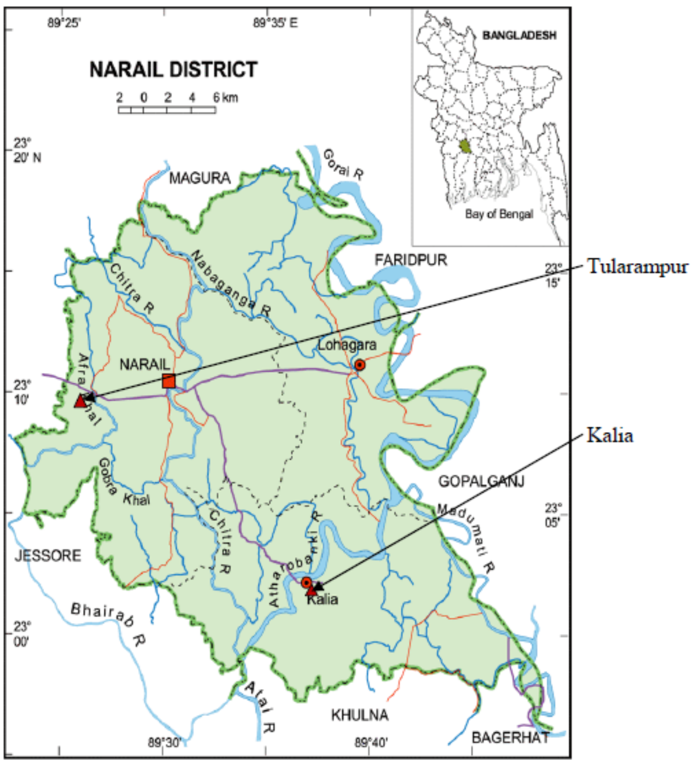
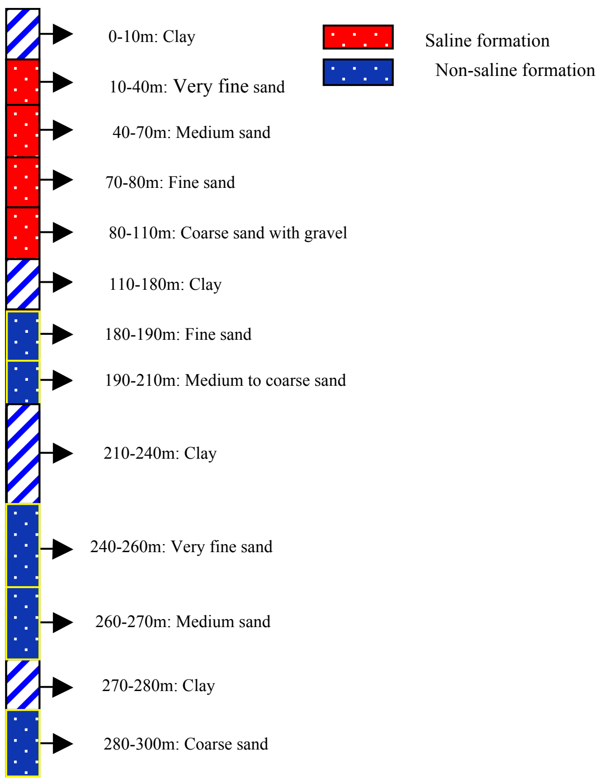


Figure 3. Exploratory drilling sites in the area

Four boreholes were drilled at two selected sites, two bore holes at Kalia and two bore holes at Tularampur. The aquifer material (sand, silt, and clay) was collected at every 6 m interval during the boring. The presence of salinity is identified with the sample tested by hand and from the experience of the well drillers. When the aquifer material shows reddish or glitters, the aquifer depth of the respective sample is considered as the saline aquifer. When the aquifer material shows clear and coarser grained then the aquifer depth of the respective sample is considered as the non-saline aquifer. Therefore, from the physical observations of the drilled logs the presence of salinity has been identified at both the locations in Kalia and Tularampur as shown in Figure 4 and Figure 5, respectively.

In Kalia, the salinity domain is identified at the upper domain where the non-saline domain is at the lower domain. In this location the saline geologic formation is located from depth 10 m down to 110 m. The bottom part of this formation is composed of coarse sand and gravel from depth 80 m to 110 m and therefore, this is considered as the saline aquifer domain. So the saline aquifer thickness is 30 m. The non-saline aquifer domain is considered from depth 280 m to 300 m which is composed of coarse sand. So the non-saline aquifer thickness is only 20 m. Above this non-saline aquifer domain there are several relatively poor non-saline aquifer formations separated by clay layers. But all the aquifer formations are structurally and hydraulically connected regionally as discussed in previous section. In Tularampur, the location of saline aquifer formation is opposite. The saline geo-structural formation is found at the bottom from depth 140 m to 300 m and from 250 m to 300 m is composed of coarse sand and considered as the saline aquifer domain for the current study. So the saline aquifer thickness is 50 m. The non-saline aquifer domain is considered in this location from depth between 50 m to100 m as this part is composed of coarse sand. So the non-saline aquifer thickness is 50 m. The presence of salinity is also confirmed from the water quality analysis.



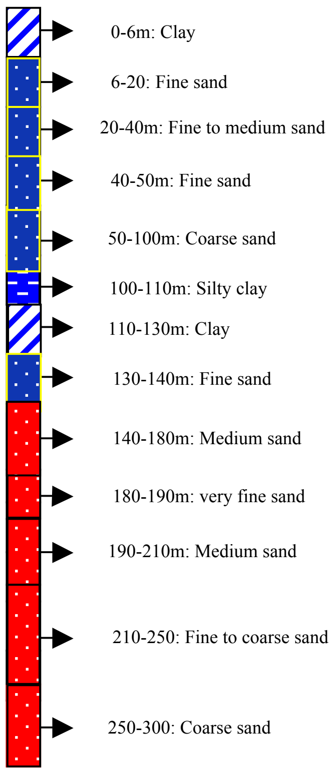


Figure 4. Bore logs at Kalia **Figure 5.** Bore logs at Tularampur

4.2.3 Water sample analysis

To collect the water samples, the monitoring wells are installed based on the aquifer structural condition (bore logs) discussed and presented in Figure 6 for Kalia and Tularampur, respectively. Due to the non-availability of data, four observation wells at the two locations are installed. The water samples from salinity observation wells installed at indentified saline and non-saline aquifer domains at Kalia and Tularampur were collected. The salinity concentration observed in the analysis with the electrical conductivity meter supports the physical observations reported in earlier section that the upper aquifer domain in Kalia and the lower aquifer domain in Tularampur are considered as the saline aquifer domains which can be seen in Figure 3 and Figure 4. From the EC value it is shown that in Kalia at shallow depth of the aquifer (100 m) the value of EC exceeds the value of predetermined level of EC = 2 dS/m. The salinity concentration was found 4.85 dS/m, whereas at the deeper aquifer (300 m) the EC value is below the value of predetermined level of EC = 2.0 dS/m and the EC value is at this aquifer depth is 0.87 dS/m. At Tularampur the EC value of deeper aquifer depth is 5 dS/m and at shallow aquifer depth is 0.98 dS/m. As a result, the shallow depth of aquifer (80 m) at Tularampur is identified as non-saline aquifer and deeper aquifer depth (300 m) is identified as saline aquifer.

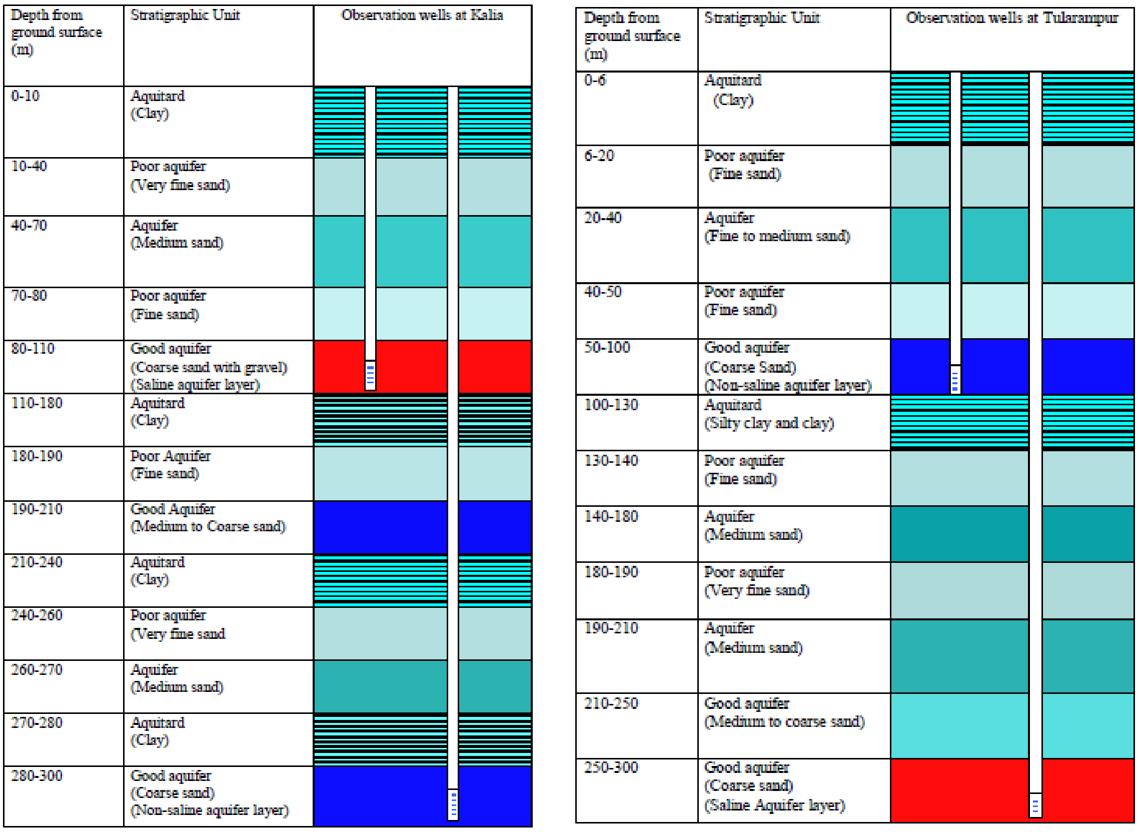


Figure 6. Salinity monitoring wells at Kalia at Tularampur

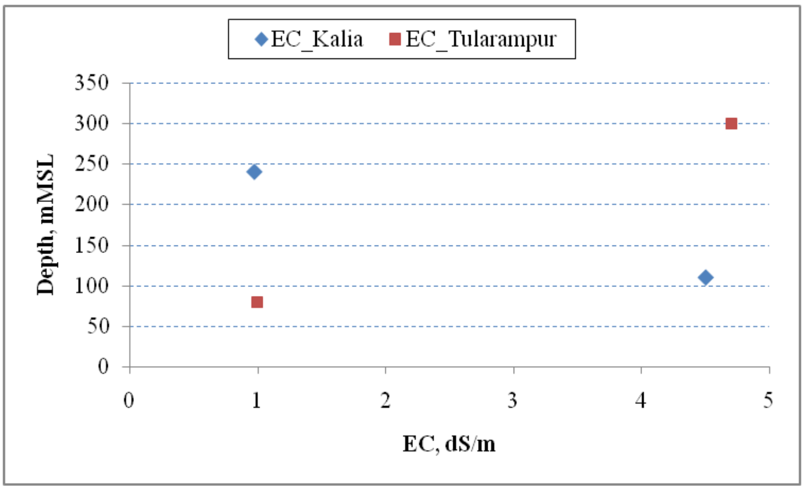


Figure 7. Salinity at different aquifer depths in two selected sites

4.3 Irrigation Water Suitability

4.3.1. Evaluation of EC

The salinity in the observation wells was observed for from March 2011 to May 2012 at Kalia and March 2011 to May 2012 at Tularampur. The data collection was based on the completion of well installation. The collected samples were analyzed in the laboratory for the major elements using standard methodologies (APHA 1999). The electrical conductivity (EC) were measured on electrical conductivity meter and presented graphically (Figure 8 and Figure 9) for both the locations.

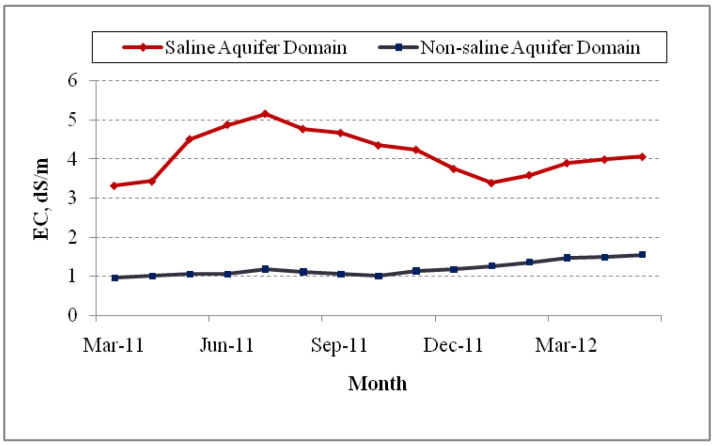


Figure 8. Variation of EC with time at Kalia

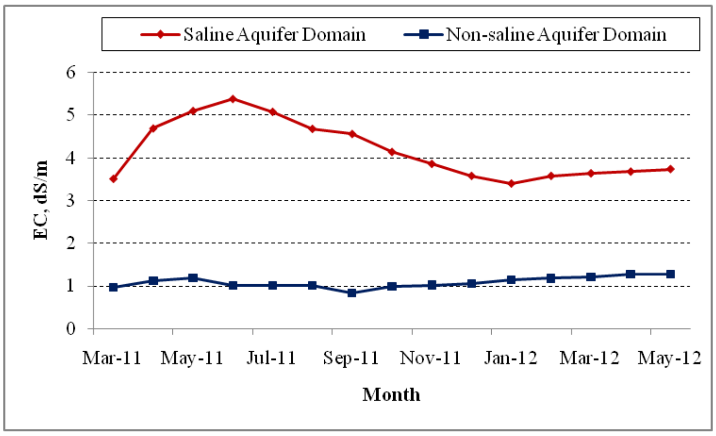


Figure 9. Variation of EC at Tularampur

At Kalia, the salinity concentration in the non-saline aquifer domain varies from 0.88 dS/m to 1.54 dS/m whereas the salinity in saline aquifer domain varies from 3.31 dS/m to 5.15 dS/m. In Tularampur, the salinity varies from 3.4 dS/m to 5.38 dS/m in the saline aquifer and 0.83 dS/m to 1.22 dS/m in the non-saline aquifer domains. Therefore, based on electrical conductivity values, two types of groundwater in non-saline aquifer depth are recognized in the study area, the groundwater that is not hazardous and needs no restriction on use and a groundwater in saline aquifer depth that needs slight to moderate degree of restriction on use. The first type of groundwater can be used for irrigation for almost all crops and for almost all kinds of soils. No soil and cropping problem will arise. Very little salinity may develop which may require slight leaching; but it is permissible under normal irrigation practices except in soils of extremely low permeabilities. But, the groundwater from saline aquifer domains cannot be used for irrigation for almost all crops and for almost all kinds of soils. Both soil quality and cropping yield problems will arise from its use for irrigation. Significant soil salinity may develop which will require leaching. To achieve a full yield potential using the second type, gradually increasing care in water application and management alternatives are required.

4.3.2. Evaluation of SAR

The physico-chemical parameters of the collected water samples were carried out following the established analytical methods (Page et al., 1982; Richards, 1954). The sodium adsorption ratio (SAR) was estimated by the equation using the values obtained for, Na^{+}, Ca^{2+}, and Mg^{2+} in me/*l* (Richards, 1954).

$$SAR = [Na^{+}] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2} \qquad (1)$$

The high SAR in any irrigation water implies hazard of sodium (Alkali) replacing Ca^{2+} and Mg^{2+} of the soil through cation exchange process, a situation eventually damaging to soil structure, namely permeability which ultimately affects the fertility status of the soil and reduce crop yield. The Sodium Adsorption Ratio (SAR) influences infiltration rate of water. So, low SAR is always desirable. In the studied samples, for Kalia the SAR values ranged from 5.83 to 12.47 as shown in Figure 10 for saline water domain. For Tularampur the SAR values ranged from 4.25 to 11.75 as shown in Figure 11 for saline water domain. The SAR value was the highest where the EC value was the highest. Referring Table 1 it is evident from the whole sample set that the SAR value varies from excellent to good category. Figure show that the SAR is always in excellent range for the non-saline aquifer domains in Kalia as well as in Tularampur. Therefore, the SAR results support that the groundwater in the different aquifer depths is free from any sodium hazard and highly suitable for irrigation. Water with SAR value less than 10 is suitable for any crop. Water with SAR within a range of 10 to 24 may cause problems on fine texture soils and sodium sensitive plants, especially under low leaching conditions. For irrigation with water having SAR of this range requires good sodium tolerant plants along with special management such as the use of gypsum. Irrigation water with SAR values more than 24 is harmful for crops in most soils, except with high salinity (1280 mg/l) and high calcium levels, and needs the use of gypsum.

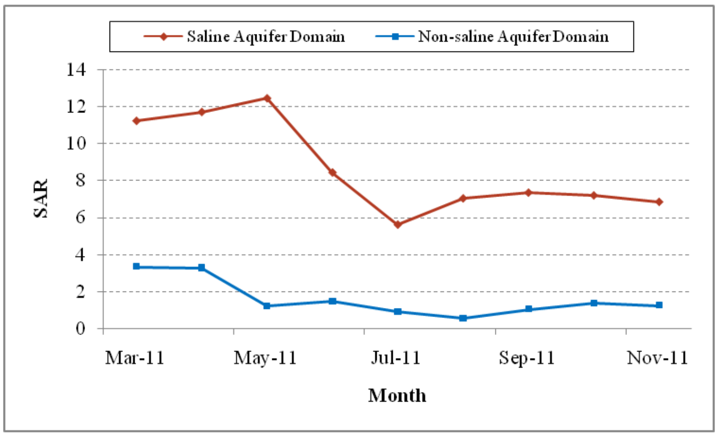


Figure 10. Variation of SAR with time at Kalia

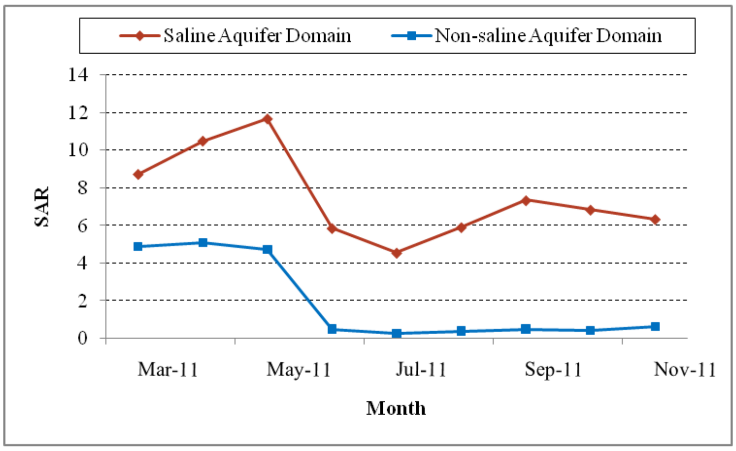


Figure 11. Variation of SAR with time at Tularampur

4.3.3 Evaluation of pH

The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The hydrogen-ion concentration is an important quality parameter of both natural waters and wastewater. The pH range suitable for the existence of most biological life is quite narrow and critical, and is typically ranges from 6 to 9 (Metcalf and Eddy, 2003). The normal range of pH for irrigation water is 6.5 to 8.5 (Pescod, 1992). Abnormally low pH is not common in the study area, but may cause accelerated irrigation system corrosion where they occur. The pH value from one aquifer domain to another does not very significantly both in Kalia and Tularampur. As a result the average value at Kalia and Tularampur are presented. The measured average pH values of the water sample of the two sites ranges from 7.65 to 8.08 for both the domains. In general, from pH point of view the groundwater of the study area are found safe and can be used for irrigation.

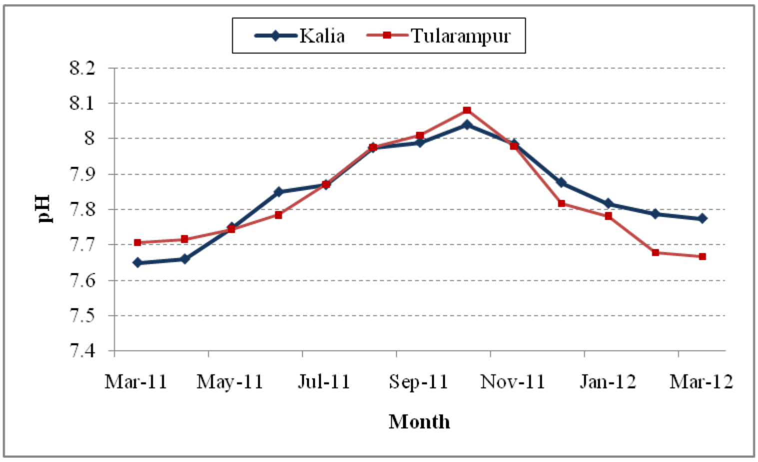


Figure 12. Variation of average pH in Kalia and Tularampur

5. CONCLUSIONS

1. In the southwest region of Bangladesh, the saline aquifer layer is found underlain by non-saline aquifer in one location and overlain by non-saline aquifer in another location.

2. In the study area at Kalia the non-saline aquifer domain is overlain by the saline aquifer domain. The thickness of the non-saline aquifer is 20 m and the saline aquifer is 30 m. The salinity concentration in the non-saline aquifer domain varies from 0.88 dS/m to 1.54 dS/m whereas the salinity in saline aquifer domain varies from 3.31 dS/m to 5.15 dS/m.

3. In Tularampur the situation is found opposite where the non-saline aquifer domain is underlain by saline aquifer domain. The thickness of the non-saline aquifer is 50 m and the non-saline aquifer is 50 m. The salinity varies from 3.4 dS/m to 5.38 dS/m in the saline aquifer domain and 0.83 dS/m to 1.22 dS/m in the non-saline aquifer domain.

4. SAR value is also excellent (in excellent category i.e., <10) in the deeper aquifer depth which reveals that the groundwater is free from any sodium hazard and supporting the highly suitability for irrigation. The pH values at both locations are found good for crop production.

5. Therefore, the salinity in the saline aquifer domains in both the location exceeds the irrigation water quality limit and the salinity concentration in the non-saline domains far below the acceptable limit for irrigation. So, as observed that due to the presence of saline layers the aquifer cannot be fully developed. This limitation of coastal aquifer is not only in the southwest region of Bangladesh; but this is common in coastal region of the world. So, it is strongly needed to use the full aquifer both saline and non-saline aquifer domain for augmentation of usable water supply by developing full coastal aquifer.

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REFERENCES

APHA (1999): Standard Methods for the Examination of Water and Waste Water, American Public Health Association, New York.

BARI (1991): Groundwater Salinity Risk in Greater Comilla-Preliminary Agricultural Investigations, Interim Report, Bangladesh Agricultural Research Institute.

DPHE-JICA (2007): Deep Aquifer Database Development Program, Department of Public Health Engineering, Groundwater Circle.

FAO (1989): Water Quality for Agriculture, 29 Rev. 1, Food and Agricultural Organization of the United Nations, Rome.

Islam, M. and Hoque, M. M. (2009): Groundwater Use and its Impact on Livelihood in the Narail District of Bangladesh, Proc. Fourth South Asia Water Research Conf., Kathmandu, Nepal, May 4-6, pp. 90-104.

IWM (2005): Impact Assessment of Climate Change on the Coastal Zone of Bangladesh, Dhaka, Bangladesh.

Karim, M. R. (2006): Brackish Water Shrimp Cultivation Threatens Permanent Damage to Coastal Agriculture in Bangladesh, In Environment and Livelihoods in Tropical Coastal Zones: Managing Agriculture-Fishery-Aquaculture Conflicts, Hoanh, C. T., Toung, T. P., and Gowing, J.W. (eds), CABI Publishing, UK, pp. 61-71.

Metcalf and Eddy (2003): Wastewater Engineering Treatment and Reuse, 4th Edn., New York, USA, McGraw Hill.

Page, A. L., Miller, R. H., and Keeney, D. R. (1982): Methods of Soil Analysis (edn.), Part 2, Am. Soc. Agron - Soil Sci. Sc. Am. Madison. Wis. USA. pp. 159-446.

Pescod, M. B. (1992): Wastewater Treatment and Use in Agriculture, Rome, Italy, FAO.

Rahman, A. A. and Ravenscroft, P. (2003), Groundwater Resources and Development in Bangladesh, Background to the Arsenic Crisis, Agricultural Potential and the Environment, the University Press Limited, Red Crescent Building, 114 Motijhil C/A, Dhaka, Bangladesh, ISBN:9840516434.

Richards, L. A. (1954): Diagnosis and Improvement of Saline and Alkaline Soils, Agricultural Hand Book 60, USDA and IBH Publishing Co. Ltd., New Delhi, India, pp. 98-99.

Sarker, M. M. H. (2005): Study on Spatial and Temporal Distribution of Groundwater Salinity in Southwest Region of Bangladesh using GIS Technique, M. Engg, Thesis, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka.

Woobaidullah, A. S. M. (1998): Application of Surface Resistivity Method to Groundwater Exploitation in the Coastal Belt of Bangladesh, Proc. 20^{th} Bangladesh Sci. Conf., Part-2, pp. 349-357.

www.rockware.com (2010): 2221 East St., Suite 101, Golden, CO 80401, USA.