

GROUNDWATER QUALITY ASSESSMENT OF BARISAL CITY CORPORATION IN BANGLADESH

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Abstract

Southern coastal belt of Bangladesh holds importance for its dramatic hydrogeological nature and aquifer systems. An attempt has been carried out to assess and evaluate the groundwater quality at Barisal City Corporation in the southern coastal city of Bangladesh. Samples were collected for the dry and wet periods from the nested wells to assess the groundwater chemistry and vertical variations for different seasons. During both periods, high concentrations of Na⁺ and Cl⁻ were measured along with high electric conductivity (>7000 μS/cm) which is telltale of brackish water, whereas, at greater depth (>150 m) these parameters played reverse role. Dominant water types in wet season were Na-Cl- HCO₃, Na-Cl and Mg-Cl while distinguished type of water was identified in different depths. Copiousness of the major ions has followed this order: Na⁺>Mg²⁺>Ca²⁺>K⁺>Cl⁻>HCO₃²⁻>SO₄²⁻>NO₃⁻>PO₄²⁻. Vertical distribution of Arsenic (As) shows significant trend in which shallower wells have higher concentration than the deeper one. Water from shallower depth is proved to be highly and injuriously contaminated by sea water intrusion but in deeper piezometers water is identified as slightly contaminated by sea water ingress. Variations in water quality may be influenced by the presence of thick silty clay layer that prevents injection from upper zone.

Keywords: Nested piezometer, Groundwater quality, Cl⁻/ (CO₃²⁻+ HCO₃⁻) ratio, Hydrochemistry, Salinity Variation.

Introduction

Water is indispensable part of life but its availability at a sustainable quality and quantity is threatened by Climate variability. Bangladesh is the most vulnerable place to global

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climate change. Sea level rise (SLR) is responsible for saltwater intrusion in coastal freshwater resources, such as the inundation of low lying areas particularly for shallow sandy aquifers along low-lying coasts and is likely the most direct impact of climate change. Expansion of deep and shallow tubewells in Bangladesh due to the increased groundwater accessibility results in excessive drawdown in intensively irrigated areas, deteriorating the groundwater quality (Qureshi et al., 2015). Groundwater levels in shallow aquifers underlying Asian mega-deltas are characterized by strong seasonal variations associated with monsoon rainfall (Shamsudduha et al., 2009). Saltwater intrusion from the Bay of Bengal in coastal areas of Bangladesh leads to contamination of natural water sources, such as rivers and groundwater; and other metal ions also pollute the freshwater sources by storm surges and upstream withdrawal of freshwater (Khan et al., 2011). Salinity is a widespread problem in shallow groundwater in the coastal region of Bangladesh, but there has been little systematic study of its origin and interaction with fresh groundwater (Taylor et al., 2014). In this regard, BWDB initiated a project to study surface and groundwater resources by mathematical modelling and to assess changes in groundwater level and hydrogeochemistry due to withdrawal in 2012-2014. Very few works have been conducted to assess and evaluate hydrochemistry in Barisal region so far (BWDB, 2013). Hydrogeochemical data helps in determining the area and extension of mixing, circulating pathways and residence time of groundwater (Edmunds, 1995).

This study has been conducted to assess and evaluate hydrogeochemistry and water quality for both dry and wet seasons of the Barisal city corporation in Barisal Sadar Upazila. This research demonstrates the chemistry of groundwater, hydrogeochemical facies changes with depth and vertical variations in groundwater quality for different seasons.

Study Area

The study area is situated in the southern coastal region of Bangladesh. It lies in 90.36° E longitudes and 22.68° E latitudes and is in the Barisal city corporation of Barisal district (Fig. 1). BWDB installed a nest with four piezometers in different depths to assess the vertical and seasonal variations of groundwater chemistry. This area is situated on the bank of the Kirtonkhola River. The geology of this area determines the groundwater potential, vertical and seasonal hydrogeochemical variations. This study area is composed of primarily Quaternary sediments having huge thickness which form the shallowest upper aquifers. The tertiary formation, having good potential of groundwater development, is composed of sandstone argillaceous and pebble bearing grits, clays (variegated) with lignite seams and pebble beds forms the main and deeper aquifers (BGS-DPHE, 2001). At present water bearing formation deeper than 150-200 m are being exploited on a great quantity in the coastal zone to cater the need of municipal

water supply and in the rural areas for drinking purpose (Zahid et al, 2009). Large-scale extraction has not been encouraged in the coastal areas due to possibility of seawater intrusion or leakage from the upper aquifer (Aggarwal et al, 2000; Zahid et al, 2009).

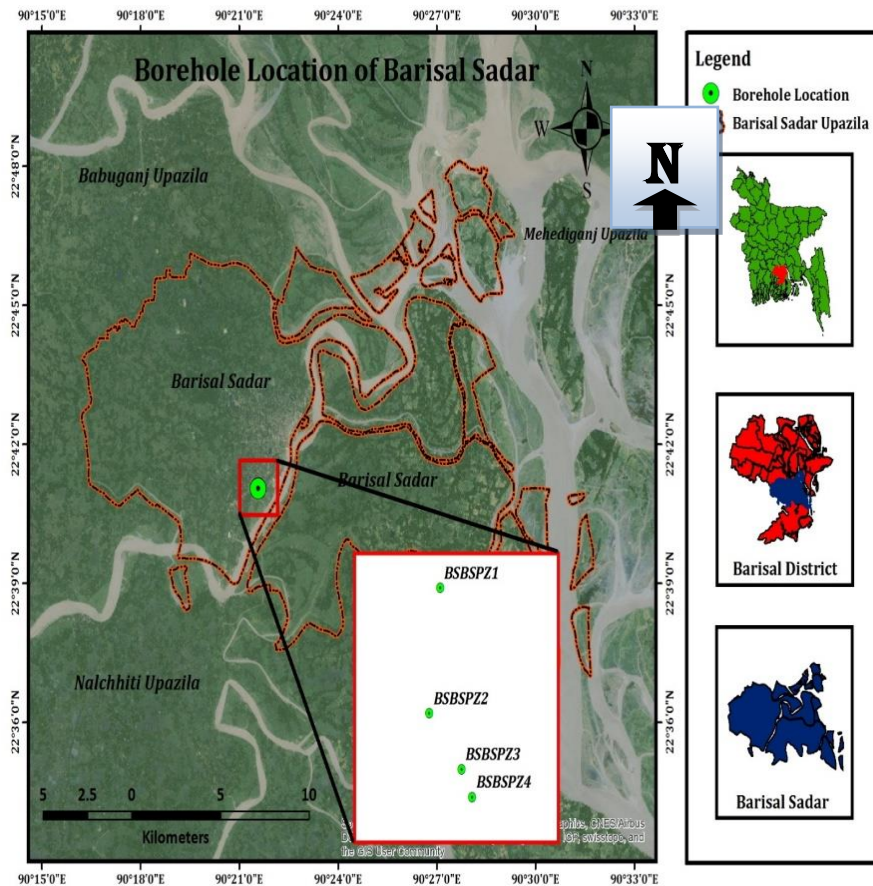


Fig. 1. Location map of the study area.

Sampling and Analyses

This study is principally based on data which were collected from the study area by BWDB in 2012-2013. A total of eight groundwater samples were collected from nested wells, marked as BSBSPZ_1, BSBSPZ_2, BSBSPZ_3 and BSBSPZ_4 for both wet and dry periods across a river along a line. Nested wells are the piezometric well screened at different depth to evaluate the vertical and seasonal changes in hydrochemistry. Collected samples were then analyzed in the BWDB laboratory to assess major cations like Na^+ , Ca^{2+} , K^+ , Mg^{2+} and anions like CO_3^{2-} , HCO_3^- , NO_3^- , SO_4^{2-} .

Result and Discussions

Lithology

Lithology of the investigated locations was identified through the well logs. The dominant geological materials were clay, silty clay, silt, very fine sand, medium sand and coarse sand. The shallower piezometers, mainly BSBSPZ_1 and BSBSPZ_2 covered depth of 107 m and 153 m respectively. The later one was installed at a layer of fine to coarse sand unit which was segregated by a thick layer (total 27 m) of silty clay and clay from the immediate lower facies of very fine sand with silt. Rest of the two piezometers (BSBSPZ_3 and BSBSPZ_4) encountered up to depth of 238 m and 268 m correspondingly where coarser and medium sized materials were found dispersedly at different depth. A multilog section has been presented in Fig. 2, showing the subsurface geology of the study location. These geological particles constitute the aquifer system of the area.

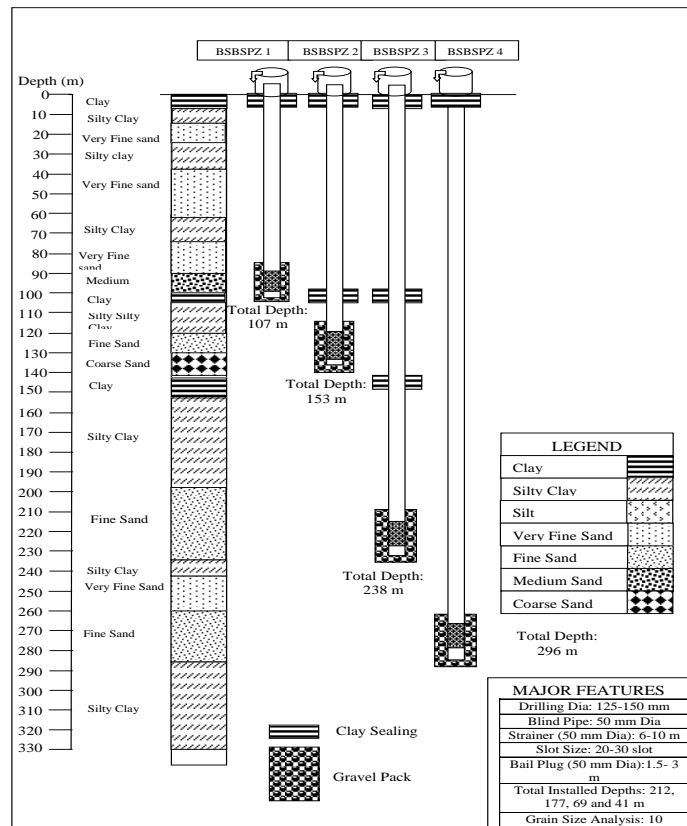


Fig. 2. Multilog section of study location (BWDB, 2013).

Groundwater chemistry

For assessing groundwater quality of the nested piezometers, concentration of various chemical ions e.g. Na^+ , Ca^{2+} , K^+ , Mg^{2+} , Cl^- , CO_3^{2-} , HCO_3^- , NO_3^- , SO_4^{2-} , Mn, Fe and As were determined through chemical analysis which are presented in Table 1. In the meantime, different physical parameters were measured during water sample collections which are also gathered in the same table. Arsenic (As) was measured by HACH kit during sampling in the field. To get clear demonstration, piezometers were marked for rainy season those were BSBSPZ_1W, BSBSPZ_2W, BSBSPZ_3W and BSBSPZ_4W whilst for dry season as BSBSPZ_1D, BSBSPZ_2D, BSBSPZ_3D and BSBSPZ_4D respectively. Among several major ions Na^+ , Mg^{2+} , Cl^- , HCO_3^- played a vital role in deciphering the geochemistry of the aquifer.

Table 1. Physical parameters and chemical composition of the groundwater (Source: BWDB, 2013).

Physical Parameters	Station ID	Depth (m)	Temperature (°C)	pH	Eh (mV)	EC ($\mu\text{S}/\text{cm}$)	Salinity (mg/l)	TDS ($0.7 \times \text{EC}$) (mg/l)			
	BSBSPZ_1W	106	28.6	7.34	-22.2	7190	3.9	3610			
BSBSPZ_2W	152	28.4	7.48	-28.9	7620	4.2	3810				
BSBSPZ_3W	237	28.6	8.12	-66.9	892	0.4	446				
BSBSPZ_4W	293	28	7.51	-22.7	1187	0.6	596				
BSBSPZ_1D	106	28.2	7.31	201	7360	4	3820				
BSBSPZ_2D	152	28.3	7.33	208	7740	4.4	4140				
BSBSPZ_3D	237	27.8	8.19	162.9	920	0.4	478				
BSBSPZ_4D	293	28.1	7.35	204	1198	0.6	623				
Chemical Parameter	Station ID	Na^+ (mg/l)	Mg^{2+} (mg/l)	Ca^{2+} (mg/l)	K^+ (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	As ($\mu\text{g}/\text{l}$)	Fe (mg/l)
	BSBSPZ_1W	166.2	123.50	77	23.43	2125	396.5	7.3639	11.96	25-30	6.86
BSBSPZ_2W	1550	130	90.05	26.34	2525	384.3	6.3855	46.8	0-15	0.21	
BSBSPZ_3W	513	7.2	16.44	3.24	235	378.2	0.0602	119.22	0-5	0.49	
BSBSPZ_4W	394.2	42.8	39.01	39.01	290	311.1	5.3739	7.95	0	11.48	
BSBSPZ_1D	263.4	111.28	9.7	27.71	2180	366	6.03	11.96	20-25	5.85	
BSBSPZ_2D	1628.9	130.25	9.3	26.35	2580	384.3	2.42	46.8	0	2.33	
BSBSPZ_3D	369.9	6.2	3.03	2.41	260	378.2	0.47	119.22	0	0.462	
BSBSPZ_4D	257.4	39.15	10.18	7.15	315	359.9	5.73	10.918	0	7.68	

From the data set, it is evident that the shallower piezometric wells (depth <160m) show higher EC and TDS than the deeper wells. Therefore, salinity is higher in the deeper wells. High concentration of Na^+ and Cl^- in both seasons in shallower piezometers proves the possibility of intrusion of saltwater. Cl^- concentration exceeds Na^+ concentration which can be explained by reverse softening reaction during the surface water influence and may be due to the anthropogenic activity. On the other hand, these two ions were encountered at a tolerable limit in the deeper piezometers. Again, Arsenic (As) is found at an extreme level of 20-25 $\mu\text{g/l}$ which exceeds WHO standard (2011) of As in the groundwater. But concentration of SO_4^{2-} remains much below than that of cutoff limit of WHO in every well for both periods. In the shallower piezometers electric conductivity (EC) of the groundwater was so high in both seasons which was always remained >7000 $\mu\text{S/cm}$. It is a characteristic phenomenon of seawater intrusion at shallower depth. On the contrary, lower value of electric conductivity (892-1198 $\mu\text{S/cm}$) had been gauged in deeper piezometers. Depth profiles of this parameter gave a sharp view of the phenomena (Fig. 3). Total dissolved solids (TDS) followed the same trend like EC, i.e. TDS was higher (3610-4140 mg/l) in shallow piezometers in both seasons while lower concentrations (446-623 mg/l) were measured in the deeper piezometers. Supremacy of the anion was led by Chloride (Cl^-). Bicarbonate (CO_3^{2-}), Sulfate (SO_4^{2-}), Nitrate (NO_3^-) and Phosphate (PO_4^{2-}) followed the Chloride. On the other side, dominant cation was Sodium (Na^+), which was followed by Magnesium (Mg^{2+}), Calcium (Ca^{2+}) and Potassium (K^+).

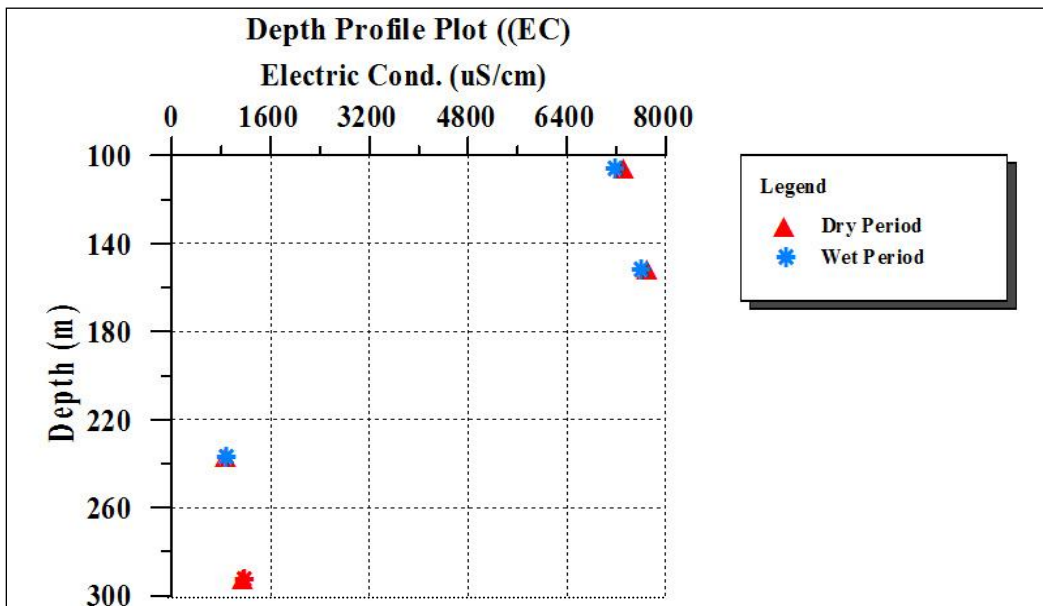


Fig. 3. Depth profile of electric conductivity.

Hydrochemical water types

A trilinear diagram, developed by Piper (1944), was used to deduce the geochemical evolution of the groundwater by plotting the concentrations (mg/l) of major cations and anions. From the Fig. 4, it is shown that 50% samples of the wet season, especially at shallower wells, were of Na-Cl-HCO₃ which is basically of saline water type whereas rest of the samples were distributed equally (25%) in Na-Cl and Mg-Cl types. On the contrary, during dry season the groundwater system can be classified as Na-Mg-Cl, Na-Cl, Na-Cl- HCO₃ and Na-Mg-Cl- HCO₃ at an ascending order of depth of the well. So it is evident that almost all the samples from the nested well for different seasons show the saline water facies which is typical of marine influence.

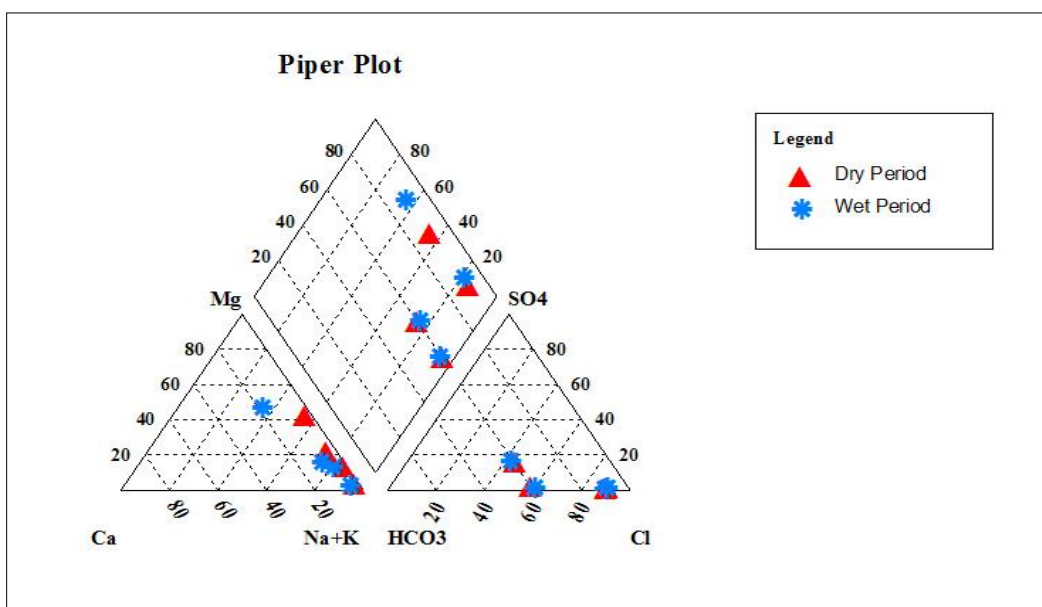


Fig. 4. Piper diagram

Seawater intrusion

Concentration of Na⁺ and Cl⁻ in the groundwater in both seasons has given a trace of seawater ingress in shallow aquifer depth ranges up to 150m. In order to weigh up and ascertain this phenomenon, an assessment has been made to establish the levels of Cl⁻, CO₃²⁻ and HCO₃⁻ quantitatively. Cl⁻ is a dominant element of sea water while CO₃²⁻ and HCO₃⁻ are copious in groundwater. A relation is proposed by Revelle (1941), Cl⁻ / (CO₃²⁻ + HCO₃⁻) ratio, which could be an indicative of groundwater contamination due to seawater intrusion (Simpson, 1946). Sarada and Bhushanavathi (2015) compiled a range of this ratio relating with the level of sea water contamination which is as follows:

Table 2. Range of $Cl^- / (CO_3^{2-} + HCO_3^-)$ vs. Salt water contamination level (After Sarada and Bhusanvathi, 2015)

Range of $Cl^- / (CO_3^{2-} + HCO_3^-)$	Remarks with reference to salt water contamination
<0.5	Normal groundwater (no saltwater contamination)
0.5-1.30	Slightly contaminated groundwater
1.30-2.80	Moderately contaminated groundwater
2.80-6.60	Injuriously contaminated groundwater
6.60-15.50	Highly contaminated groundwater (near sea water)
>200.00	Sea water

Groundwater of the studied four piezometers (for both seasons) is demarcated taking in consideration the above mentioned ratio and ranges. The qualitative status of the groundwater seems like following:

Table 3. $Cl^- / (CO_3^{2-} + HCO_3^-)$ Ratio of the samples taken in wet season and dry season (After Sarada and Bhusanvathi, 2015)

Station ID	Location	$Cl^- / (CO_3^{2-} + HCO_3^-)$	Remarks
BSBSPZ_1W	Barisal sadar	5.339196	Injuriously contaminated groundwater
BSBSPZ_2W	Barisal sadar	6.519494	Injuriously contaminated groundwater
BSBSPZ_3W	Barisal sadar	0.61891	Slightly contaminated groundwater
BSBSPZ_4W	Barisal sadar	0.927703	Slightly contaminated groundwater
BSBSPZ_1D	Barisal sadar	5.931973	Injuriously contaminated groundwater
BSBSPZ_2D	Barisal sadar	6.687403	Injuriously contaminated groundwater
BSBSPZ_3D	Barisal sadar	0.684751	Slightly contaminated groundwater
BSBSPZ_4D	Barisal sadar	0.87161	Slightly contaminated groundwater

Salinity variation

A radical change has been detected in salinity variation with the change of depth. At shallower depth of 106 m and 152 m, the salinity was measured at value more than >7000 $\mu S/cm$ in both seasons which represents brackish water nature. But the quality of water

was changed tremendously at greater depth (237 m and 268 m) which ranges from 892-1198 $\mu\text{S}/\text{cm}$. Water from these layers is quite different from the upper aquifers having quality of fresh water. This would be possible as connate water was not affected by seawater intrusion. Presence of a thick silty clay layer may act as a barrier for the saline water intrusion into the lower aquifer.

Arsenic and iron distribution

Excessive As content in groundwater, 10–100 times the WHO guideline for drinking water (10 $\mu\text{g}/\text{l}$), menaces human health and production of irrigated crops across broad floodplains of the Ganges, Brahmaputra and Meghna rivers of the Bengal Basin in West Bengal and Bangladesh (BGS/DPHE, 2001; Ravenscroft et al., 2009). As contamination in groundwater in the Ganges delta and some low-lying areas in the Bengal basin is confined to middle Holocene sediments. Safe water options in this region are further aggravated by salt water intrusion in the low lying coasts which contaminates the surface water bodies and groundwater as well. As distribution in the study area has been shown in the Fig. 5. There is a usual trend of distribution having higher content As in the shallow aquifer and less in the deeper. Besides this, the shallowest and deeper piezometers show higher concentration of Fe for both dry and wet seasons (Fig. 6) which may be caused by reducing reactions in the subsurface.

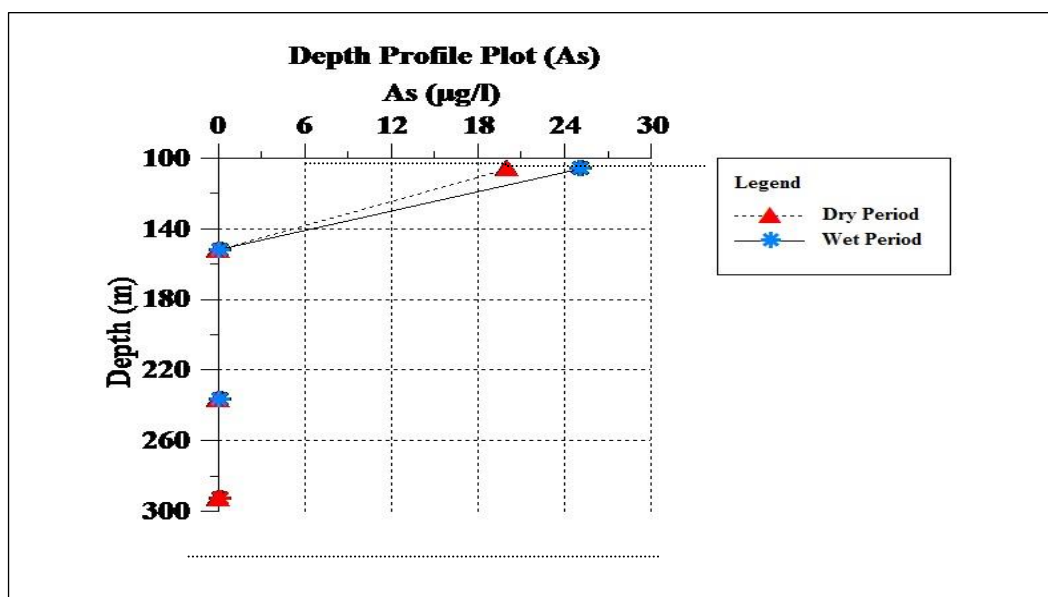


Fig. 5. Depth profile of arsenic.

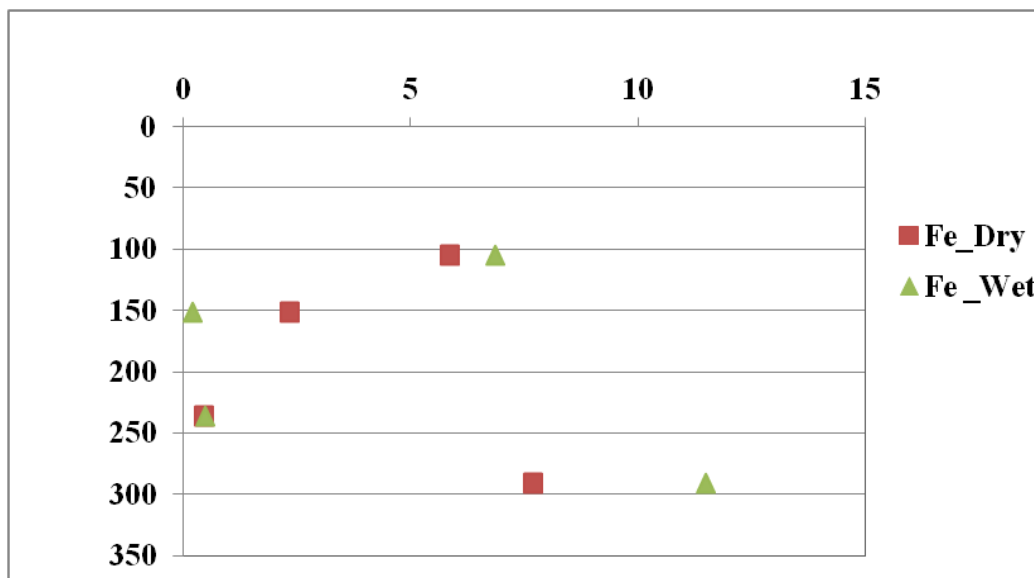


Fig. 6. Iron (Fe) distribution.

Conclusion

The groundwater quality of the study area is controlled by various physio-chemical parameters and sea water intrusion. Groundwater quality is mainly controlled by mixing of the surface water which is basically saline and ion exchange reactions. The Mg^{2+} and Ca^{2+} are derived mainly from dissolution of carbonate precipitates along with ion exchange process in the groundwater. Dominant water type in wet season was Na-Cl- HCO_3^- , Na-Cl and Mg-Cl while distinguished type of water was identified in different depth. Copiousness of the major ions has followed this order: $Na^+ > Mg^{2+} > Ca^{2+} > K^+ > Cl^- > HCO_3^{2-} > SO_4^{2-} > NO_3^- > PO_4^{2-}$. Vertical distribution of Arsenic (As) shows significant trend in which shallower wells have higher content than the deeper one. Shallower piezometers (up to depth of 106 m and 152 m) encountered more or less finer sediments while medium to coarser particles were found dominant from deeper piezometers (237 m and 268 m deep). A thick layer of silty clay has segregated the upper aquifer from lower aquifer. Chemistry of the brackish water collected from shallower piezometers suggests that it's vulnerable to neither drink nor irrigation. Meanwhile, extraction from the greater depth would be a good option for daily use as its proven slightly injurious by means of $Cl^- / (CO_3^{2-} + HCO_3^-)$ ratio. Electric conductivity and chemical parameters also indicate the same phenomena for both cases. Thick silty clay layer may have played a tremendous role in making difference in water quality between shallower piezometers and deeper piezometers. It may be preventing sea water to intrude in large amount in lower subsurface.

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