◆Research Paper

Groundwater Assessment of Coastal Aquifers in Karachi: Impact of Seawater Intrusion

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Abstract: Present study is aimed at assessing the groundwater quality in coastal part of Karachi and detection of seawater intrusion through major ion geochemistry of the coastal groundwater occurring in Korangi and DHA areas. For this purpose 6 groundwater samples were collected from deep wells (mean depth: 600ft) of Korangi and DHA phase VIII. Groundwater pH is slightly variable which ranges between acidic to alkaline (6.6-8.5) with a mean of 7.7. The groundwater is classified as moderate to highly saline (mean TDS: 21234 mg/L) and very hard (hardness: 3221.3 mg/L). Hydro-geochemical analysis of collected samples revealed that the dominant hydrofacies in the groundwater is Na-Cl. In addition, excess of Ca and Mg followed by dominance of Cl over alkali ions suggest that the groundwater is highly saline mixed through sea water intrusion. The overall major ion chemistry reveals that such groundwater is not suitable for domestic purpose.

Key words: Groundwater quality, seawater intrusion, Major ion chemistry, Karachi coast.

Introduction

Groundwater is primary source of water for human consumption, as well as for agriculture and industrial uses in many regions all over the world especially coastal areas (Prasad et al, 2015, Mondal et al, 2014). The water supply and its quality has been a recent global challenge for many countries all around the world. Quality of water used for domestic and agricultural purpose has impact on health and live stocks. Hence it is important to assess the water characteristics especially in coastal belts which get rapidly urbanized and where the groundwater is under continuous threat of sea water mixing. The groundwater composition is modified by mixing of the water that enters in to the aquifers and reacts with the minerals present in the aquifer sediments. Groundwater quality is controlled by both natural processes and human activities. Contamination by different pollutants, mainly due to the intense agricultural and urban development, has placed whole environment at greater risk (Prasad et al, 2015).

It is widely believed that the water demand is higher for the public living in the urban areas as compared to the rural one. Due to this fact, dependency on local water resources increases by the time. If the available water resources are not evaluated for the quantity and quality the consequences are worst in terms of water demand and supply. Thus, it is very important to find out the groundwater and saline/sea water interaction especially in the wake of increasing population in coastal areas (Mondal et al, 2010). Karachi is the biggest city of Pakistan which is exponentially being urbanized especially during last few decades. Study parts including Korangi and DHA phase VIII were selected for present investigation as these areas occur in the coastal belt of Karachi city and have short fall of municipally supplied water. These areas are mainly supplied with water by hydrants or tankers for the domestic uses. Due to rapid increase of settlements in study parts, water supply is being affected. The alternative switch over is groundwater which will be exploited intensively in the future to meet the water demands in study sites. It is known that the groundwater quality is main factor determining its suitability for drinking, agriculture and industrial purpose. On the other hand, seawater intrusion results in the contamination of coastal aquifers and therefore a reduction in the available water for human consumption and agriculture (Hutching and Tarbox, 2008). Hence it is important to assess the quality of water available in the aquifers of these coastal parts of Karachi. Up to the knowledge of authors, no study has been carried out so far to investigate sea/salt water interaction with groundwater of coastal aquifers of Karachi. Therefore, present study is aimed at assessing the groundwater status of deep aquifers for seawater impact. Present study will focus on water type, classification of water for various purposes and assessment of water quality through major ion geochemistry.

Study Area

The selected study sites are coastal parts of Karachi including Korangi and DHA phase VIII which lies between latitude 24°81′49″ to 24°80′30″ and 24°78′12″ to24°78′12″ and longitude of 67°00′71″ to 67°86′78″ and 67°03′74″ to 67°21′07″. Korangi lies on south of Karachi city while DHA is located on south west of it. Korangi is bordered by Malir River on the north which extends to the west and discharges to the Arabian Sea in the south. On the other hand, DHA occurs in the west of Malir river mouth (Fig.1).

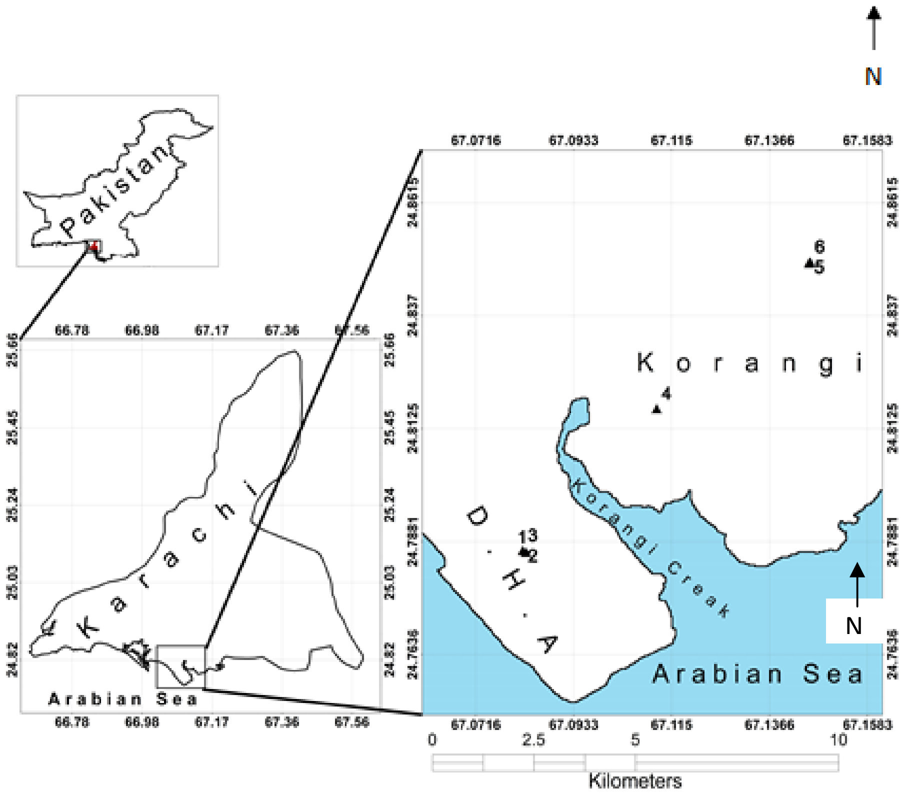

Figure 1 Sample location map and study sites (Korangi and DHA Phase 8).

Location and Climate

The study sites are part of Karachi city which lies in the northern tropical zone of the earth. This tropical zone includes most of the desert belts of world in which major mountain belt aligned north- south on the west (Farooq et al, 2010). Study area has relatively mild climate and low precipitation with very hot summers. However, due to proximity with the sea, these sites maintain the humidity level. Total average rain fall in Karachi city is about 200mm per year based on the last 50 years record (Farooq et al, 2010; PMD, 2012).

Temperature of Karachi city fluctuates between 34-38°C during summer and varies between 24-28°C during winter.

Geology of Study Area

The soil in the study sites is rich in salts including sodium chloride, sodium carbonate and nitrates with some calcium, which comes from shell fragments (Fig. 2). Generally the thickness of soils increases in the south-east direction (Hamid et al, 2014). The maximum thickness of soils developed on alluvial deposits and dissected plateau are noted in some

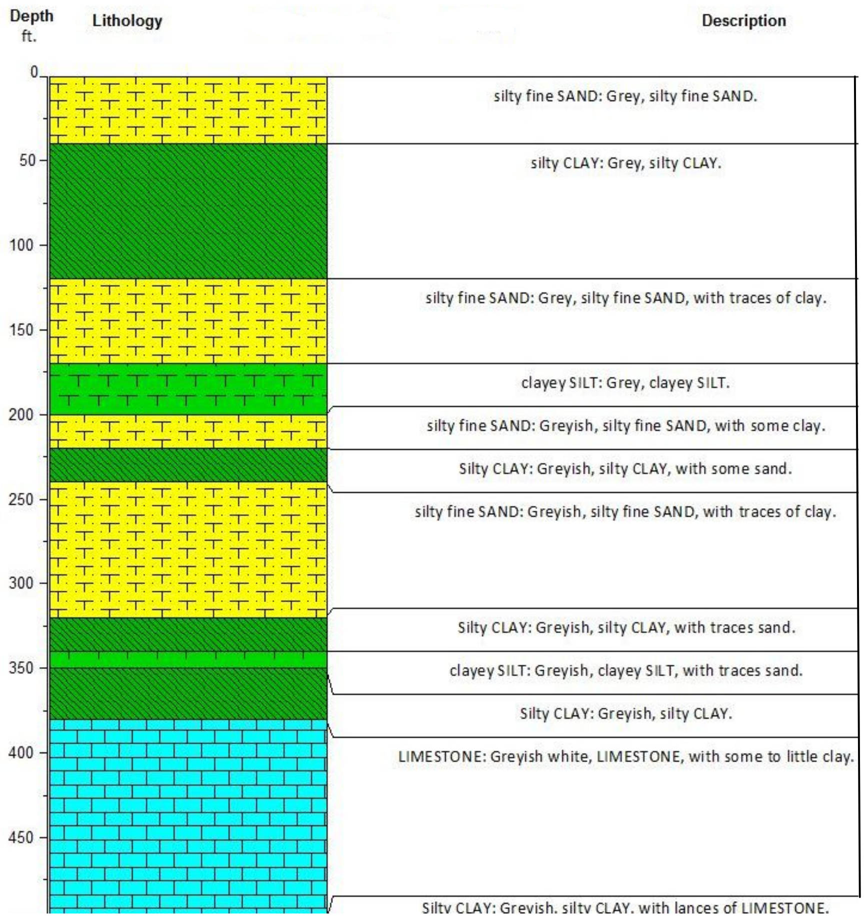

Figure 2 Stratigraphic succession of the study area by well logging up to the depth of 500ft.

areas including Korangi (Hamid et al, 2014; Pithawala and Marten-Kaye, 1946). The subsurface rocks in study area comprise Gaj Formation of Miocene age. The trend of subsurface rocks is north-east and south-west orientations (Hamid et al, 2014). The columnar section up to the depth of 500 ft revealed that the rocks are mainly composed of silty sand with subordinate clayey layers. The sand is highly conductive and transmissive. The lower units are comprised of limestone which is fossiliferous in nature (Fig. 2).

Hydrogeology of Study Area

Hydrogeologically, Karachi lies in Malir River basin it is bounded by Hub River in the west and Malir River on east. Malir basin is mainly drained by the Malir River followed by the Lyari channel. Both these channels are ephemeral hence the flowing water is usually sewage and industrial effluent. Hub River follows on the western margin of the city which is ephemeral in nature but it is devoid of any sewage or anthropogenic influences. The coastal aquifers of Karachi are mainly recharged by Malir or Lyari Rivers (Mashiatullah, 2002) with same contribution from Hub River. Hub River is recharging the confined aquifers of Tertiary age (Nari and Gaj formations) while Malir and Lyari Rivers are mainly recharging alluvial aquifers of Quaternary age in the coastal parts of Karachi city.

Materials and Methods

Sample Collection

For the evaluation of groundwater quality and sea water intrusion in coastal aquifers, samples (n=6) were collected from various locations of study areas at an average depth of 600 ft. Samples were collected in clean plastic bottles of 500/ml and 100capacitiy for physicochemical analyses. These bottles were first washed with distilled water and then with the sample water then filled with the same water.

Physicochemical Analyses

Water samples were analyzed to determine the physicochemical parameters. American Public Health Association (APHA, 1996) standard method was adopted for determining physicochemical parameters. Physical constituents include pH, electrical conductivity (EC), hardness and total dissolved solids (TDS) while chemical parameters include major cations (Ca, Mg, Na, K,) and anions (NO_3, SO_4, Cl and HCO_3). Turbidity was determined visually while other aesthetic characters (color, odor and taste) were also determined accordingly. EDTA titration method was used to measure hardness of collected samples in terms of calcium carbonate.

Statistical Analyses

SPSS software (16.0) was used to determine the correlation between Ca-Mg, Cl-HCO_3 and Na-Cl in order to evaluate sea water intrusion as worked by Mondal, 2010 and Karfali and Jurdi, 2010. The hydrochemical facies were identified with the help of Piper (Piper, 1953) diagrams using AqQA chem software (19.0)to elaborate diagnostic chemical characters of water solution in hydrologic system. The ratios between various major ions were calculated to find out the dominant facies in groundwater of study area.

Results and Discussion

Physical Parameters

The results of physicochemical analysis of collected groundwater samples (n=6) have been summarized in Table1.

pH

Groundwater data reveal that pH varies between 6.6-8.5 in the study area which is showing the typical fresh water pH range. Generally pH has no direct impact on the quality of water but the value less than 6.5 or more than 8.5 can impair the potability of drinking water (WHO, 1993). For example, toxicity of cyanides and sulfides increases with decrease in pH and ammonia becomes more toxic with increase in pH (Williams, 2003). Hence occurrence of slightly alkaline (mean pH = 7.7) ground water favor its use for drinking purpose in study area.

Total Dissolved Solid (TDS)

Extremely high values of TDS are reported from both Korangi and DHA sites which is ranging between 3440 to 77618 mg/L with a mean of 16353 mg/L. The occurrence of salinity almost 32 times higher than the WHO recommended value (500mg/L) for drinking water in study areas strongly negate its use for drinking purpose. According to Robinove et al., (1958) classification the ground water of study sites can be classified as moderately saline to very saline (Table 2).

Table 1 Statistical analysis of Physicochemical parameters for collected samples.

	Min.	Max.	Mean	SD
pH	6.6	8.5	7.68	0.77
TDS	3440	77618	21234	26087
EC	4914.28	110883	29468	40746
Hardness	304	13012	3221.3	4984
Alkalinity	148	319.9	241.98	75.02
COD	126.5	1007.3	706.6	502.49
Ca	28.9	496	175.1	192.2
Mg	56.4	651.8	200.58	255.4
Na	1116.7	25030	6645.4	9177
K	28.1	52.8	36.96	13.74
Cl^-	1272.1	46023	11490	17258
HCO_3	180.6	347.9	629.87	72.03
SO_4	560.9	2378.5	1248.6	672.7
NO_3	0.15	3.5	2.21	1.80
Fe	0.13	8	2.93	3.23
F^-	0.09	0.7	0.29	0.35

*All the units are mg/L except Alkalinity (milimol/L), EC (µS/cm) and pH.

Table 2 Classification of groundwater samples based on TDS (after Rabinove et al, 1958)

Classification of groundwater	Total dissolved salts (ppm)	No. of samples
Non-saline	<1000	Nil
Slightly saline	1000 - 3000	Nil
Moderately saline	3000 - 10000	2
Very saline	>10000	4

Sources of soluble salts in groundwater of study area may be attributed to dissolution of minerals from bedrock (Peters, 1984; Freeze and Cherry, 1979) High TDS in the groundwater of study area depicts sea water influence as mixing of seawater with groundwater disturbs the hydro geochemistry of groundwater by increasing TDS (Asa Rani and Suresh Babu,2008). Low recharge of aquifers due to scarce rainfall and the retreating rivers also causes seawater intrusion. Since groundwater is not over abstracted by the dwellers of study area the latter phenomenon is more plausible for the seawater intrusion in the coastal parts of Karachi.

Hardness

Ground water hardness is extremely variable in Korangi and DHA area where it fluctuates between 304 to 13012 mg/L with a mean value of 3221.3 mg/L. According to Hem (1970) classification, groundwater of study area is categorized as very hard (Table 3).Ca and Mg are the main constituents responsible for the increase in hardness of water which can be released in water by dissolution of carbonate minerals e.g. dolomite or calcite (Basavarajappa and Manjunatha, 2015). On the other hand since these deep aquifers occur in the Karachi coast the excessive amount of Ca and Mg seems to be incorporated by seawater which is main source of both these ions. Well log data collected from study area revealed that aquifers are overlain by the limestone units (Fig. 2). Dissolution of such limestone may be the other source of Ca and Mg in the groundwater which ultimately results in increased hardness of the groundwater in the aquifers of study area.

Table 3 Classification of Water based on Hardness as $CaCO_3$, (after Hem, l970)

Hardness as CaCO,	Remarks	No. of Samples
0- 60	Soft	Nil
61 - 120	Moderately hard	Nil
121- 180	Hard	Nil
> 180	Very hard	6

Alkalinity

The groundwater samples are slightly alkaline with mean value of 241.98m.mol/L. Hydroxides, carbonates and bicarbonates are the main sources of alkalinity in natural waters. These ions are natural buffers that can remove excess hydrogen (H^+) ions (Murdoch, 1999; 1998). The comparatively high alkalinity in the study area probably reflects the hydro-geochemically mature nature of groundwater (Demetriades, 2010). Considerable amounts of bicarbonates can be released in soil by reactions of calcium or magnesium carbonate with carbon dioxide (Park et al, 2003). Organic acids, such as humic acid can also increase the alkalinity of water. The interaction of groundwater with seawater may be the reason of high alkalinity due to increase in CO_3 ion mixing from seawater. Although alkalinity itself has no impact on health but highly alkaline waters have bad taste and may cause gastrointestinal discomforts (Williams, 2003).

Chemical Parameters

The relative abundance of cations varies in the order of Na^+> Mg^{++}>Ca^{++}> K^+, while anions follow the sequence of Cl^->SO_4^-> HCO_3^-> NO_3^-.Ca and Mg concentrations varied from 28.9 to 496 (mean: 175.1 mg/L) and 56.4 to 651.8(mean: 200.58 mg/L) respectively. Very high standard deviation in the concentration of Ca and Mg suggests that multiple sources are acting in the geochemical environment of aquifers of study areas.Ca concentration in DHA phase VIII is almost 3 to 16 times higher than its content in Korangi wells(Table 5). In Korangi, two wells (5 and 6) shows lightly higher Ca content above WHO permissible limit (100 mg/L)for drinking purposes while Mg exceeds the permissible limit of WHO (50 mg/L) set for drinking water in all the groundwater samples where it rises up to13 times higher than corresponding guideline in DHA area. Beside, calcite/aragonite dissolution, a in groundwater may also source from sandstone bearing minerals (Basavarajappa and Manjunatha, 2015; Bower, 1978).

Sodium the dominate cation, ranges between 1116.7 mg/L to 25030 mg/L with the mean of 6645.4 mg/L which is almost 33 times higher than WHO limit (200 mg/L) set for drinking water. British Columbia Water Association (2007) published a fact sheet which identified few possible sources of sodium in groundwater including erosion of salt deposits or sodium bearing rock minerals, and salt water intrusion in coastal areas. These all factors seems to act in study areas as surface soil is water logged and saline and seawater is culminating in study areas.

Major ions (Cl, SO_4, HCO_3, NO_3) various between 1272-46.23, 561-2378.5, 180.6-348, 0.15-3.5 and 0.05-0.1 mg/L respectively. Chloride is the dominant ion (mean: 11490mg/L), which is 4 times higher than the permissible limit of WHO (250 mg/L) set for drinking water. The distinct abundance of chloride in the groundwater of study sites shows its fresh-saline water interaction. It is one of the main contributors to the groundwater salinity (Zghibi et al, 2013) and may be increased by ionic exchange (Drever, 1997) through sea water intrusion (Zghibi et al, 2013). On the other hand, sulphate shows very high values (mean: 1248 mg/L) where it volute bypass the WHO limit (250 mg/L) in all wells of Korangi and DHA. In coastal areas, the main natural sources of SO_4 are cyclic mineral salts, weathering of sulphide minerals and dissolution of sulphate evaporates (Samborska et al, 2013; younger, 2007; Alpers et al, 2000). Weathering reactions can naturally supply large fluxes of sulphate to groundwater (Drever, 1982), both from sulphide mineral oxidation (Moncaster et al., 2000) and evaporites (Gunn et al., 2006). Water table drawdown caused by changes in water abstraction can accelerate sulphide oxidation reactions. Subsurface conditions become more oxidizing during intense abstraction of water as shallow water is drawn into deeper flow paths and ore sulphide dispersed within the extended vadose zone is exposed to air (Samborska et al, 2013;Andersen et al., 2001).

Elevated concentration of bicarbonate (mean: 629.87mg/L) is reported from both study sites which is more than double the permissible limit of WHO (300mg/L) for drinking water. Bicarbonate dissolved in the groundwater is mainly derived from organic matter decomposition and mineral sources (Bikundia and Mohan, 2014). The dissolution of same carbonate minerals which release Ca and Mg to solution also yield abundant dissolved HCO_3 (Younger, 2007). Subsurface geology of study area demonstrated occurrence of silica sand followed by limestone (Fig.2).Its suppose to the leading of lime stone near to the aquifer to release bicarbonate and indicate the organic matter decomposition due to lack of clay layers.

Ionic interrelationships

In order to identify the sources of certain ion in the groundwater, the ratio between major ions have been calculated. Summary of these ratios is given in Table 4. Concentration ratio of an ion with reference to other take values that are related to the aquifer (host rock), the rocks through which the water passes, the degree of replenishment of ground water, or its mixing with sea water, (Demetriades, 2010; Mandel and Shiftan, 1981).

Table 4. ratios between major ions of collected groundwater samples from coastal areas of Karachi city (DHA and Korangi)

Ratio	Values
Mg/Ca	1.38
Na / Cl	0.7
Cl/ $HC0_3$	18.3
Cl / SO_4	6.48

Mg /Ca

Generally fresh water is dominated by Ca and sea water by Mg (Mondal et al, 2010). The ratio of Mg/Ca in all groundwater samples (except one) exceeded 1 (Table 4) which depicts the occurrence of seawater intrusion in study area. Sample1 which was collected from DHA is found to be depleted in Mg and rich in Ca, indicating freshwater.

Na/Cl

The dominance of Na and Cl ions in most of the water samples of study area indicate the significant effect of seawater via direct mixing, marine spraying, and fall-out of airborne marine salts (Park et al, 2005). Na/Cl ratio is found to be < 1, suggesting probable pollution of the aquifer by seawater intrusion (Demetriades, 2010). Generally the ratio between these ions remains 1 if the source is same. Since Cl shows conservative behavior so its occurrence in the system is representative however Na may be scavenged by any process like adsorption or co-percipitation which may reduce the Na/Cl ratio as indicated by the groundwater of study sites.

Cl/HCO_3

The ratio of HCO_3/Cl is found to be less than 0.5 in all wells of study area. Extremely low HCO_3/Cl ratio and high Mg/Ca ratio clearly indicated the transformation of fresh groundwater to saline water (Mondal et al, 2010) in these coastal aquifers of study areas.

Cl/SO_4

Fresh water generally contains relatively high sulphate content as compared to seawater. Similarly, very high chloride concentration exists in the marine environment which is relatively more alkaline water (pH > 8). Cl/SO_4 ratio is associated with salinization and occurrence of residual salts in the aquifers. The ratio of Cl/SO_4 is found to be extremely high (9.4) in case of both Korangi and DHA wells. It is clearly indicating the role of seawater intrusion as explained by other workers somewhere else (e.g. Zghibi et al, 2013; Demetriades, 2010; Park et al, 2005).

Hydrogeochemical Evaluation

Piper diagram is used to classify the groundwater with reference to hydro-geochemical process (Baride et al, 2014; Piper, 1953) and dominant ions which reveal common composition and origin of ions in groundwater (Gautam et al, 2015; Singh et al, 2012). Chemical data of collected samples were plotted on Piper diagram in order to infer type of hydrofacies, saline water, mixing of water from different sources, sulfate reduction and other problems related to the hydro facies as explained by others (e.g Bashir et al, 2015; Herojeet et al, 2013; Prasad et al, 2009). Data plotted on the diagram shows that most of the samples fall in the field of Na + K and Cl water types, followed by Na+K- Ca, Ca+Mg and very mild CO_3+HCO_3(Fig.3). The figure also expressed that alkali cations (Na^+ and K^+) dominate over alkaline cations (Mg^+ and Ca^+) and anions of strong acids ($SO_4{}^-$ and Cl^-) dominate over weak acids (HCO_3^- and CO_3^-) which clearly indicates sea water mixing with these aquifers. Na-Cl hydrofacies dominate in the groundwater of study area which is indicator of seawater intrusion (Bashir et al, 2015; Karfali and Jurdi, 2010; Rani and Babu, 2008).

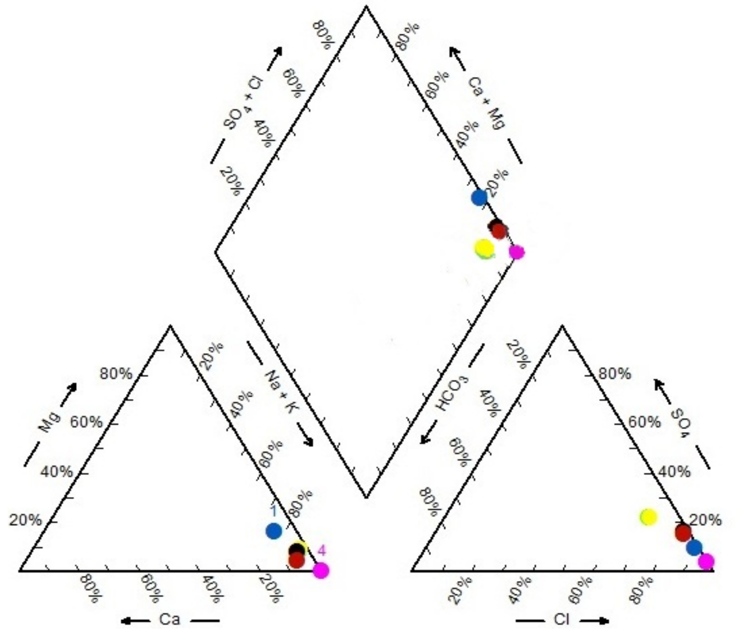

Figure 1 Piper diagram of groundwater samples from DHA Phase VIII and Korangi.

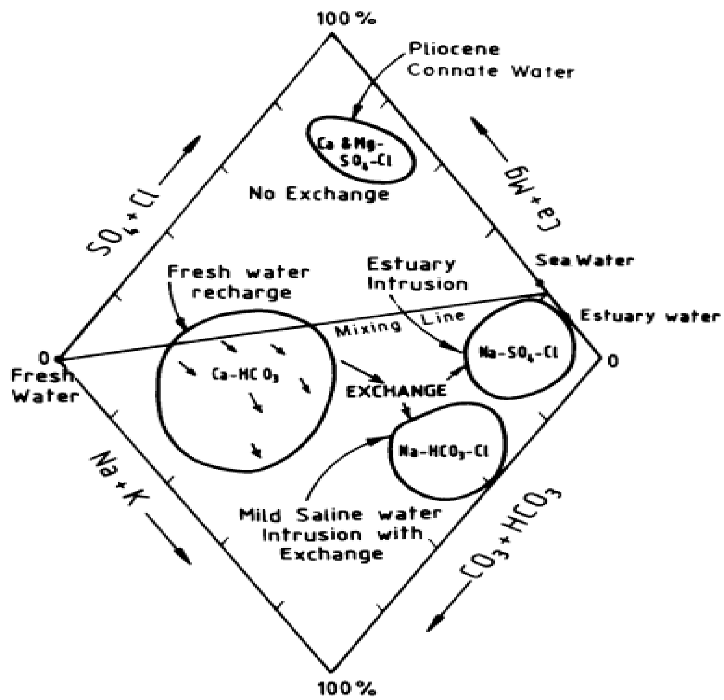

Figure 2 Piper's plot showing the processes controlling chemistry of groundwaters (Sukhija et al., 1996)

The Piper's plot depict not only the quality of groundwater but also possible pathways of freshwater and saline water movement and abstracted geochemical processes (Sukhija et al., Fig. 1996) . Figure 4 shows that all the groundwater samples fall into the field of estuary and seawater. It is consistent with the fact that Korangi and DHA lies on the Malir River mouth (estuary) where it exchanges water with Arabian Sea.

Conclusion

It is concluded from present study that groundwater occurring in deep aquifers in both Korangi and DHA sites is not suitable for drinking purpose. On the basis of various quality parameters assessed (SAR, RSC, NA and Chlorinity index) the water is classified as bad in salinity classification. Both Korangi and DHA aquifers are found to be contaminated by seawater intrusion. Piper diagram shows that groundwater is mainly Na-Cl type in these sites. Detailed study is required to assess the other parts of Karachi coast for delineating the seawater intrusion impacts as the present study is focused on only two pockets of Karachi coast.

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