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Research Article

GEOCHEMICAL SIGNATURES FOR THE IDENTIFICATION OF SEAWATER INTRUSION IN AN ALLUVIAL AQUIFER IN PALGHAR DISTRICT, MAHARASHTRA

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ABSTRACT

Seawater intrusion generally occurs when withdrawal of fresh groundwater from coastal aquifers results in declining groundwater levels, facilitating lateral and/or vertical migration of saline water causing deterioration of groundwater quality. Hydro-chemical studies are widely used to determine the interaction between groundwater and saline water/seawater in coastal aquifers. Sea water ingression study was undertaken in the Kelwa-Mahim coastal area in Palghar district. Water quality parameters of water samples from 47 well were also measured using handheld multi-parameter instrument. The depth to saline-fresh water interface varied from <1 to 5 m at different locations. The high salinity clay horizons are identified at various depths. Hydro chemical data was analyzed using hill-piper diagrams and statistical plots to understand groundwater-seawater mixing/interaction in the coastal aquifers. In this area NaCl was dominant solvent and MgCl occurred at few locations. Higher EC and TDS were noted in the western part of the area close to the sea. Vertical distribution of ground water salinity indicates that fresh water sea water interface is about 15-20 m.bgl.

INTRODUCTION

Seawater intrusion is the ingress of confined or unconfined coastal aquifers, which in turn affects the quality of groundwater for agriculture and human consumption. As the coastal aquifers are generally connected hydraulically to the sea, the seawater which is slightly denser initially intrudes at the bottom of the fresh water aquifer. Over-exploitation of groundwater from such coastal aquifers to meet the increasing demand accelerates the progress of intrusion of seawater. Thus the wells no longer contain potable water and hence these wells are abandoned causing shortage of groundwater. Seawater is characterized by the dominance of Na and Cl with the total dissolved solids of about 35,000 mg/l. In contrast, continental fresh groundwater is characterized by a highly variable chemical composition, although the predominant anions are HCO_3, SO_4 and Cl (Fritz *et al.,*1979; Korfali and Jurdi, 2010). The total dissolved solids in potable groundwater generally vary from 150 to 1500 mg/l. Thus, the mixing trends between seawater and groundwater can be understood from total dissolved solids (>2000 mg/l), Cl (>1000 mg/l) and some minor ions. Mixing can also be identified when electrical conductivity (EC) of groundwater exceeds 3000 μS/cm (Karahanoglu, 1997). In seawater intruded regions, the concentration of Mg will be greater than SO_4+HCO_3, and Cl greater than Na, whereas regions with meteoric waters salinized by the marine salts will have Na greater than Cl (Howard and Lloyd, 1983).

Quality of groundwater is dependent on the physical and chemical parameters. The characteristics of groundwater (hard or soft; mineralized or non-mineralized) depend on the chemical interactions with the country rock (Edmunds, 1994). Hence, it is important to know the mineral characteristics of the country rock. Various international bodies such as the World Health Organization (WHO), European Economic Community (EEC) and Bureau of Indian Standard (BIS) have given certain standards for potable water. For a hydro geologist, an understanding of the geochemical characteristics of groundwater systems is very important in determining the physical properties of flow system. Hydro-chemical data can help to estimate such properties like the amount of recharge, the extent of mixing, the circulation pathways, maximum circulation depth, and temperature at depth and residence time of groundwater (Edmunds, 1994). The concentration of salts in groundwater depends on the geological environment and movement of groundwater (Raghunath,1987). Groundwater has higher concentrations of dissolved constituents than surface

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water because of its greater exposure to soluble minerals of the geological formations (Todd, 1980).

Earlier geophysical studies in this area have also shown that eastern part of Kelwa-Mahim area lies in the low groundwater potential zone and saline water. The west part of this area shows high groundwater potential indicating a fresh water aquifer for exploitation (Goud and Mathur, 2018).

Study Area

The study area lies between the north latitudes $19^0$35' & $19^0$41' an east longitude $72^0$42'00" & $72^0$47'30" (Fig.1). The area falls in quadrant C-2 of Survey of India Topo Sheet No.47A/14 and 47A/10.

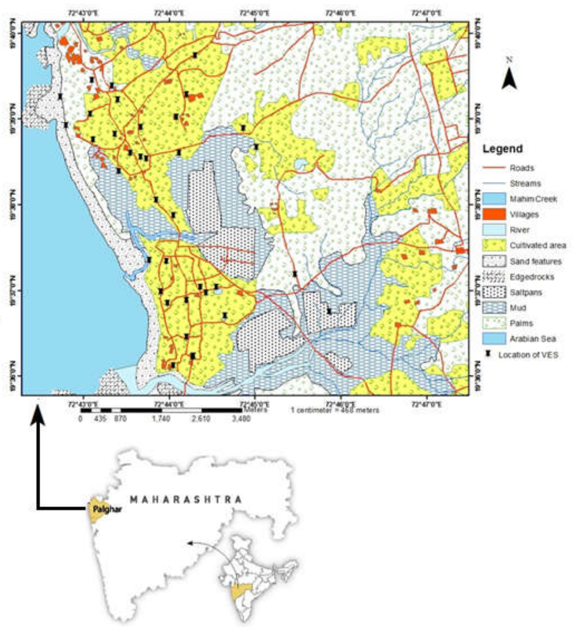


Fig 1 Location map of Study area

Kelwa and Mahim villages located in the western most coastal part of Palghar taluka covering an area of approximately 74.00 Sq. Kms. The area receives an average annual rainfall of 2500 mm. A major part of the area is occupied by coastal alluvium and basalt rock formations that act as a productive aquifer. There are more than 500 irrigation wells in these villages, the crops like Coconut, Chikku, Banana, Betel nut (Supri) and Betel leaves (Nagveli Pan) are the main cash crops here. These villages are located close to Mumbai Mega city and thus have good market for the agriculture produce. The utilization of groundwater for agriculture purpose is done on a large scale since few decades. Due to the heavy exploitation of groundwater in the area seawater has started encroaching towards freshwater aquifers, thus deteriorating the groundwater quality. At present the intrusion of saline water has reached up to the distance of 3.5 to 4.5 kms inland causing a sever threat to the groundwater regime and environment of the area.

Groundawater in A Coastal Environment

The chemical composition of groundwater is controlled by many factors that include the composition of precipitation, mineralogy of the watershed and aquifer, topography and climate (Chenini and Khemiri, 2009). The interaction of all factors leads to various water fancies. Usually, major ions studies are used to define hydrochemical fancies of waters where the spatial variability can provide insight into aquifer heterogeneity and connectivity (Murray, 1996; Rosen and Jones, 1998). Groundwater quality depends, to a large extent, on its chemical composition (Wadie and Abduljalil, 2010) which may be modified by natural and anthropogenic sources. Assessment of both the existing and potential sources of contamination and the spatial extent of the existing groundwater contamination is needed before considering methods to monitor and prevent future groundwater quality problems.

METHODOLOGY

Water samples were collected for 47 locations during pre-monsoon and post monsoon period from dug wells and bore wells which were earmarked as observation wells. Groundwater samples were divided based on the well type as shallow (from dug well <15 m) and deep (from bore well>15 m).

The samples were analyzed for bicarbonate, hardness, chloride, sulfate, sodium, potassium, calcium, and magnesium using standard methods for the examination of water. The pH and electrical conductivity (EC) were measured in the field, and anionic parameters of the water samples were measured immediately after sampling. Total dissolved solids (TDS) were calculated using EC values, considering the relative ion concentrations. The bicarbonate, alkalinity, hardness ($CaCO_3$concentration) and chloride were determined by standard titration methods A Systronics flame atomic absorption spectrometry was used for the determination of cations. Sulfate was measured using the Systronics spectrophotometer. All instruments were calibrated appropriately according to the commercial grade calibration standards prior to the measurements.

RESULT AND DISCUSSION

In order to identify the extent of seawater intrusion indicators such as EC, TDS, Na, Ca and Mg were used. The results and inferences arrived are discussed in the following section.The geochemistry of groundwater is influenced by factors such as the rock type, residing time in the rock, previous composition of the groundwater and other characteristics of the flow path. Groundwater usually maintains a constant composition with time and may vary slightly from well to well due to slower movement and longer residing time as compared to surface.

Charactarization of Groundwater (hydro chemical facies)

Piper trilinear plot of the groundwater samples collected during May 2015 depicts three groups, as shown in Fig.2. Freshwater samples are mostly Mg-HCO_3 type whereas two saline clusters are Na-Mg-Cl and Na-Cl (Na-SO_4-Cl) types. High magnesium in fresh groundwater indicates contribution of weathered products derived from basaltic rocks. In the case of saline waters, high $Na^+$and Cl^- are observed indicating contribution of marine sources. Groundwater samples collected during Feb. 2015 show that freshwater samples have similar hydro chemical facies as observed in pre monsoon during the period June 2016. A gradual migration of hydrochemical faciesfrom Mg-HCO_3 type to Na-Mg-Cl-HCO_3 type and finally to Na-Mg-Cl (Na-Cl) type are as depicted in Fig.3. It is to be noted that groundwater exploitation is high during this season in the year.

This indicates migration of saline front into fresh aquifers due to withdrawal of fresh groundwater.

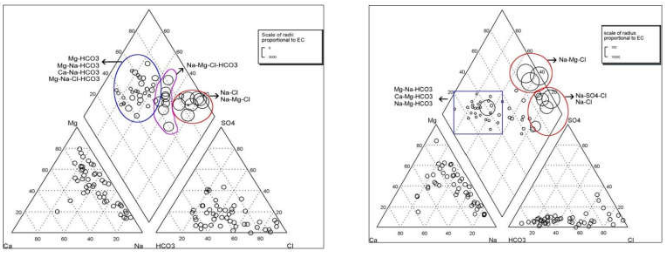
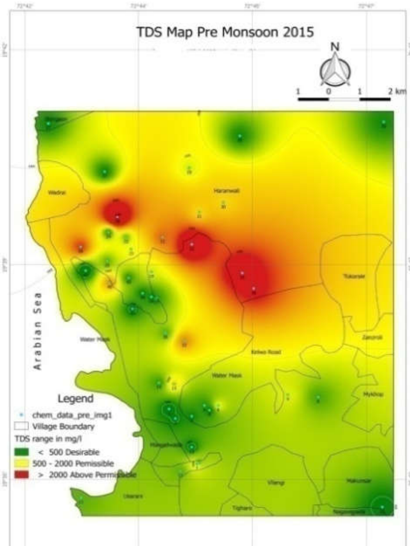


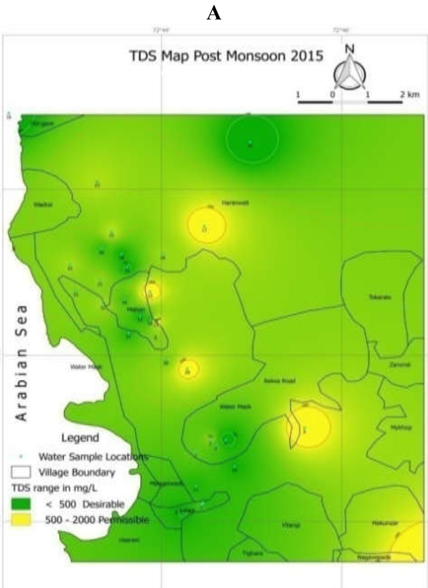
Fig 2 &3 Piper trilinear plots of major ion data – May 2015 & Feb 2016

Total Dissloved Solids (TDS)

The distributions of TDS values for both seasons are shown in fig.4.(a and b). The TDS values for the crystallines fall well below 300mg/l. But in the case of the coastal belt, the values are pretty high in many wells and ranges from 79mg/l to 3392 mg/l. According to (Venugopal.1998) and Aravindan (1999) the TDS values are higher during pre-monsoon than the post-monsoon season.



A



B

Fig 4 contour maps of TDS (a) pre-monsoon and (b) post-monsoon

In the present study also this feature is very evident from the isocone map of TDS. The contours show considerable thickening in the pre-monsoon when compared to the post-monsoon. This can be attributed to the dilution resulting from the rainfall. As discussed earlier, total dissolved solids (TDS) are a measure of the dissolved minerals in water and also a measure of drinking water quality. There is a secondary drinking water standard of 500 milligrams per litre (mg/l) TDS; water exceeding this level tastes salty. Groundwater with TDS levels greater than 1500 mg/I is considered too saline to be a good source of drinking water. (Kelly and Wilson, 2003).

Table 1 The potability of water in terms of TDS (mg/I) as per WHO (1984)

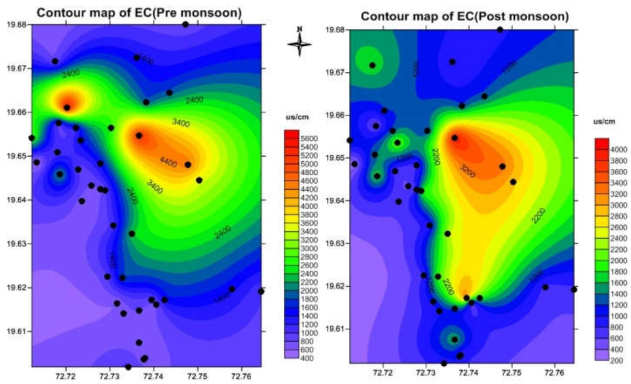
Water class	TDS mg/l
Excellent	< 300
Good	300-600
Fair	600-900
Poor	900-1200
Unacceptable	>200

Concentrations in 5 wells exceeded 500 mg/l. A high TDS value of3392mg/l is observed by a well at located in Temkipada and Ingelapada in the coastal belt.

Electrical Conductivity (EC)

In coastal areas, groundwater with EC greater than5000 µS/cm is considered as affected by seawater intrusion (Kim et al. 2003a). In this study area the EC of groundwater varied from 400 to 25,000 µS/cm and the increase was towards the coast region. Very high EC were measured in groundwater of wells closer to the sea in the Eastern part and few wells from the northern part of the study area. This indicates that the Eastern part of the areais severely affected by seawater intrusion as wellas saline water recharge from salt pans and saline backwaters.

Electrical conductivity is very useful for determining water quality since it is an indicator of salinity in water, which affects the taste and has an impact on the user acceptance of water as potable. The major chemical constituents, which contribute to the electrical conductance, are components of hardness (Ca and Mg). Other components that contribute to the electrical conductance are Nitrate, Chloride and Sulphates. In the present study the EC values during pre-monsoon season for the samples taken from the coastal belt where as the crystalline terrain shows values between 400 to 6000µS/cm(fig.5a). In the post-monsoon the values for the coastal region ranges from 200 to 4000µS/cm(fig.5b).



A **b**

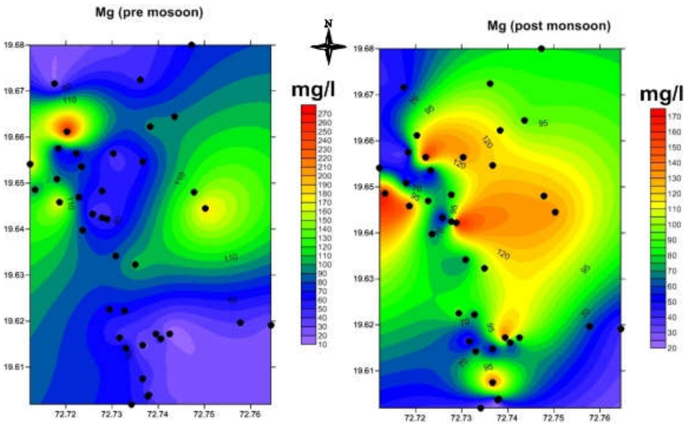
Fig 5 Contour map of EC (a) pre-monsoon (b) post-monsoon

The comparative study clearly reveals that in both pre-monsoon and post-monsoon periods wells in the crystalline terrain shows low EC values and hence these are suitable for drinking and agricultural purposes. In the coastal belt higher values are noticed and the quality of water ranges from excellent to saline.

Composition of Magnesium

Magnesium (Mg) is commonly associated with calcium and causes hardness of water. The Geochemical behaviour of Mg is different from that of Ca. In igneous and metamorphic rocks, magnesium occurs in the form of insoluble silicates; weathering breaks them down into more soluble carbonates, clay minerals and silica Magnesium is relatively non-toxic to humans. Magnesium salts act as cathartics and diuretics (Manivasakam, 1996) among animals as well as human beings. Calcium and magnesium ions in irrigation water tend to keep soil permeable and in good tilth.

The zonation map of Mg is given in fig.6. In the present study it is found that in all the wells except the one at Temkipada, the Mg value is well below the permissible limit of 30mg/l set by ISI. The crystalline terrain of the study area shows very low values of Mg when compared to the coastal belt ranging from O.1mg/l to 4mg/l during pre-monsoon and 0.5mg/l to 9.0 mg/l during post-monsoon. The wells in the coastal belt show values ranging from 10 mg/l to 270 mg/l for pre-monsoon and from 20 mg/l to 170 mg/l for post-monsoon.

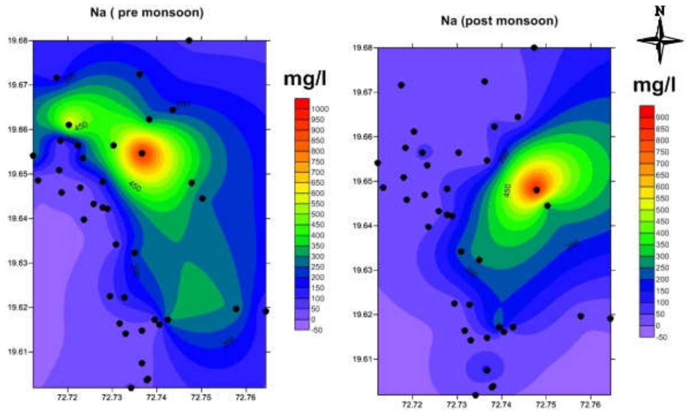


a b

Fig 6 Contour Map of Mg (a) pre-monsoon (b) post-monsoon

Consentration of Sodium (NA)

Sodium (Na) unlike calcium, magnesium and silica is not found as an essential constituent of many of the common rock-forming minerals. The primary source of most sodium in natural water is from the release of soluble products during the weathering of plagioclase feldspars. The most important source of sodium in groundwater, with concentration of over 50 ppm of sodium is the precipitation of sodium salts impregnating the soil in shallow water tracks, particularly in arid and semi arid regions. The zonation map of Na in the study area is given in (fig.7a & b). The Na values for the crystalline terrain in the study area fall between 3.0 mg/l and27 mg/l during pre-monsoon and between 4.2 mg/l and 14.8 mg/l for post monsoon, which is well below the WHO standard of 200mg/l. But the coastal belt shows wide variation in Na values and abnormally high values were observed in some wells in this belt. Certain clay minerals and zeolites can increase the sodium content in groundwater by base Exchange reactions.

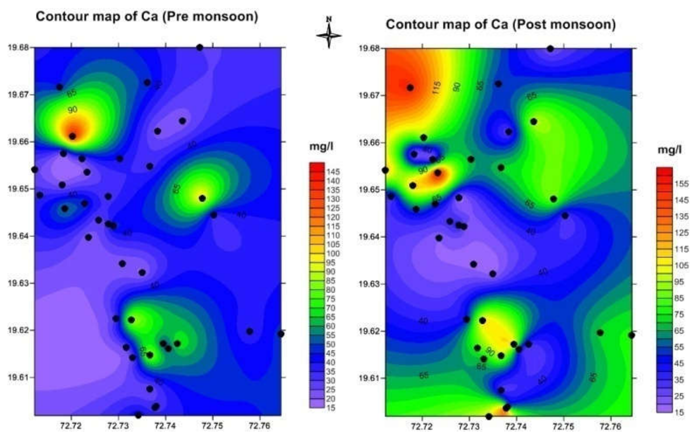


a b

Fig 7 Contour map of Sodium (Na) (a) pre-monsoon and (b) post-monsoon

Consentratioin of calcium (Ca)

Calcium (Ca)ions dissolve easily in rock and soil formations. The principal sources of calcium in groundwater are some members of silicate mineral groups like plagioclase, pyroxene and amphibole among igneous and metamorphic rocks and limestone, dolomite and gypsum among sedimentary rocks. Calcium is present in water as Ca^{++}, which forms complex with some organic anions. Concentration of calcium in normal potable groundwater ranges between 10 and 100 ppm. Calciumin this concentration has no effect on the health of humans. Indeed as much as 1000 ppm of calcium may be harmless. The zonation map of Ca is given shown in figure 8. In the present study the value for Ca is found to vary between 15 to 145 mg/l in the coastal area during pre monsoon and the postmonsoon vary between 15 to 175.2 mg/l for the coastal belt. The WHO standard prescribed for Ca in groundwater is 75-200mg/l. All the wells except the well at Temkipadain the coastal belt falls within the limit prescribed. Very low values are noticed towards the eastern part of the study area where the wells are in the crystalline terrain.



a b

Fig 8 Contour map of Calcium (a) pre-monsoon and (b) post-monsoon

CONCLUSION

Most of the groundwater samples are fresh in quality. About 10% of the total samples are found to be saline (EC;5000 to 25000 µS/cm). Hyper saline samples are also found at locations close to salt pans with EC up to 6,000µS/cm, Hydro chemical facies are mainly dominated by Na-type and Mg-type. A gradual migration of facies from Mg-HCO_3 type to Na-Mg-Cl-HCO_3 type to Na-Cl type is noticed, which indicates migration of saline water into fresh aquifer. The ratio of Cl/HCO_3 is greater than unity in most of the samples which is indicative of sea water ingression. Iso-TDS maps show higher concentration of TDS in eastern part of the area. Vertical distribution of groundwater salinity indicates that freshwater-seawater interface is about 15-20m.bgl

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