Evaluation of groundwater potential and saline water intrusion using secondary geophysical parameters: A case study from western Maharashtra, India

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ABSTRACT

Aquifers along the coastal regions around the world are facing severe level of saline water intrusion problems. Rapid development and the associated increase in groundwater withdrawals intensify the problem. Extensive mapping of migration and extent of salt water plumes is difficult and costly. Several surficial geophysical methods have been developed for measuring salinity levels in coastal aquifers. The present study is an attempt to delineate the saline water and fresh water intrusion in parts of west coast of Maharashtra, India. A total of 86 vertical electrical soundings were carried out using the Schlumberger configuration. The contour maps for Dar-Zarrouk parameters viz. the transverse resistance (T), longitudinal conductance (S), and coefficient of anisotropy (λ) were computed at 84 sites to generate the resistivity regime of saline and fresh water bearing formations. The results exemplify that the Dar-Zarrouk parameters provide a practical elucidation in demarcating the saline and fresh water aquifers, particularly when the resistivity data interpretation encounters constraints due to intermixing of saline water aquifers, fresh water aquifers etc. Several NE-SW and NW-SE oriented major lineaments and its cris-crosses have been observed in this region.

INTRODUCTION

Saltwater intrusion can pose severe problems to coastal areas with freshwater aquifer having marine-aquifer hydraulic interaction. Saltwater intrusion happens when low density of fresh groundwater interacts with the high density of saltwater in natural conditions. Other sources of contamination include anthropogenic activity like domestic/industrial waste water and agricultural activities. In these studies, hydro-geochemistry analysis from monitoring wells and geophysical methods were used. The most widely used geophysical method to assign, particularly in salinity mapping, is geo-electrical method (Loke, 2000). Various researchers around the world have applied geo-electrical method in demarcating coastal-area hydrogeology condition (Maiti et al., 2013; Gupta et al., 2014).

The present study area is located in Sindhudurg district, western Maharashtra, India, where sand and gravel aquifers are dominant, which are favourable for constructing high-yielding wells, are scare (Fig. 1). In the overburden, the aquifers are mainly composed of clayey sand. Shear zones are expected at several places in the study area (Deshpande, 1998), where the exposed basement is fractured. The fractured zones are likely to be potential proxy indicators for groundwater prospecting. Therefore, the delineation of geologically weaker zones such as fractures is of significant societal importance.

Direct Current (DC) resistivity sounding method is one of the most popular methods that have been extensively applied for solving hydrological, geothermal, environmental and engineering problems (Zohdy et al., 1989). In the DC resistivity method, current is introduced directly into the ground through a pair of current electrodes and resulting voltage difference is measured between a pair of potential electrodes. The method provides the apparent resistivity distribution against depth which is generally found to be approximately one-third of the distance between the electrode separations. The study area is covered by the Deccan volcanic rocks, most of the soils are derived from lateritic rocks and the groundwater, is circulated through a network of voids, conduits, joints and fractures. Hence monitoring the shallow distribution of true resistivity pattern in the area is vital for mapping the faults, fractures, joints, conduits and lineaments for groundwater exploration.

In the present work, VES data from 84 stations have been analysed using secondary geophysical indicators like longitudinal conductance, transverse resistance and coefficient of electrical anisotropy, in order to understand the inhomogeneous infiltrations of fluids through pores and geologically weak zones, such as faults and fractured zones, fluid percolation pattern near the sub-surface area and the sea water intrusions effects.

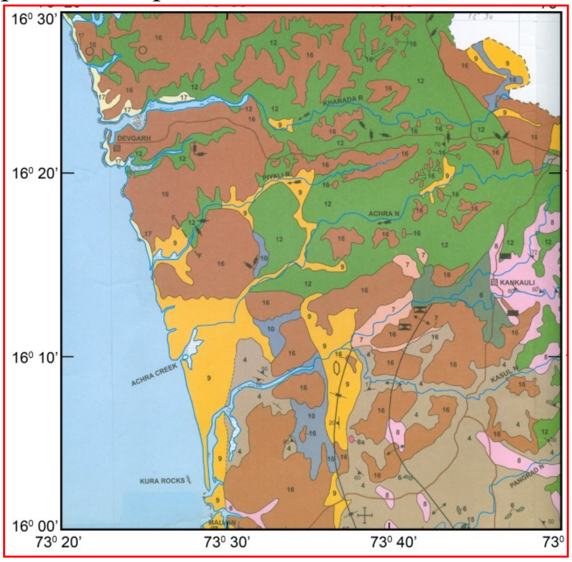

Figure 1. Geology of the area.

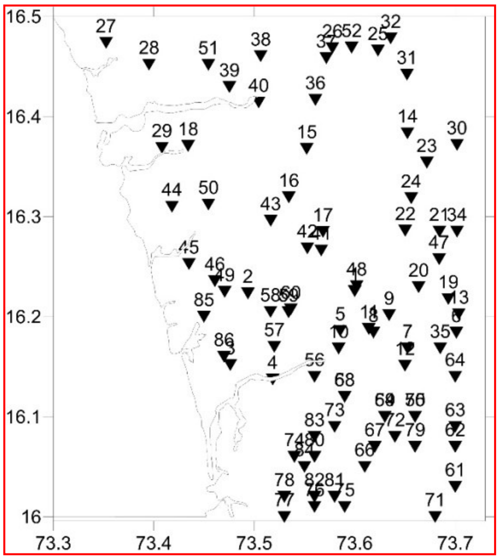

Figure 2. VES location map.

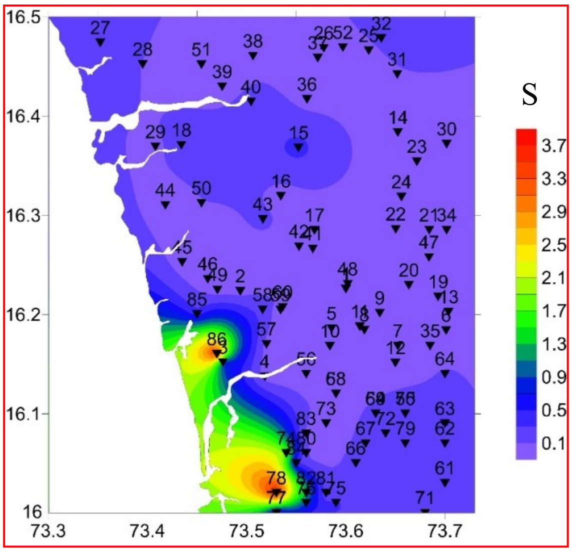

Figure 3. Longitudinal conductance map.

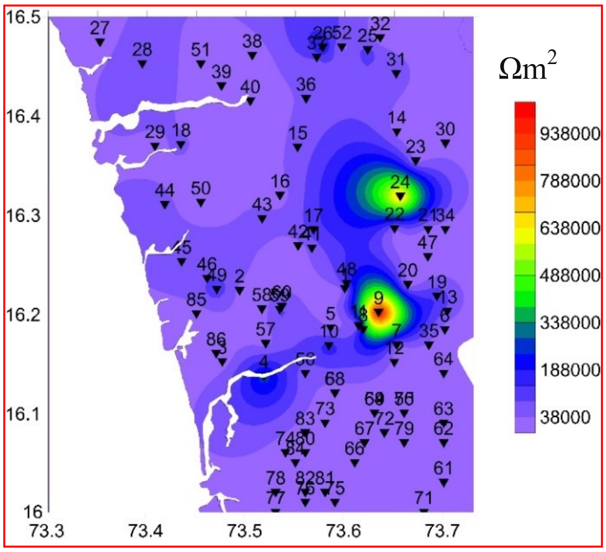

Figure 4. Transverse resistance map.

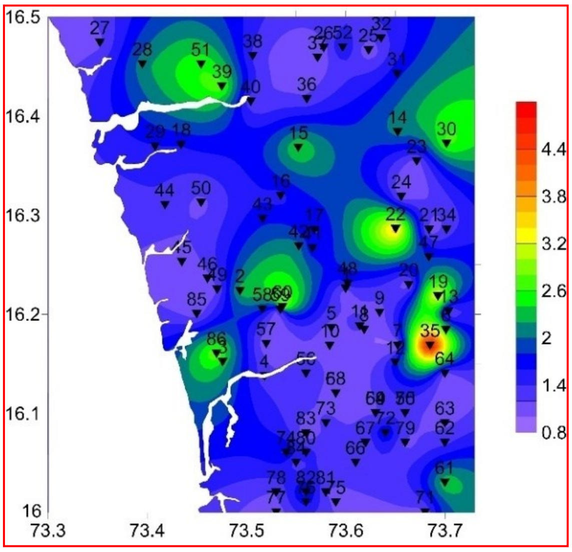

Figure 5. Electrical anisotropy map.

MATERIALS AND METHOD

The present study encompasses parts of Malvan-Vijaydurg-Kankavli, Konkan region (Fig. 2). Data were acquired with Schlumberger electrode configuration at 86 sites using IGIS made SSR-MP-AT instrument, with maximum current electrode spread (AB) of 200 m. The field data was processed and modelled using IPI2win inversion software (Bobachev 2003).

The sounding curves on log-log graph suggest 3-5 layered structure in the study area (Orellana and Mooney 1966). The resistivity and thickness values thus generated provided the primary parameters which were used to establish the secondary geoelectric indicators like transverse resistance (*T*), longitudinal conductance (*S*) and coefficient of anisotropy (λ), which helps in interpreting the subsurface lithological and structural characteristics with reduced uncertainty (Maillet 1947).

Total longitudinal conductance (*S*) is defined as,

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \tag{1}$$

Similarly, the total transverse unit resistance (*T*) is defined as,

$$T = \sum_{i=1}^{n} h_i \, \rho_i \tag{2}$$

Where (ρi) and (hi) are the resistivity and thickness respectively and the subscript *i* indicates the position of the layer in the section.
Using eq. (1), the longitudinal resistivity of the current flowing parallel to the layers is given by,

$$\rho_l = \frac{H}{S} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{\rho_i}} \tag{3}$$

Where *H* is the depth to the bottom most geoelectric layer.
Similarly, the transverse resistivity of the current flowing perpendicular to the layers is expressed using eq. (2) as,

$$\rho_t = \frac{T}{H} = \frac{\sum_{i=1}^{n} h_i \, \rho_i}{\sum_{i=1}^{n} h_i} \tag{4}$$

The longitudinal resistivity (ρ_l) is generally less than the transverse resistivity (ρ_t), unless the medium is uniform (Flathe 1955). Further, Keller (1982) suggested that ρ_l is dominated by the more conductive layers (in the present case, clay and weathered/fractured basalts) whereas ρt increases rapidly even if a small fraction of resistive layers are present.

Combining eq. (3) and (4), the coefficient of anisotropy (λ) is given by,

$$\lambda = \sqrt{\rho_t / \rho_l} \quad (5)$$

Here the secondary geophysical indices, namely T, S, ρ_l, ρ_t, and λ were evaluated at all the 84 VES sites so as to study the anisotropic nature and fracture geometry in the trap covered hard rock terrain for groundwater exploration. Kumar et al., (2014) suggested that high values of λ indicate different degrees of fracturing, with better water-holding ability in hard rock areas.

RESULTS AND DISCUSSION

The longitudinal conductance (S) value ranges between 0.0001 to 3.78 Ω^{-1} in the study area (Fig. 3), which help to differentiate changes in the total thickness of low resistivity materials (Galin 1979). This parameter reveals the disparity of the highly resistive basement topography, implying that high S values are indicative of deeper basement and vice versa. Also if the geologic sequence and clayey overburden is moderately thick, then high longitudinal conductance is suggestive of better protective capacity of aquifers (Oladapo and Akintorinwa 2007). Low S values of the order of 0.0001 to 0.4 Siemens is evenly spread in the central part of the study region encompassing VES stations 1, 2, 4-14, 16, 17, 19-26, 28-31, 33-57, 59-65, 67-73, 77, 79-81 and 83. In the western and southern part of the study region, high S values(0.5 to 3.78 Siemens) are observed covering the VES stations 3, 15, 18, 27, 32, 58, 66, 74-76, 78, 82, 84-86. The western part (VES stations 3, 78 and 86) is encroached by saline water presumably due to the vicinity of Arabian Sea. Geochemical analysis of groundwater in the study area (Suneetha and Gupta, 2017) reported that the electrical conductivity (EC) ranged between 174 and 9420 μS/cm (mean =686.4 μS/cm). The EC values recorded at VES points 3.78 and 86 falls beyond the acceptable level for drinking prescribed by World Health Organization (WHO, 1984), and were attributed due to the intrusion of saline water from Arabian Sea. The total dissolved salts (TDS) value at VES 3 (2,845 mg/l) also exceeds the acceptable limit prescribed by WHO (1984). Nutrient enrichment due to fertilizers and saline water intrusion could enhance TDS and, in turn, increases the EC in the study area, a fact which can be observed in other parts of the study area, reflecting high S values (VES points 3, 78 and 86). It is evident from Fig. 3 that there is a clear demarcation between saline and fresh water regions. The contour pattern and boundaries are distinct, clear and do not display any overlapping character. Due to limited depth of the investigations, these soundings end in fresh water zones. Hence the anomaly of fresh water is reflected in the S values. From the patterns of contours, it becomes easy to differentiate the region of saline water aquifers from that of the fresh water aquifers.

The transverse resistance (T) value varies from a minimum of 61 Ωm^2 to a maximum of 1055955 Ωm^2 in the entire study area (Fig. 4). Larger T values are associated with zones of high transmissivity and, hence highly permeable to fluid movement. The transverse resistance map gives a clear picture of the regions of saline and fresh aquifers. In the present scenario, saline aquifers categorize their presence by attaining T values in the range of 61-2000 Ωm^2 at VES points at south-eastern and VES 86 at the coastal side. Low T values are also observed at VES points 7, 9-10, 13, 16, 18-19, 24-25, 27-28 towards north, central and east.

Electrical anisotropy in the study area varies from 0.9-4.3 (Fig. 5). The coefficient of anisotropy is not uniform in all directions and is observed to increase from SW to NE and also from SE to NW, thus playing a major role in fracturing. More fracturing towards the NE an SW directions suggest relatively more prospective groundwater zone. Resistivity of subsurface rocks affects both the electrical anisotropy and porosity. The coefficient of anisotropy is generally 1 and rarely exceeds 2 in most of the geological settings (Zohdyet al. 1974). If the λ value varies between ~1 and up to 1.5, it is considered to be a prospective groundwater zone. Therefore low λ values are associated with lowest water table fluctuation and high λ values are related to higher water table fluctuation in the region.

CONCLUSIONS

Groundwater typically occurs in discrete aquifers in geologically intricate region and thus delineating the potential aquifer zones is often a tedious task. In the present study, the Dar Zarrouk (D-Z) parameters are particularly important and play a significant role in the construing of groundwater flow paths. Thus the D-Z parameters of the VES sounding points have been computed and the analysis shows that these parameters are useful and provide a confident solution in delineating the saline water and fresh water aquifers. This is more so when the resistivity data interpretation encounters constraints due to the intermixing of the resistivity of saline water aquifer and freshwater aquifer (Mondal et al. 2013). The behaviour of the D-Z parameters and its pattern in space over parts of Konkan region with respect to the occurrence of saline water and fresh water aquifer bodies in the coastal aquifer system has also been established. Excessive groundwater exploration may seriously affect the groundwater quality through the phenomenon of saline upconing. Therefore, it is important to maintain the balance between the fresh and saline water bodies in the coastal aquifer of Konkan region. Further these results will be useful to gain better insights of the complex geology of different intrusions in the hydrogeological system of the area.

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