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Hydro-geochemical Assessment to Evaluate the Suitability of Groundwater for Domestic and Irrigation Purpose in Parts of Sindhudurg District, Maharashtra

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Abstract

Groundwater is regarded as one of the major sources of drinking water for the society. It is also used for agricultural, industrial, and various other domestic purposes. However, intrusion of saline water, particularly in the coastal areas, creates a major concern for its safe uses. In addition to this, the coastal aquifers are subjected to various harmful contaminants, such as agricultural fertilizer, pesticides and waste. The main objectives of the present study are to assess and classify the groundwater quality for domestic and irrigation purpose of western Maharashtra. A total of 85 vertical electrical sounding points have been acquired from the study area. Also water samples have been taken from 36 locations. The true resistivity contour map shows moderate resistivity in the central part of the study area at a depth of 10 m and 15 m. The north-eastern part of the area shows higher resistivity values at 10 m to 20 m due to the presence of hard rock beneath; whereas south-western part reveals the lowest resistivity values from 1 m to 15 m of depth indicating the presence of saline water. The groundwater quality of the study area is classified into three categories: “Very good”, “Good”, and “Unsuitable”. Water quality index of the study area shows that more than 50% of groundwater is in the range of excellent to good quality, while parameters analysed for the irrigation suitability of water are found to be in good to moderate in most cases except at a few places within the study area.

Keywords: Groundwater quality, resistivity, coastal aquifers, Maharashtra

Introduction

Groundwater is a major source of clean drinking water all over the world. It has been an important resource especially in the arid to semi arid part of the world. Increased demands for water have stimulated development of underground water resources. As a result, techniques for investigating the occurrence and movement of groundwater have improved, better equipment for extracting has been developed, concepts for resource management have been established, and the research has contributed to a better understanding of the subject.

The ingress of saline water through inland drains due to tidal influence also makes the potable water unfit for consumption. In such areas, exploration and differentiation of fresh water aquifers from saline water aquifers becomes the primary objective (Bear et al., 1999). An attempt is made here to carry out geoelectrical and geochemical studies along the coastal tract of western Maharashtra to analyze the effects of sea water intrusion, in locating fresh groundwater pockets and to evaluate the quality of water.

Sindhudurg district is located in the Konkan region of Maharashtra State and covers a geographical area of 5087 sq. km. The district is located between north latitude 15°37’ and 16° 40’ and east longitude 73° 19’ and 74° 13’ (figure 1). This district is covered by the Deccan volcanic rocks, most of the soils are derived from lateritic rocks and the

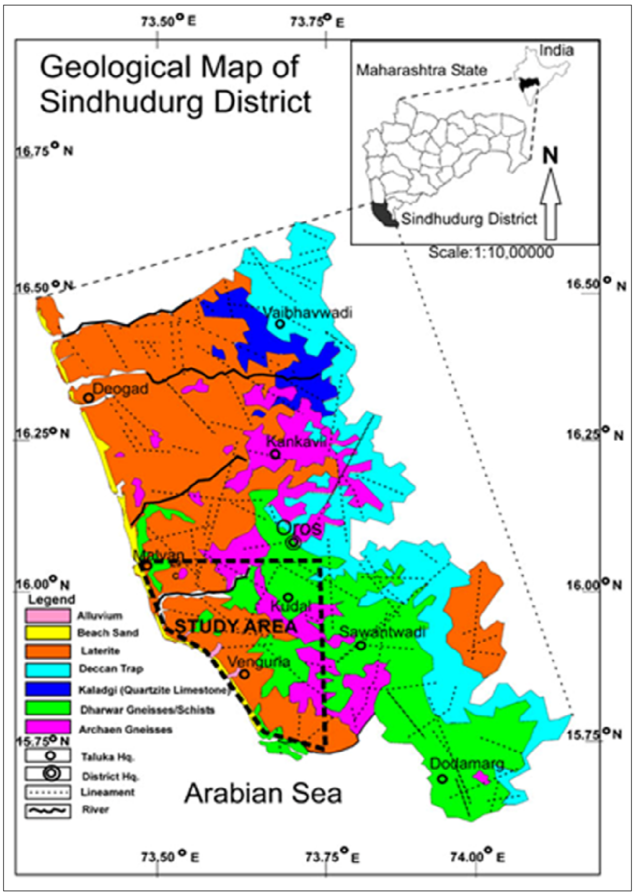

Fig. 1. Location map of the study area

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.

Hydrogeology of Konkan Region

Sindhudurg district is located in the Konkan region of Maharashtra State and covers a geological area of 5087 sq. km. The district is bounded in the north by Ratnagiri district, west by Arabian Sea and in the east by Kolhapur district and in the south by Goa State and Belgaum district of Karnataka State. The entire coastal stretch of Konkan was tectonically active during the Miocene-Pliocene period. The study area has three stretches of beach Mochemad beach, Shiroda beach and Redi beach.

It is generally not possible to make a meaningful interpretation of the hydrogeological-petrophysical aspects of an area without having first examined the geological framework. Different rock formations exist in Sindhudurg district and within the study area (figure 2). Each formation generally has different petrophysical properties, which will impart different capacities to store and transmit a fluid (in this case water). On top of the differences in petrophysical properties of the various lithological units, the capacity to store and transmit fluid is further modified by the geological history and structural development of the area.

The Archaean and the Cuddapah formations are found only in the southern half of the district, while the entire northern portion of the district is occupied by lava flows referred to as Deccan traps. The Dharwars are the most ancient formations in the area and are represented by banded hematite quartzite, varieties of schist and granitic rocks. Vengurla has a moderate to bold relief with hills and deep valleys. It has a coastline on its western side with a NNW-SSE trend. The coastline of Vengurla is rocky, but it is not so in the south. River Karli flows from east to west and borders the northern part. River Talvada flows from north-east to south-west and joins the sea at Mochemad. River Redi, which marks the southern border of Vengurla, has a north-south flow on the eastern side and abruptly changes to east-west direction near Shiroda, to join the sea. The general trend of the major rivers in the area is from east to west. Two more rivers join the sea at the Vengurla port hill, situated on the northern and southern sides of the hill. These rivers have a major east-west trend. The important rock units in the region are banded hematite quartzite, quartzite, and schist (amphibolites and garnet), as well as granitic rocks. The area is structurally disturbed and influences the geology and the drainage pattern to a large extent (Deendar, 2003). Faulting is a major factor influencing the deformation and rock alterations, facilitating the formation of residual ore deposits and iron ore containing rocks in the area. The sustainable iron ore deposit of Redi, thus formed, has supported large-scale mining operations over a long period, with workable reverse of about 48 metric tons (Hiremath, 2003).

Geological conditions, on which the occurrence of groundwater depends, vary in different parts of Maharashtra. Nearly 82% of the total area of the state is occupied by Deccan basalt flow. Dharwarian metasediments (Archean), Kaladgi formation (Precambrian), Deccan Trap lava flows (Upper Cretaceous to Lower Eocene age), Laterite (Pleistocene) and Alluvial deposits (Recent to Sub-Recent) are the water bearing formations observed in Sindhudurg district (CGWB, 2009). However Kaladgi formation occurs in very limited patches and does not form potential aquifer in the district. The Alluviums also has limited areal extent found mainly along the coast.

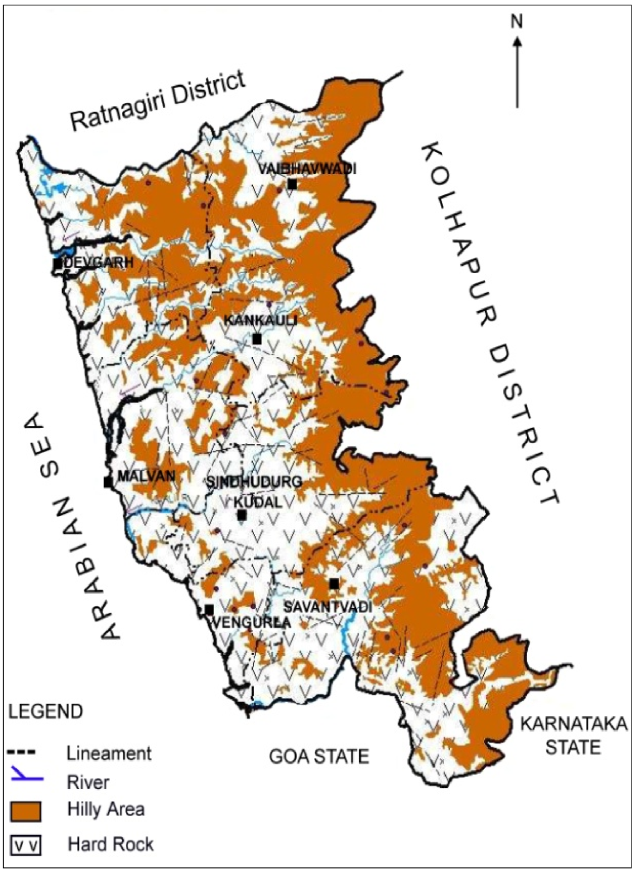

Fig. 2. Hydrogeological map of Sindhudurg district

Analysis and Cpmputational Techniqies

Analysis of VES Data:

Vertical electrical sounding (VES) studies are based on measuring the potentials between one electrode pair while transmitting direct current (DC) between another electrode pair. The depth of penetration is proportional to the separation between the electrodes, in homogeneous ground, and varying the electrode separation provides information about the stratification of the ground (Dahlin, 2000). This method is carried out to decipher problems of saline water intrusion into freshwater in the hard formation such as the Deccan Trap region.

The VES was carried out in the study area with the SSR-MP-ATS resistivity meter supplied by IGIS, Hyderabad. The location of electrical soundings and wells is shown in figure 3. Electrical resistivity soundings were conducted at 85 different locations by using the Schlumberger array for delineating vertical distribution of water bearing zones, constituting the aquifer bodies in this region and to delineate the zones of seawater intrusion (Song et al., 2007, Maiti et al., 2013). The Schlumberger soundings were carried with maximum current electrode spacing (AB) of 200 m (AB/2=100 m). The field data acquisition was generally carried out by moving two or four of the electrodes used, between each measurement. The resulting geoelectrical layer succession was used for identifying various conducting zones based on true resistivities.

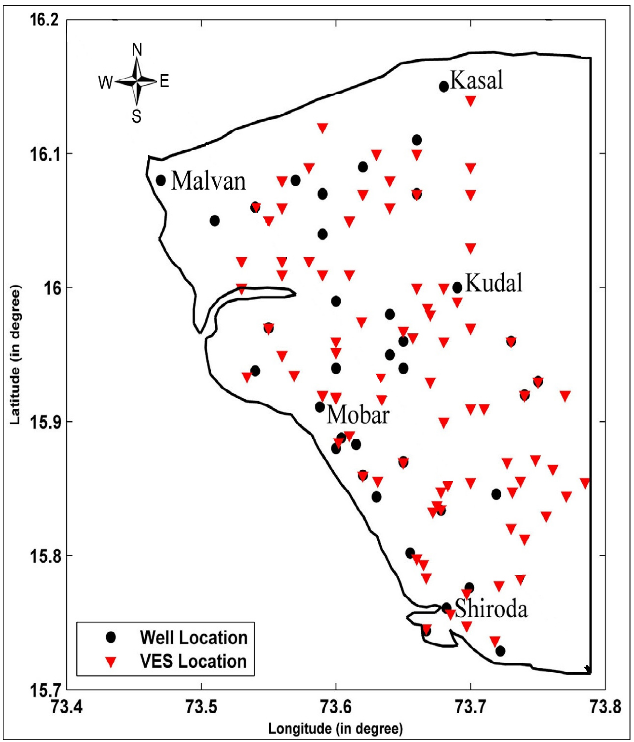

Fig. 3. VES and Well location in the study area

The data obtained from the field was processed and modeled using IPI2WIN software, version 3.0.1.a7.01.03 (Bobachev, 2003) for interactive semi-automated interpretation. IPI2WIN is designed for automated and interactive semi automated interpreting of vertical electrical sounding and induced polarization data obtained with any of a variety of the most popular arrays used in the electrical prospecting. It is presumed that a user is an experienced interpreter willing to solve the geological problem posed as well as to fit the sounding curves. Targeting at the geological result is the specific feature distinguishing IPI2WIN among other popular programs of automatic inversion. Due to handy controls the interpreter is able to choose from a set of equivalent solutions the one best fitting both geophysical data (i.e. providing the least fitting error) and geological data (i.e. geologically sensible resistivity cross section). Comparing various concepts of the geological structure along the surveyed observation line rather than independent formal sounding curves, inversion is the approach implemented in IPI2WIN. This approach provides the opportunity to use a priory geological data and extract information to the greatest possible extent in the complicated geological situations. For viewing curves and models, the pseudo cross- section of a specified value and resistivity cross-section are displayed (VES-IP mode: or chargeability cross section) in the pseudo cross section and resistivity cross section window, which can be used for interpretation.

IPI2Win is capable of solving resistivity electrical prospecting 1-D forward and inverse problems for a variety of commonly used arrays for the cross section with resistivity contrast within the range of 0.001 to 10000 ohm-m. The forward problem is solved using the linear filtering. These thoroughly tested filters and filtering algorithm implementation provide fast and accurate direct problem solution for a wide range of models, covering all reasonable geological situations.

The inverse problem is solved using a variant of the Newton algorithm of the least number of layers or the regularized fitting minimizing algorithm using Tikhonov's approach to solving incorrect problems. A-priory information on layer depths and resistivites can be used for regularizing the process of the fitting error minimizing. The inverse problem is solved separately for each sounding curve.

One-dimensional inversion results of VES sounding curves in the area are H-type and the rest are of Q-type and A-type. The apparent resistivity vs. half of the current electrode separation (AB/2) on log-log graph suggests three to four layered structures in this study area.

Geochemical Analysis:

Geochemical information were obtained by analyzing 36 water samples collected during March 2011 from representative dug wells and bore wells distributed throughout the area. The location of the geochemical sample collection points has been marked in figure 3. Water samples were collected at 0.5 m below the groundwater table from each well. All the wells are functional, and duration of each pumping lasted at least 5 min. Samples were collected in a 1.0-l-capacity plastic bottle. The bottles were first washed with diluted HNO_3 and then with distilled water thoroughly in order to make it ready for sample collection. EC and pH were measured immediately, while all other parameters were determined in the laboratory. EC was measured in microsiemens per centimeter at 25 °C. Except pH and EC, all other parameters are expressed in milligrams per liter (mg/l). It is noted that methods of water sample collection and analysis were essentially followed by Brown et al. (1974) and APHA (1985).

During sampling, greater emphasis was given on the areas where pollution was suspected. Most of the bore well samples were collected at locations where the local people complained of brackish taste of water due to proximity of the area with Arabian Sea. Attempt was made to collect at least one water sample from every village in the study area. It is important to note that geophysical data could be complimented to geochemical information where no water samples would be collected due to the unavailability of well.

The study of groundwater salinity in Konkan area of Maharashtra was observed based on different indices for irrigation and drinking uses. The groundwater management is essential for long-term irrigation system as well as for drinking and industrial use; it persuades the soil properties (Kannan and Joseph 2010). In irrigation water evaluation, emphasis is given on chemical and physical characteristics of water. Irrigation groundwater salinity is generally judged by some determining factors such as Sodium Absorption Ratio (SAR), Soluble Sodium Percentage (SSP), Kelly's Ratio (KR), and Permeability Index (PI) and should be computed.

Sodium Absorption Ratio (SAR): The sodium adsorption ration (SAR) indicates the effect of relative cation concentration on sodium accumulation in the soil; thus, sodium adsorption ration (SAR) is a more reliable method for determining this effect than sodium percentage. Sodium adsorption ration (SAR) is calculated using the following formula given by Richards (1954) as,

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

Soluble Sodium Percent (SSP): Soluble Sodium Percentage (SSP) was calculated by the following equation (Todd, 1959),

$$SSP = \frac{(Na + K) \times 100}{Ca + Mg + Na + K}$$

where the concentrations of Ca, Mg and Na are expressed in milli equivalents per litre (epm). The Soluble Sodium Percent (SSP) values less than 50 or equal to 50 indicates good quality water and if it is more than 50 indicates the unsuitable water quality for irrigation.

Kelley's Ratio (KR): Sodium measured against Ca_2^+ and Mg_2^+ is used to calculate Kelley's ratio. The formula used in the estimation of Kelley's ratio is expressed as,

$$KR = \frac{Na}{Ca + Mg}$$

where, all the ionic concentrations are expressed in meq/L.

Permeability Index (PI): The Permeability Index (PI) was calculated according to Doneen (1964) by the following equation,

$$PI = \frac{(Na + \sqrt{HCO_3})}{Ca + Mg + Na} \times 100$$

where, all the ions are expressed in meq/L.

Results and Discussion

Spatial distribution of VES data

Inversion of all the 85 VES apparent resistivity data of the study area have been performed in IPI2Win software, and the true resistivity and layer thickness has been obtained. From the inverted data of true resistivity with depth, the contour maps has been plotted at different depths from 1 m to 30 m to show the distribution patterns of the true resistivity (figure 4). The contour maps of true resistivity at a depth of 15 m, 20 m and 25 m suggest lower values of resistivity at two major locations namely Kelus and Shiroda, where the resistivity values are < 1.00 Ω-m. The lower ranges of resistivity at these locations can be attributed to the ingress of saline water from the adjoining Arabian Sea. All along the coastal part of the study area, lower resistivity is revealed due to the saline water intrusion into the fresh aquifers. The central portion of the study area reveal the resistivity ranges of good freshwater zone at some sounding locations at a depth of 10 m and 15 m. The north-eastern and north-western part of the area reveals higher resistivity values from the depth of 10 m to 30 m.

Water Chemistry for Irrigation

Sodium Absorption Ratio (SAR)

Ions are expressed as milli equivalents per litre (meq/L). The potential for a sodium hazard increases in waters with higher sodium adsorption ratio (SAR) values. The sodium adsorption ratio (SAR) content in the study area has shown variation from 0.82 to 22.83 with an average value 4.76 (see Table A). 94.44% Sodium adsorption ratios for groundwater samples of the study area are less than 10 indicating excellent quality for irrigation and thus these samples fall in excellent category; while 2.77% Sodium adsorption ratios for groundwater samples of the study area are within the range 10-18 indicating good quality for irrigation and hence these samples fall in good category (Table B).

Table: A- Characteristics ratios and indices of water samples

Sr.No.	SAR	PI	SSP	KR
1	8.21	50.94	45.12	0.72
2	6.52	40.50	34.49	0.49
3	1.30	25.32	14.55	0.13
4	1.89	30.59	20.41	0.19
5	4.13	38.61	30.83	0.40
6	1.49	28.03	15.60	0.16
7	1.15	21.12	11.56	0.11
8	0.99	21.14	11.39	0.10
9	0.85	19.34	8.73	0.08
10	1.00	20.90	10.02	0.10
11	3.67	36.65	28.76	0.36
12	3.63	32.26	25.87	0.30
13	1.01	21.12	10.96	0.10
14	1.77	26.57	19.78	0.17
15	1.15	19.44	10.89	0.10
16	5.24	31.43	27.38	0.33
17	0.82	19.13	10.57	0.09
18	9.20	53.51	48.01	0.88
19	2.48	27.20	20.88	0.23
20	8.57	51.65	48.07	0.79
21	7.97	51.07	43.79	0.72
22	6.25	41.70	35.59	0.49
23	5.14	29.98	26.08	0.32
24	6.96	45.06	37.24	0.55
25	4.42	36.34	26.22	0.32
26	22.83	50.06	49.32	0.94
27	0.97	16.79	9.45	0.07
28	2.56	23.76	17.54	0.15
29	3.37	30.66	20.28	0.25
30	4.40	31.61	26.00	0.30
31	6.11	41.48	34.71	0.50
32	16.45	55.13	49.81	0.98
33	8.47	44.17	38.50	0.57
34	5.47	44.73	38.08	0.52
35	1.69	17.00	9.61	0.09
36	3.34	35.21	25.52	0.29

Table: B- Classification of groundwater on the basis of SAR, KR and SSP

Parameter	Range	Water Class	Samples	%age
SAR	< 10 10–18 18–26 > 26	Excellent Good Doubtful Unsuitable	34 1 1 00	94.44 2.77 2.77 00
KR	<1 >1	Good Unsuitable	36 00	100 00
SSP	<50 >50	Good Bad	36 00	100 00

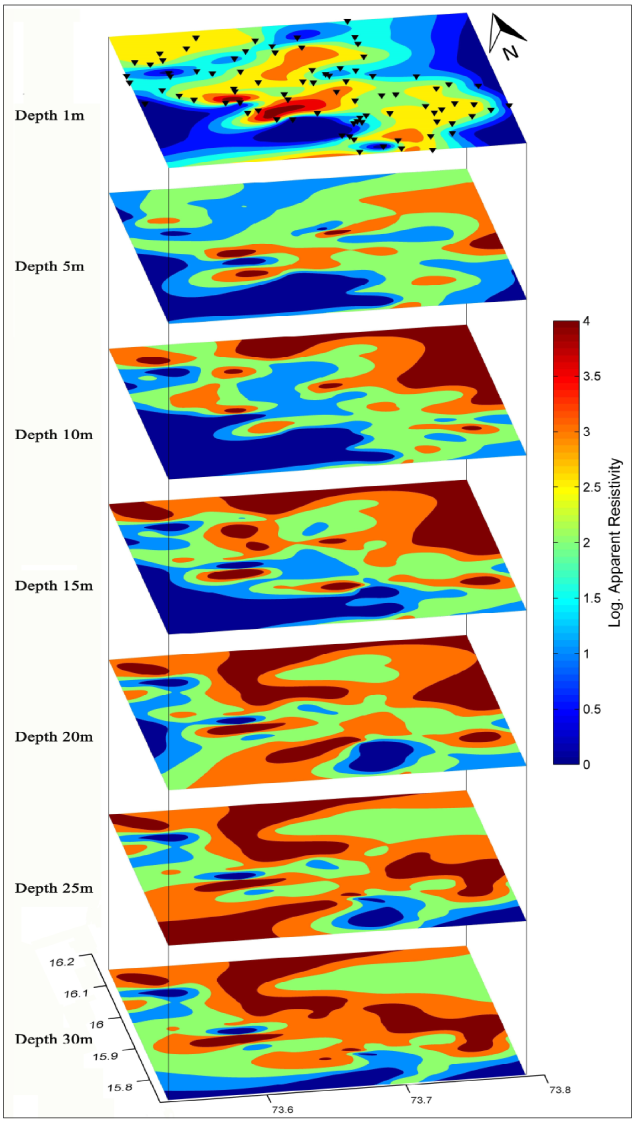

Fig. 4. Spatial distribution of true resistivity with depth

Kelley's Ratio (KR)

A Kelley's Ratio (KR) of more than one indicates an excess level of sodium in waters. Hence, waters with a KR less than one are suitable for irrigation, while those with a ratio more than one are unsuitable for irrigation. 100% KR values for the groundwater of study area are less than 1 and thus indicate good quality water for irrigation purpose.

Soluble Sodium Percent (SSP)

The concentrations of Ca_2^+, Mg_2^+ and Na^+ are expressed in milli equivalents per litre (epm). The Soluble Sodium Percent (SSP) values less than or equal to 50 indicates good quality water and if it is more than 50, the water quality is unsuitable for irrigation. The values of SSP ranges from 8.73 to 49.81 with an average value 26.15 (Table A). 100% SSP values for the groundwater of study area are less than 50 and hence indicate good quality water for irrigation purpose.

Permeability Index (PI)

Doneen (1964) has assessed the suitability of water for irrigation based on the permeability index (PI). According to this classification, Class I & Class II possess maximum permeability (>75%) are classified good for irrigation while third category (Class III) having 25% maximum permeability are unsuitable for irrigation purpose. In the present study area, the PI values are varying from 16.79 to 55.13. On the basis of PI classification the groundwater in the study area falls under Class II and hence the water is considered suitable for irrigation.

Spatial distribution of the geochemical facies

The spatial distribution of the geochemical facies of all the water sampling points over the entire region was evaluated by the krigging method using SURFER software and the results are discussed below. Table C illustrates the geochemical parameters used for further modelling.

Table C-The geochemical parameters used for forward modeling

Geochemical/ geophysical attributes	Very good (1.00)	Good (0.50)	Unsuitable (0.00)	Permissible limit (WHO 1984)
pH (−log10 H^+)	7.51–8.5	7.1–7.5	0.01–7.0 and 8.51–14.0	7.5–8.5
EC (µS/cm)	0.01–750	751–1,500	1,501–3,000	750
TDS (mg/l)	0.01–500	501–1,500	1,501–3,000	1,000
HCO_3^- (mg/l)	0.01 -200	201-300	301-500	300
Cl^- (mg/l)	0.01–100	101-200	201-1000	300
SO_4^{2-} (mg/l)	0.01 - 100	101 - 200	201 - 500	200
NO_3^- (mg/l)	0.01-25	25-45	45-100	45
Ca^{2+} (mg/l)	0.01-50	51-75	75-500	75
Mg^{2+} (mg/l)	0.01-20	21-30	31-200	30
Na^+ (mg/l)	0.01-50	51-200	201-500	200
K^+ (mg/l)	0.01-10	11-100	101-200	100

Contour Map of pH

When pH value is less than 7, the water is acidic in nature; while pH value is greater than 7 the water is basic in nature (WHO, 1984). And at pH= 7, it is neutral water. The pH value (figure 5) is increasing towards the south and it ranges from 7.4 – 7.8. It is however decreasing towards east and west. At central portion of the map where contour values are concentrated, the pH value is about 5.9-6.4. A very low pH (5.9) is observed on the western part of the map near the coast (longitude 73.65°). Low pH in the groundwater here could be due to the presence of the laterite which is porous and permeable. The excessive use of fertilizers like ammonium sulphate and phosphate in agriculture also causes

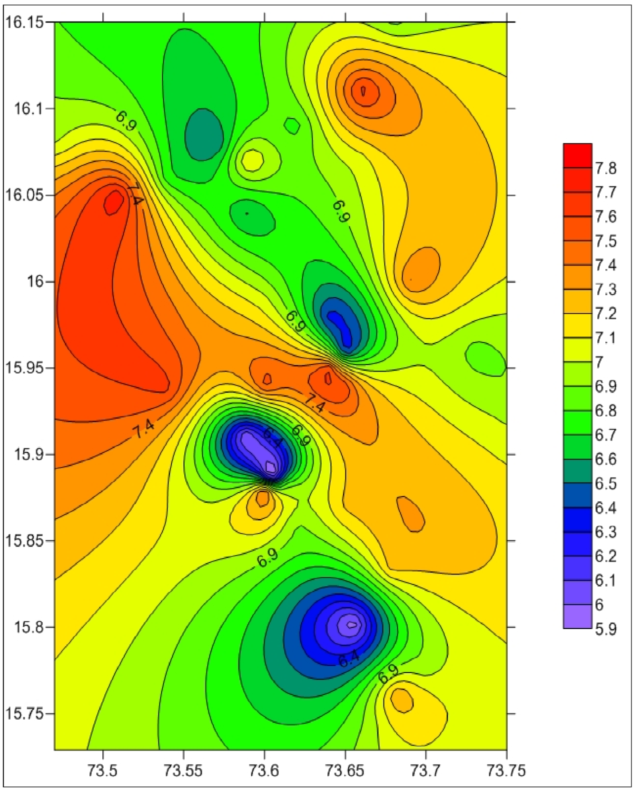

Fig. 5. Contour map of pH

low pH in groundwater. The low pH value in northern, southern and eastern part of study area is due to the interaction of water with rock like quartz, chlorite, amphibole, schist and ferruginous phyllite.

Contour Map of Electrical Conductivity

From figure 6, a high concentration of EC is observed at the central part. The electrical conductivity of this water is very high and it ranging between 3200 – 4400 µS/cm towards the coastal part (longitude 73.65°). At remaining portion of this map contour values are increasing and electrical conductivity is decreasing having a range of 0 – 1600 µS/cm. The high EC value at Shiroda and Kelus in the vicinity of the coast is due to the intrusion of saline water from Arabian Sea (Mondal et al, 2011). The SE and NW part of the study area has less EC concentration and thus the wells in this part of the study area are not affected by seawater intrusion.

TDS Contour Map

Figure 7 shows total dissolved solids (TDS) value very high at the central part (longitude 73.6°) and ranges in between 2200 to 2800 mg/l. These regions correspond to Kelus and Shiroda near the coast. These values exceed the acceptable limit prescribed by WHO (1984). The remaining part of the study area has low TDS values these are ranges in between 0 to 800 mg/l. Nutrient enrichment due to fertilizers and saline water intrusion could enhance TDS and in turn, increases the EC in the study area.

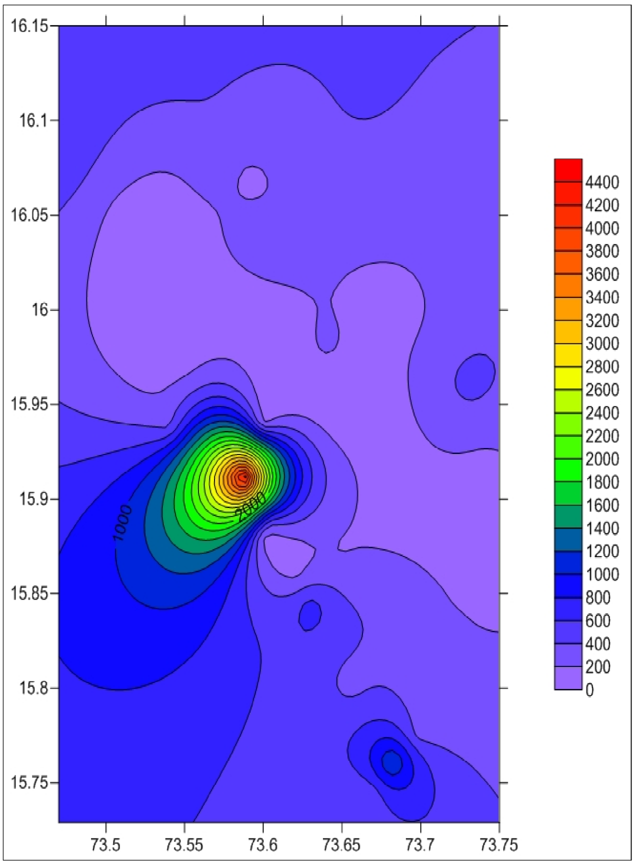

Fig. 6. Contour map of electrical conductivity

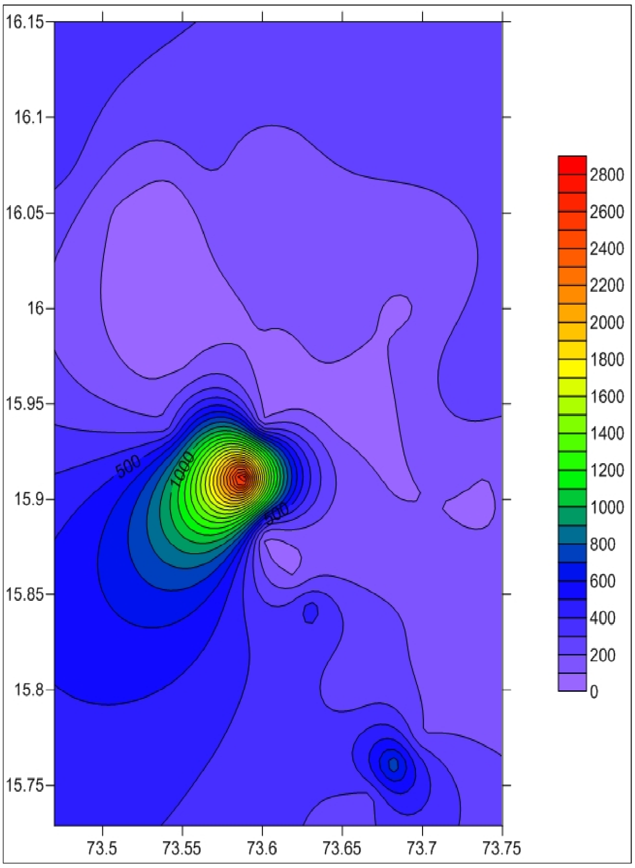

Fig. 7. Contour map of TDS

Chloride Contour Map

The chloride (Cl^-) occurs naturally in all types of water and is the dominant ions of seawater. Cl^- concentration recorded at Kelus and Shiroda (650-800 mg/l) falls beyond the permissible limit (200 mg/l) as suggested by WHO (1984) (figure 8). The high concentration of Cl^- at these places is mainly due to the saline water intrusion and secondarily due to the influence of discharged agricultural, industrial and domestic waste waters. The North and NW part of the areas show less concentration of chloride in the range 0-200 mg/l. A little portion towards the SE is also showing little higher Cl^- concentration.

Calcium Contour Map

The Calcium (Ca_2^+) contour map (figure 9) shows a high calcium percentage at central-western part. The values range in between 135-175 mg/l. The areas Kelus, Malvan, Shiroda, Aronda and Nivti falls beyond the permissible limit (75 mg/l) (WHO, 1984). The crystalline limestone and extended agricultural activities could influence directly or indirectly to enhance the mineral dissolution in groundwater (Bohlke 2002). Ca_2^+ concentration is less in North and NE part of the study area.

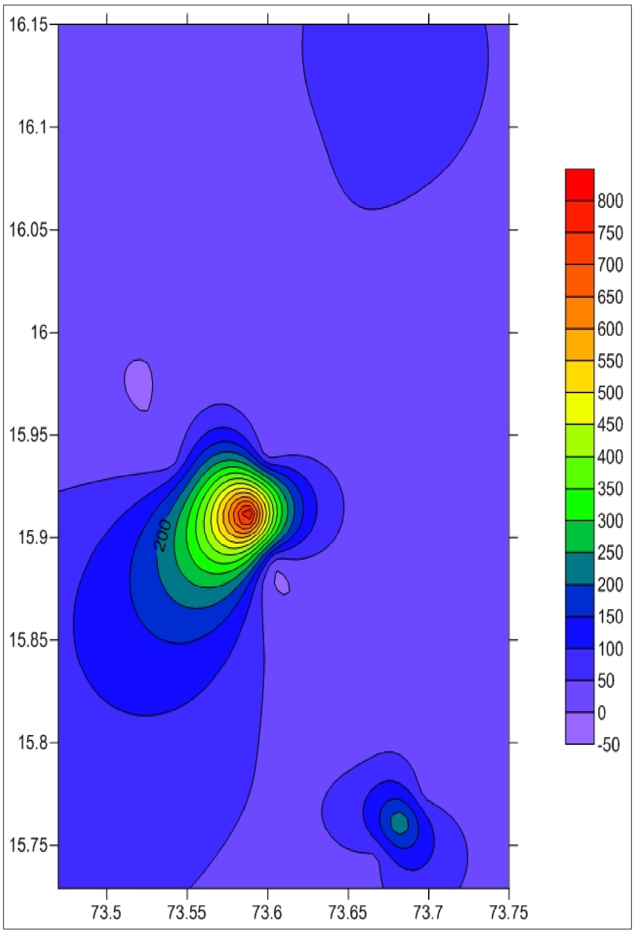

Fig.8. Contour map of chloride concentration

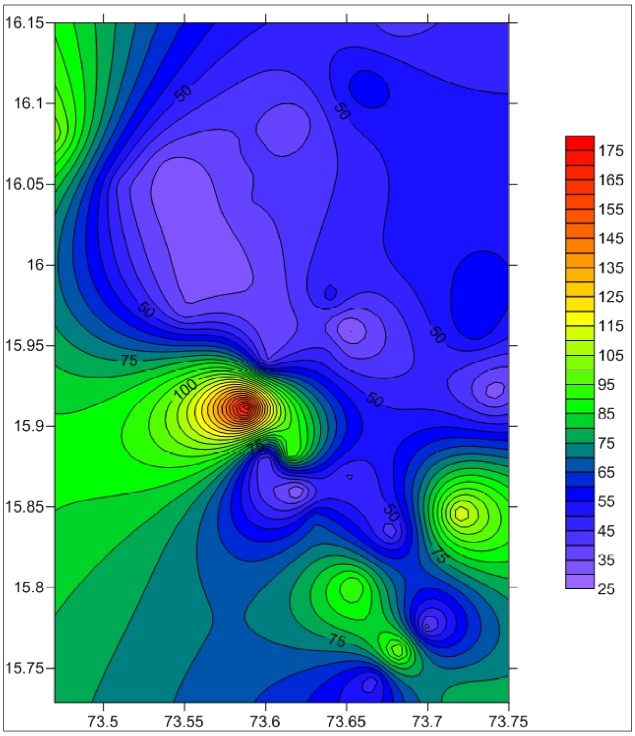

Fig. 9. Contour map of Calcium concentration

Magnesium Contour Map

Very high Magnesium (Mg_2^+) value is present at central portion (in Kelus) (figure 10), and it ranges in between 90-110 mg/l, which falls beyond the permissible limit (WHO, 1984). The content of Mg_2^+ is comparatively less than that of Ca_2^+. It's solubility in water is around five times that of calcium. The concentration of Mg_2^+ is high in NE part of the study area.

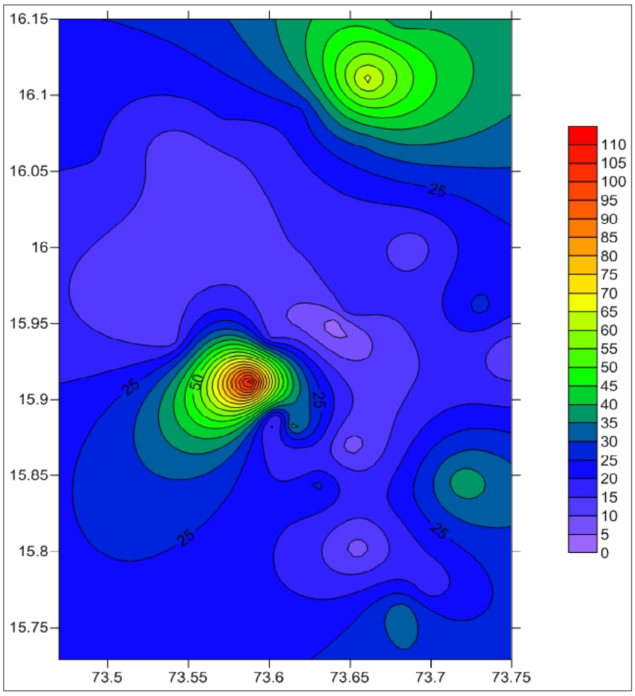

Fig. 10. Contour map of Magnesium concentration

Sulphate Contour Map

The high percentage of sulphate (SO_4^{2-}) is observed in the north at Malvan and the value ranges in between 260 – 300 mg/l (figure 11). Rainwater and anthropogenic activities can be important sources for other constituents such as sulphate. The primary mineral sources of sulphate ions include evaporate minerals (calcium and gypsum) and sulphates of magnesium and sodium (Maiti et al., 2013). The NE part of the study area, including Matond, shows higher sulphate concentration than that of Shiroda and Kelus.

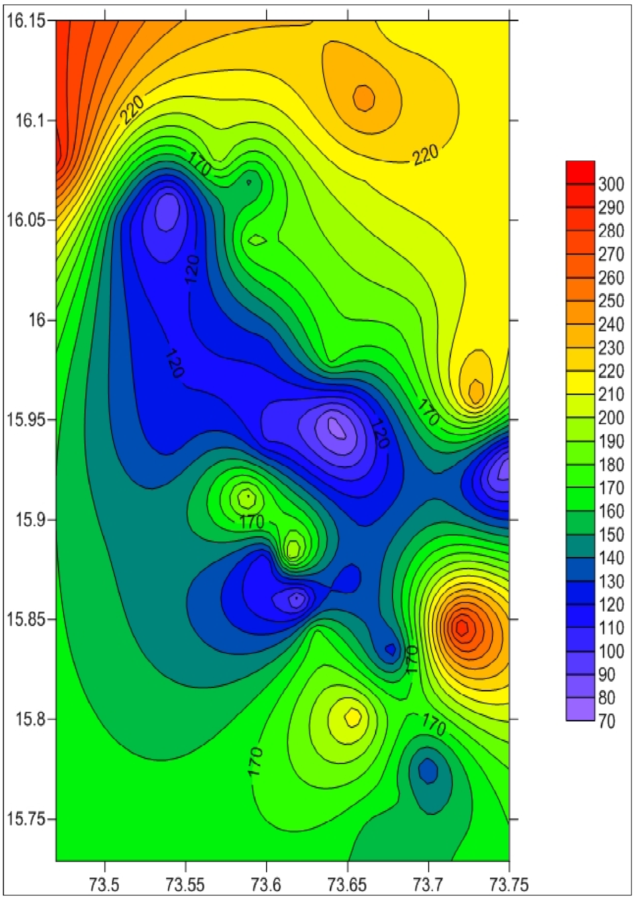

Fig.11. Contour map of Sulphate concentration

Sodium Contour Map

The high sodium (Na^+) percentage is concentrated at central region (figure 12) in the vicinity of Kelus, Shiroda and Aronda and it ranges in between 80 – 270 mg/l. These fall beyond permissible limit (WHO, 1984). Another small high concentration of Na^+ is observed in the SE part. Sodium ions are leached in the area primarily due to the reaction of feldspars with the groundwater (hydrolysis). The higher value is due to the interaction of groundwater with rock type of plagioclase feldspar and granite gneiss (Maiti et al., 2013). In coastal area, sodium could be added to the groundwater through saline water from Arabian Sea whereas in lateritic terrain groundwater is contaminated due to leaching during the process of lateralization.

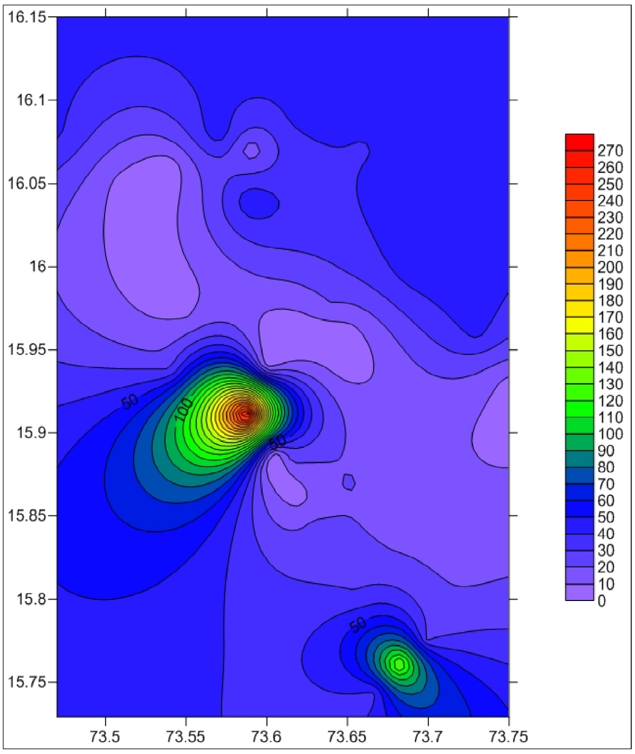

Fig. 12. Contour map of Sodium concentration

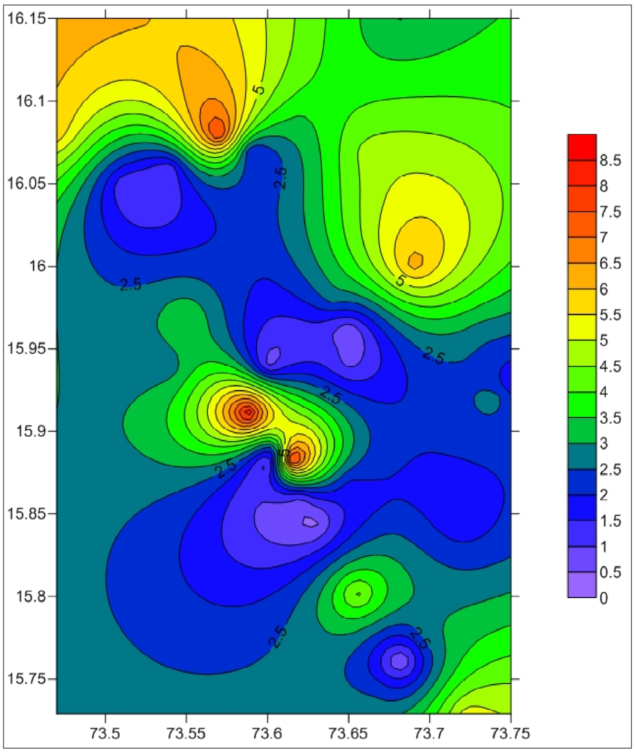

Fig.13. Contour map of Potassium concentration

Potassium Contour Map

The potassium (K^+) value recorded in the study area falls within the permissible limit (WHO, 1984), though this is observed high in north, NE, SE and the central part of the study area (figure 13). This involves the dissolving of feldspar minerals in the granite by hydrogen. The feldspar reacts with hydrogen in water producing Kaolin (china clay) in the process of Kaolinisation, which occurs due to the circulation of water through granite (Maiti et al., 2013).

Conclusion

The above results suggest that, groundwater quality is very good in most of the region of the study area, except for Kelus and Shiroda in the coastal part and thus may be recommended for domestic uses. The high TDS is closely related with high Cl^- in the groundwater which is mainly attributed to saline water intrusion from Arabian Sea.

Deplorable quality of groundwater arising from saltwater intrusion, natural leaching, and anthropogenic activities is one of the major concerns for the society. Assessment of groundwater quality is, therefore, a primary objective of scientific research.

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