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Groundwater exploration in a part of Jaisalmer basin of Western Thar Desert using Remote sensing and resistivity methods

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Abstract: - The Thar desert is the most densely populated arid region among all deserts of the world. The Jaisalmer basin as a part of the Thar desert, is one of the water-scarce regions in India in which sand dunes and desert are major landforms of the area. The lack of moisture due to very low and highly variable rainfall, along with high evaporation conditions makes the desert a draught-prone area. Due to the lack of surface waterbody, the area is in dire need of exploration of groundwater aquifers. Remote sensing along with a resistivity survey was incorporated for groundwater exploration. Optical and microwave images along with secondary data were used to generate thematic maps of all the parameters controlling groundwater development. Slope, elevation, and drainage density maps were made using SRTM DEM data. Landsat-8 and ALOS-PALSAR data were found helpful for lineament density and dunes mapping. Secondary data such as Geology, Geomorphology and Hydrogeology map along were integrated into the GIS platform. From the geological and hydrogeological point of view, the resistivity survey was carried out at thirty-seven locations in the study area. Apart from resistivity and depth of the layer, three other parameters, total longitudinal conductance, total transverse resistance, and the total thickness of the formation demonstrate the state of an aquifer. Eighteen probable sites were identified for groundwater extraction.

Keywords*: Jaisalmer basin, Remote sensing, Groundwater exploration, ALOS PALSAR, Resistivity survey*.

1. Introduction

Groundwater is a dynamic and replenishable natural resource for a continuous supply of clean water for drinking, domestic, irrigation as well as industrial purposes. However, its usage is limited by slow recharging capacity. The term “Groundwater” is used to represent all the water below the earth’s surface (Bear et al., 2012). It is an integral part of nature that supports the health, development and diversity of plants and animals. Groundwater has constant temperature, vast and continuous availability, low cost and limited vulnerability and is an important source of water supply in both urban and rural areas of developed as well as developing countries (Todd & Mays, 2005). Both quality and quantity are important aspects of water. However, the problem is finding the desired quality and quantity of water which should be economically exploitable. Further, increasing population, rapid industrial development and excess usage of groundwater has caused water scarcity in many places. The demand for groundwater supply for industrial, domestic, and irrigation purposes has led to an increase in the number of drilled wells. The borewell technology has led to extensive extraction of groundwater beyond its recharge capacity. Water pollution and contamination have further aggravated scarcity to another level. The discharge of untreated or unscientific disposal of waste and polluted surface water leaches out contaminants into the groundwater. In India, environmental degradation and improper management of water resources result in the lack of access to safe potable water supply to millions of people. India has 53.5 million hectares of irrigable land, 32 percent of which is irrigated through surface water, whereas 56 percent is through groundwater (Bobba et al., 1997).

The Jaisalmer basin as a part of the Thar desert in Rajasthan is one of the water-scarce regions in India, built with sand dunes and desert as the major landform of the area. Droughts faced by the area frequently result in lowering of the water table, reduction of water storage in reservoirs and crop failure. The erratic rainfall conditions with very few rainy days along with very high aridity makes the land even more dry due to high variability in runoff and stream flows. Most of the formations present in the region have very poor water-yielding capacity. The temperature in the region is very high providing a high evapotranspiration rate. All these factors make the area highly drought-prone resulting in a dire need for the exploration of groundwater aquifers. In addition to water scarcity, the region also suffers from water quality problems. Jaisalmer basin has highly saline groundwater, thus making fresh drinking water requirement a basic concern in the villages of the basin. Increasing urbanisation, industrial development, irrigation and tourism have put even more pressure on this land to yield water as the demand increases manifold (Mukhopadhyay et al., 2018; Shiklomanov, 2000; Mishra et al., 2010). This condition of potable water even worsens in summer promoting drought conditions. To overcome the water scarcity conditions through groundwater exploration, remote sensing and GIS along with geophysical data are found useful for surface and subsurface signature of groundwater respectively.

Remote sensing is an important tool for exploring, evaluating and managing groundwater resources at spatial, spectral and temporal scales. It provides valuable baseline information about all the controlling factors that influence the hydrogeology of groundwater. Groundwater locations can be identified using a single sensor such as a microwave or a combination of multiple sensors such as thermal, visible and infrared (Mukherjee et al., 2008). Microwave dual polarisation sensor is also found useful in geological mapping, surface roughness, feature orientation, electrical properties like dielectric constant, lineament extraction and geomorphological studies (Carver et al., 1985). Resistivity studies have been widely used in recent days to study groundwater exploration. Resistivity is the volumetric property determining the resistance of current flow in a medium. The resistivity of geological formations varies with density, porosity, the shape of the aquifer materials, quality of water present in the aquifers, presence of water in between the rocks holding various structural and textural characters and temperature of the subsurface setting (Telford et al., 1990, Jaiswal et al., 2003). The high ionic strength of groundwater that is found in geological formations encounters very low resistivity values (Gilkeson & Wright, 1983), but that does not mean that these regions are water-bearing zones. It is possible that anomalies or discontinuities can be mistakenly chosen as water-bearing zones. Dry geological formations have high resistivity values as compared to ones saturated with water. The massive rocks having minute interconnected pore spaces present in them show high resistivity values, whereas rocks with saturated pore spaces show lower resistivity values. Apparent resistivity maps and profiles are used to demarcate the groundwater-bearing zone (Zohdy et al., 1974; Todd, 1980). In the present study, the sub-surface geological investigation was carried out to infer fracture zones and lithology by using a resistivity survey. The basic aim of this study is to delineate low resistivity settings as well as to infer the changes in resistivity values along the geological structures to determine the possibilities of the aquifers. Schlumberger array was used for the resistivity survey. Geoelectric parameters were further quantified to overcome the differences between lithological boundaries and resistivity layers.

Study area: The study area lies in the western Thar desert in the Northwestern part of Jaisalmer district, Rajasthan along the India-Pakistan international border extended from 69°54’57.47” E to 70°20’30.12” E and 27° 31’44.79” N to 27°17’14.50” N. It extends starting from the Mari region of Pakistan and then forms a fraction of the Indus basin (Sharma, 2007). The Kishangarh – Ranau - Longewala to Ghotaru makes northeast to southwest approachability from Jaisalmer to Ramgarh. There are two depressions in the region, namely Kishangarh shelf on the northern side and the Sahahgarh depression on the southern side. The area lies in the Jaisalmer basin of the Thar desert. These two depressions are divided by Jaisalmer-Mari high along the northwest-southeast direction (Datta et al., 2022). Widespread sand dunes/loose sands make the area highly unapproachable except along the tar roads. The study area is almost barren covered with sand with no rivers or perennial streams. Only some small seasonal and ephemeral nallas are present in the name of drainage in the region (Bakliwal et al., 2003). The region is thinly populated as compared to other parts of India; however, it is one of the most densely populated arid regions of the world. It experiences a unique ecosystem, developed to evolve the symbolic relationship between man and environment over the past thousands of years in which all life forms: humans, animals, and vegetation survived even in fragile ecosystems. Though all conditions are very hostile to the existence of life, a large human and livestock population inhabits the area.

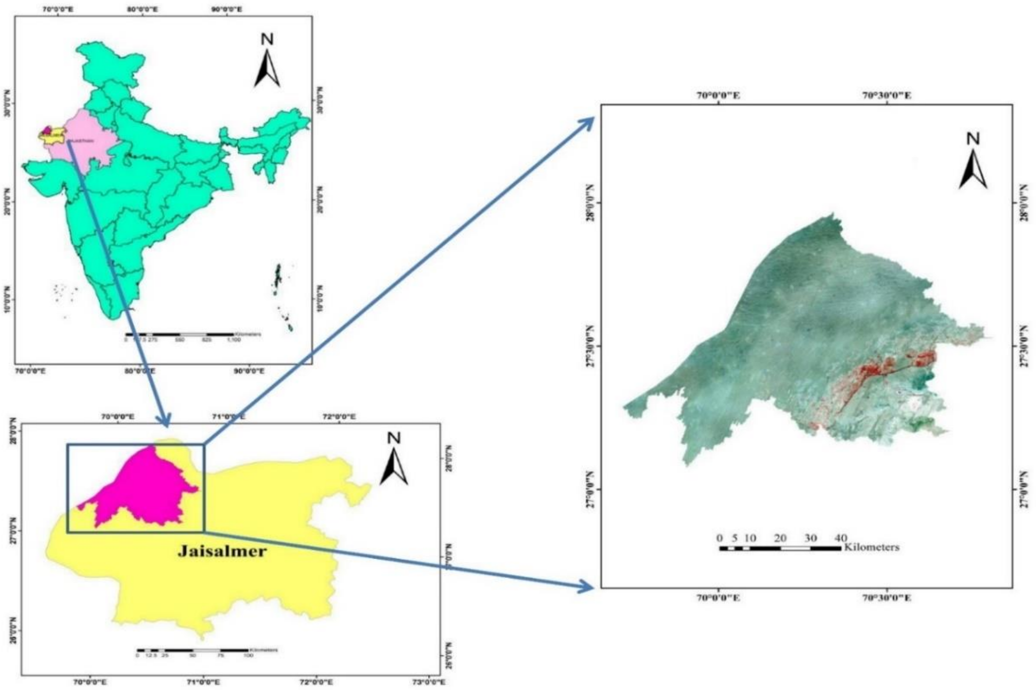


Fig. 1 Groundwater exploration sites of the study area

Lithostratigraphy

Jaisalmer basin is overlaid by a concretised gritty conglomerate, coarse sand with lateral and vertical variation to mottled finer sand and clays. Over this layer, well-sorted consolidated calc-sedimented sands, impersistent calcareous concretions, and coarse subangular and fluvial sands are found. This layer is further overlaid by Marly clays, calcareous sand, and silt with massive indurated calcrete over it. Coarse sand sheet flows and run-off deposit, kankar pans, calcareous and non-calcareous fine sand and silt and rolled kankar clast overlay the massive calcrete. On top of this layer, calcareous/non-calcareous fine sand with kankar, crossbedding and bioturbation structures are present. It is overlaid by calcareous sand and silt along with a weakly developed kankar pan. The uppermost layer comprises of non-calcareous, loose fine sand mixed with alluvium (Zadan and Arbab, 2015; Pandey et al., 2012).

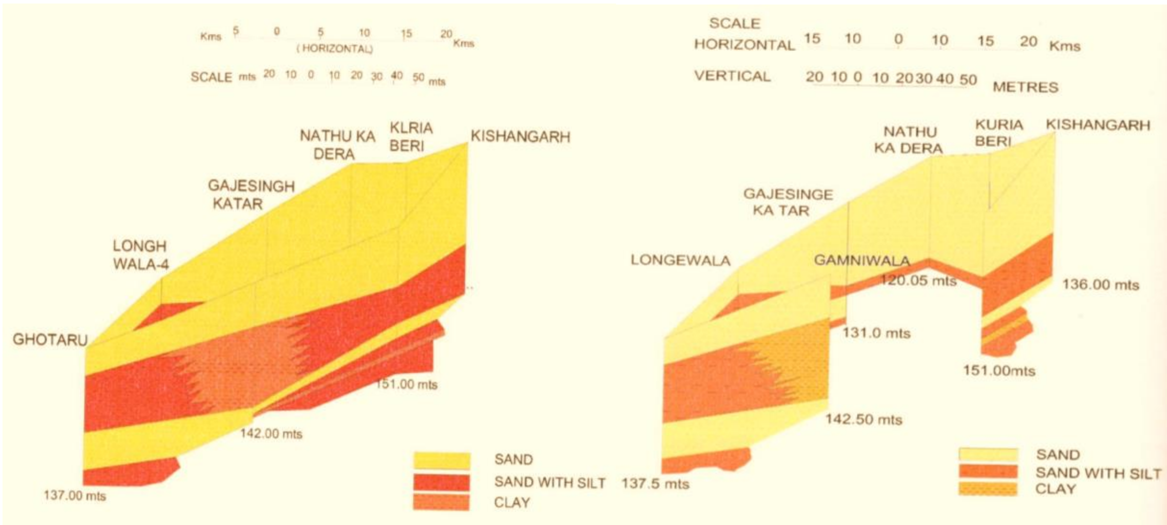


Fig. 2, 3 Lithology of the western Thar

2. Objectives

The primary objective of the work is to delineate of groundwater potential zones using an integrated approach of satellite data and resistivity survey method.

3. Methods

Geospatial and geophysical analysis were carried out to infer the groundwater exploration sites. The dataset of Landsat-8 (resolution 15-30 m), ALOS-PALSAR dual polar (HH, HV) (20m resolution), IRS- LISS III (resolution 23m), SRTM DEM (30 resolution) was used for lineament extraction, sand dunes terrain mapping, digital elevation model (DEM), slope, and drainage using ArcGIS 10.8. Lineament extraction was done using PCI Geomatica 8.2. Geology (Wadhwan, 1988, GSI, Jaipur) and geomorphology (Bhuvan thematic services) mapping were plotted to get the basic idea of the topography and possibilities of water flow and water yield. A resistivity survey in the Schlumberger array was carried out to extract all the possible locations for groundwater zones.

$$\rho_A = \frac{V}{I}\pi\frac{b\,(b+a)}{a} \approx \frac{V}{I}\pi\frac{b^2}{a} \quad \text{if } a \ll b$$

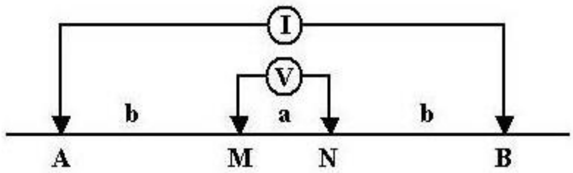


Fig. 4 Schlumberger_Array of resistivity survey

(https://openei.org/wiki/DC_Resistivity_Survey_(Schlumberger_Array)

The total longitudinal conductance, total transverse resistance and total thickness of the formation were calculated using ArcGIS 10.2.

4. Results

Thematic layers of the Study Area

Several parameters influence subsurface hydrology and groundwater development (Mukherjee, S. 2005). These parameters are proportional to groundwater development either directly or inversely but with different weightages. Satellite images provide information about the parameters of groundwater, even in inaccessible areas (Mukherjee, S. 2008). Geologically, most of the area is covered by abur/fatehgarh series and alluvium formation. Pariwar and tertiary sandstone are found in Jaisalmer/Lathi series (Asjad et al., 2021) (figure). Lithostratigraphically, the Jaisalmer basins have been grouped into Jaisalmer and Lathi formations (Singh et al., 2006). The Precambrian Malani rhyolite and Jodhpur sandstone constitute the basement of overlying successions of the Jaisalmer basin. The basin was formed in Jurassic time after the breakup of Gondwana in the southern margin of Tatheyan sea with a considerable possibility of hydrocarbon in the sedimentary stones. The study area is entitled with ramgarh fault, ghutaru fault, LONG structure, Barhri tibba structure, ghuturu structure along with mari-Jaisalmer arc (after Das Gupta, 1975). Aeolian plain of aeolian origin with some denudational patches in the southern side are the major geomorphological features in the area as shown in figure 6. The dune map of the area showed the aeolian structure in which transverse dunes dominate on the southern side, longitudinal dunes dominate on the northern side and complex dunes lie in between both and near to settlement area (figure 7). The drainage density lies between 0 to 18.05 km/km^2 (figure 8). Southern and southeast regions showed patches of maximum drainage density. The slope of the region is maximum in the northeast and minimum in the southwest region in the range of 0 to 25.27 degrees as shown in figure 9. In the case of elevation, it decreases from southwest to northeast directions between 67 to 244 meters (figure 10).

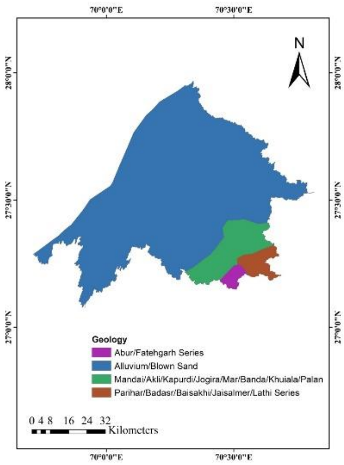


Fig. 5 Geological map of the study area (after Das Gupta, 1975)

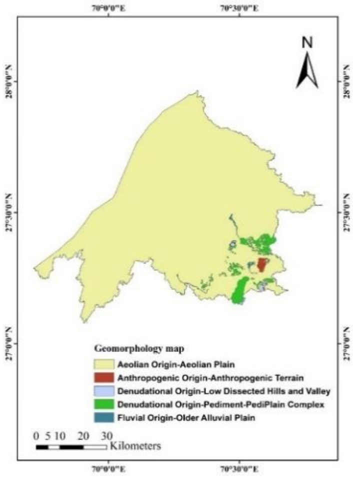


Fig. 6 Geomorphological map of the study area (BHUVAN geospatial portal)

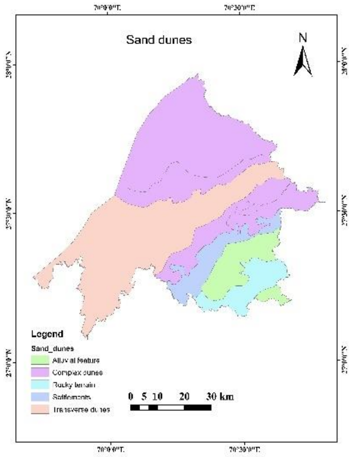


Fig. 7 Dune map of the study area

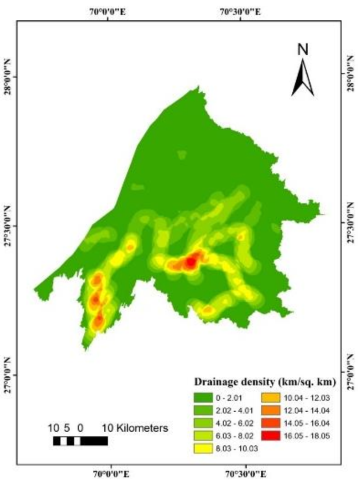


Fig. 8 Drainage density map of the study area

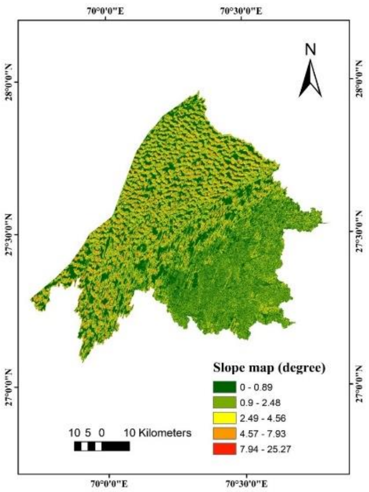


Fig. 9 Slope map of the study area

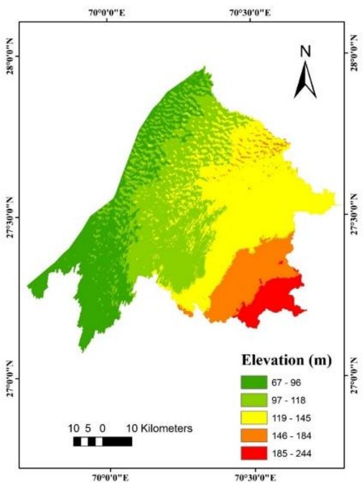


Fig. 10 Elevation map of the study area

The resistivity of Geological Formations

A resistivity survey was carried out at thirty-seven locations in the study area. From the geological and hydrogeological point of view, both quantitative and qualitative analysis was done to delineate potential groundwater zones. The spatial distribution of resistivity survey points is shown in figure 11.

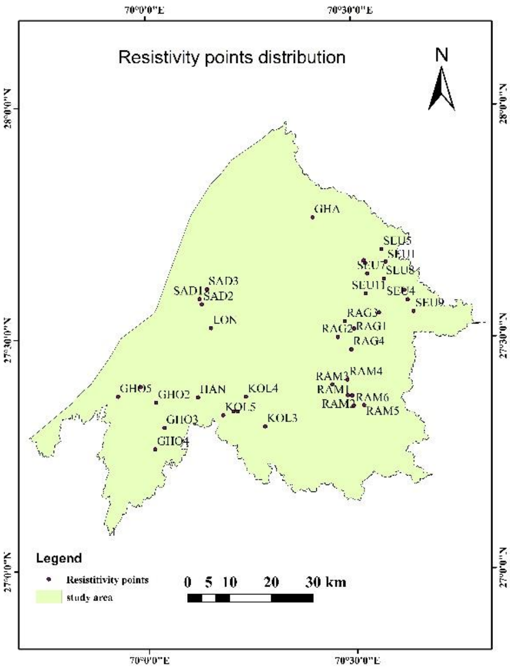


Fig. 11 Resistivity point distribution map of the area

Isoelectric Maps depicting changes in the resistivity values in the area

Apparent electric resistivity maps were analysed to understand the quantitative interpretation of Vertical electric sounding (VES) data (Venugopal, 1988; Aravindan, 1999). This method gave a brief idea about the geological structures and the variation in geo-electric cross-section. The thickness of layers and their resistivity values are two important variables for the determination of the subsurface geoelectric section. Further interpolation maps along with a contour diagram of each resistivity layer and thickness were generated for the spatial understanding of the area is shown in figure 12-19.

The resistivity value was highest from the northeast to southeast direction in the first two layers of resistivity and also had maximum thickness in this region too. Ghotaru (GHO3) showed maximum resistivity in all the layers of resistivity layer. The third layer of resistivity had higher resistivity in the southwest to southeast direction and abnormally high in the northeast area. The fourth layer of resistivity has higher resistivity values in the southwest area of the study area.

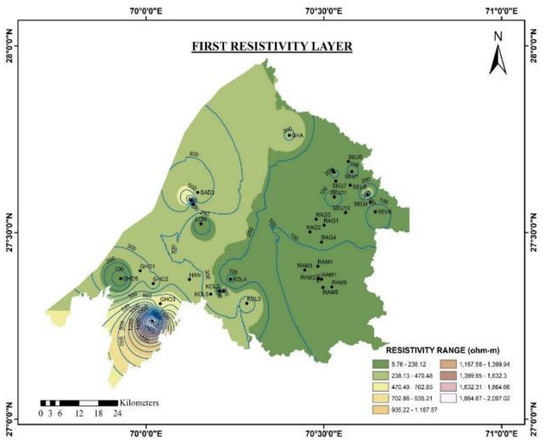


Fig. 12 First Resistivity layer of the area

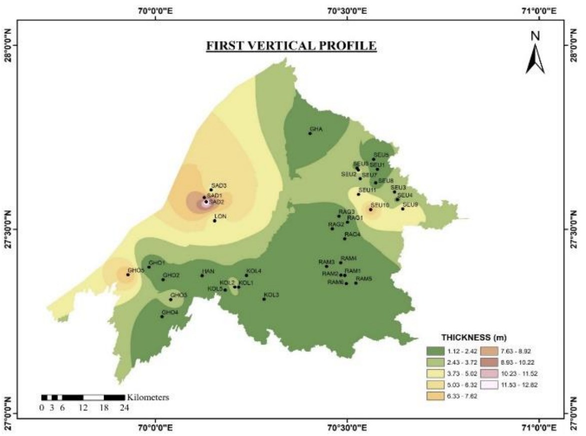


Fig. 13 First Vertical profile of the Area

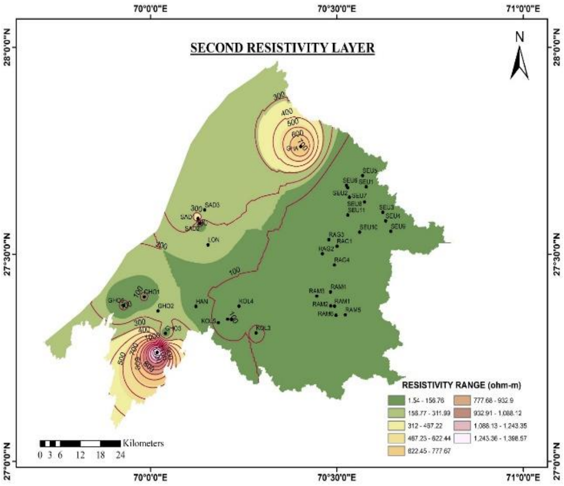


Fig. 14 Second Resistivity layer of the Area

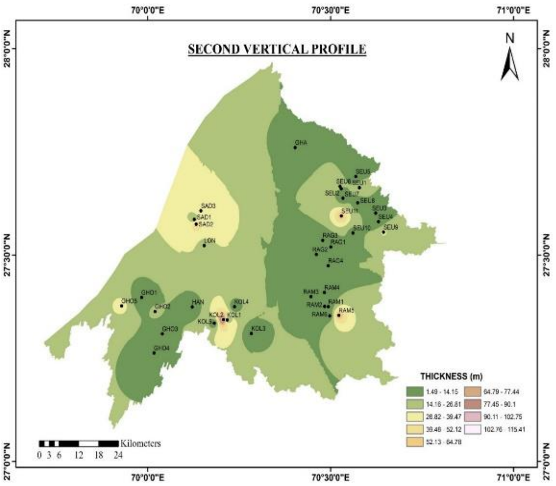


Fig. 15 Second Vertical profile of the Area

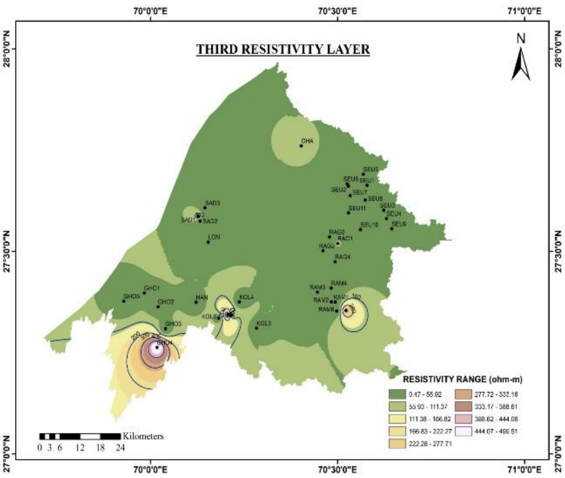


Fig. 16 Third Resistivity layer of the Area

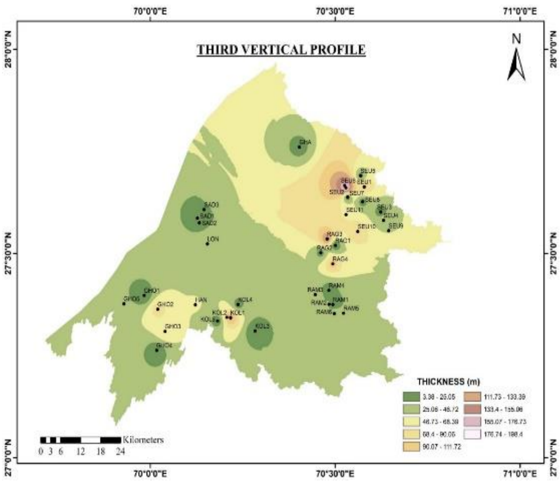


Fig. 17 Third Vertical profile of the Area

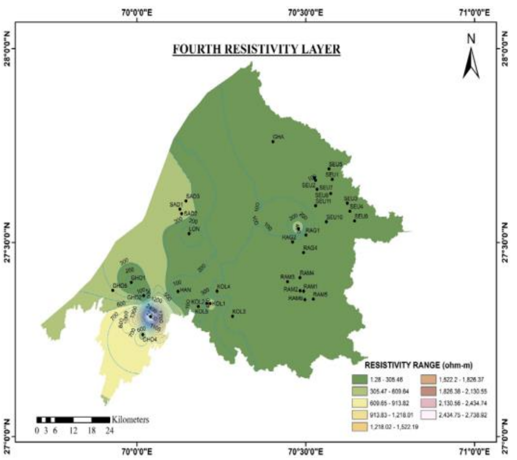


Fig. 18 Fourth Resistivity layer of the Area

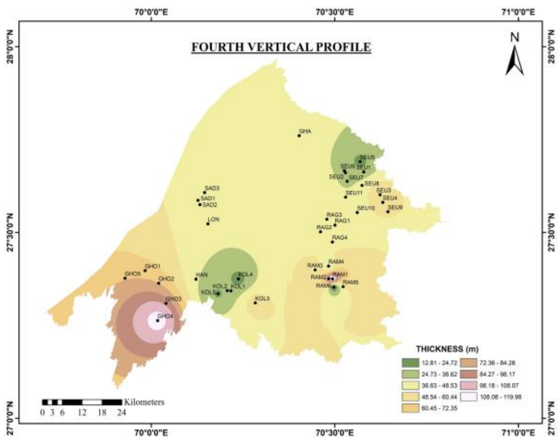
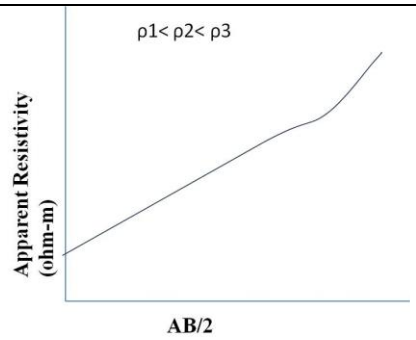


Fig. 19 Fourth Vertical profile of the Area

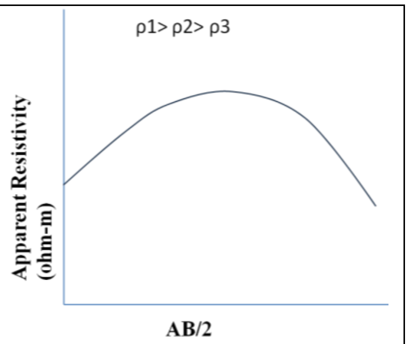
Qualitative interpretation

Curve matching technique

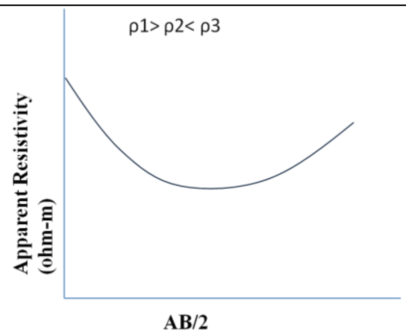
A theoretical curve of dimensionless coordinates was prepared. All interpretation and computation were done using two parameters resistivity and the thickness of the layer. Though a first-layer system is not enough to depict the exact locations of water possibility, two-layer, three-layer and four-layer curve was generated. In a two-layer system, curves are either ascending or descending. If the curve is descending type (ρ1> ρ2), then the topsoil or weathered layer is overlying over loose sand mixed with clay (resistive basement). However, if the curve is ascending type, then a thick clay layer or saline water is underlain by a consolidated or hard top layer (conductive basement). In a three-layer system, four types of curves are possible. If three successive resistivity layers are ρ1, ρ2 and ρ3 then four possible curves are named as Q (ρ1< ρ2< ρ3), R (ρ1< ρ2> ρ3), S (ρ1> ρ2< ρ3), T (ρ1> ρ2> ρ3).



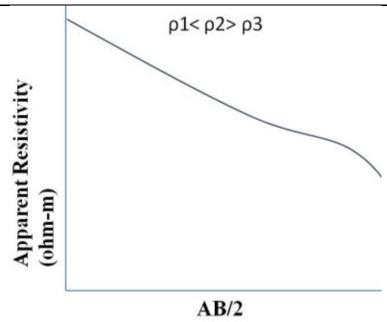
Curve Type Q of three layers of resistivity system



Curve Type R of three layers of resistivity system

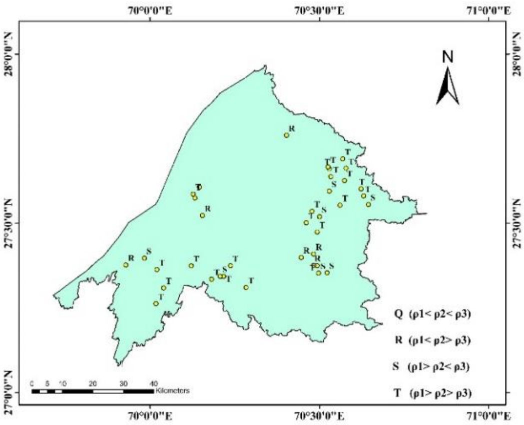


Curve Type S of three layers of resistivity system



Curve Type T of three layers of resistivity system

Four-layer system- There are eight possible curves. Their notation was done in such a way that increased value after the third layer is denoted by adding H (P_H, Q_H, R_H, S_H), whereas decreased value is shown by adding L to three-layer notation (P_L, Q_L, R_L, S_L). Eighteen samples are found to have higher resistivity values at the fourth layer and eleven samples had lower resistivity values as compared to the third layer of resistivity.



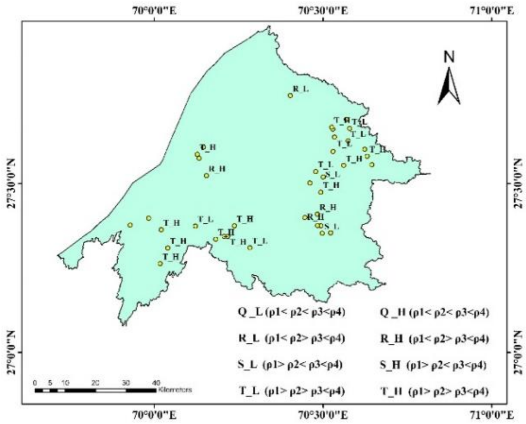


Fig. 20, 21 Three-layers system and four-layer system of resistivity

Table 1 statistical distribution of layers in each curve

Sr. No.	Curve type	Number of sites
1	**Q**	0
2	**R**	6
3	**S**	7
4	**T**	22

Quantitative interpretation

Most of the area encounters sand dunes. Some parts in the southwest side comprise unconsolidated to consolidated alluvial deposits and rocky terrains. The subsurface information of the depth of bedrock aids in the interpretation of resistivity data. Low resistivity values may encounter clays, saline sand, or fractured rocks (CGWB 1989). It is not necessary that the fractured zone is a water-bearing zone. A low resistivity value and thickness of the layer to the bedrock is an indicator of a groundwater prospect zone (Balakrishna et al., 1984; Balasubramanian et al., 1985).

Table 2 Resistivity data along thickness and curve type

S N	Locations	h1 (m)	h2 (m)	h3 (m)	h4 (m)	h5 (m)	ρ1 (Ωm)	ρ 2 (Ωm)	ρ 3 (Ω m)	ρ 4 (Ω m)	ρ 5 (Ω m)	Curve type	
1	GHA	1.2	7.0	15.9	43.4		308.9	701.6	97.5	27.9	23.1	R	R_L
2	SAD1	7.4	14.8	20.0			800.0	400.0	130.0	400.0		T	T_H
3	SAD2	13.0	52.0				200.0	40.0	0.0				
4	SAD3	4.1	32.8				410.0	267.0	0.0				
5	LON	4.0	24.0	27.0			120.0	180.0	10.0	150.0		R	R_H
6	HAN	1.3	3.9	48.0			340.0	113.0	9.3	4.6		T	T_L
7	KOL1	1.6	3.2	120.0			330.0	109.9	13.5	405.0		T	T_H

8	KOL2	4.0	120.0				135.0	13.5	405.0			S	S
9	KOL3	1.5	3.0	7.2	53.0		340.0	113.0	28.0	12.0		T	T_L
10	KOL4	1.6	4.8	16.5	22.0		65.0	22.0	8.0	15.0	7.5	T	T_H
11	KOL5	1.4	2.1	14.0	24.0	70	300.0	100.0	14.0	8.0	16.5	T	T_L
12	SEU1	1.3	26.0	96.2			59.0	20.0	1.1	15.0		T	T_H
13	SEU2	5.0	10.0	200.0			300.0	19.9	2.6	78.0		T	T_H
14	SEU3	3.5	7.0	8.5	56.0		350.0	70.0	5.7	1.9	9.5	T	T_L
15	SEU4	2.0	4.0	43.2			96.0	9.6	1.5	30.0		T	T_H
16	SEU5	1.6	3.2	16.0	22.5		100.0	20.0	2.7	1.2	3.5	T	T_L
17	SEU6	1.1	22.0	160.0			64.0	21.3	1.5	120.0		T	T_H
18	SEU7	3.0	6.0	7.0	36.0		200.0	66.0	8.0	1.5	15.0	T	T_L
19	SEU8	1.5	6.0	11.2			150.0	7.8	6.0	2.0		T	T_L
20	SEU9	5.0	29.0				16.3	1.8	4.5			S	S
21	SEU10	7.6	10.4	88.0			140.0	7.4	2.0	62.4		T	T_H
22	SEU11	5.0	60.0				16.0	1.6	48.0			S	S
23	RAG1	1.5	4.5	2.3	37.0		150.0	50.0	66.0	1.7	17.0	S	S_L
24	RAG2	1.7	3.4	15.2	45.0		130.0	26.0	3.3	1.4	17.0	T	T_L
25	RAG3	1.4	4.2	141.0			150.0	49.9	3.2	480.0		T	T_L
26	RAG4	1.7	6.8	102.0			130.0	13.0	2.0	60.0		T	T_H
27	RAM1	1.9	3.8	5.0	120.0		110.0	37.0	0.8	3.5		T	T_H
28	RAM2	1.4	2.8	30.0			4.9	9.8	1.4	4.2		R	R_H
29	RAM3	1.5	6.0	38.0	48.0		60.0	90.0	2.2	14.0	0.0	R	R_H
30	RAM4	1.4	1.4	9.9	39.0		5.7	8.5	0.6	2.0	4.0	R	R_H
31	RAM5	2.2	65.0				39.0	1.5	312.0			S	S
32	RAM6	1.5	6.0	42.0	12.6		13.0	1.3	2.3	44.0	22.0	S	S_L
33	GHO1	1.1	3.3	7.2			270.0	90.0		150.0		S	S
34	GHO2	1.9	15.2	80.0			240.0	160.0	16.0	53.0		T	T_H
35	GHO3	2.9	8.7	66.0			520.0	104.0	11.0	2750.0		T	T_H
36	GHO4	1.2	4.8	10.4	112.0		2100.0	1400.0	500.0	540.0	15.0	T	T_H
37	GHO5	7.6	30.4				9.0	90.0	2.5			R	R

First layer resistivity and thickness

The thickness of the first layer is from 1.20 to 13.0 m and resistivity values were in the range of 4.9 to 2100 ohm-m. KOL4, SEU1, SEU4, SEU6, SEU11, SEU9 RAM2, RAM3, RAM4, RAM5, RAM6 have resistivity value below 100 ohm-m.

Second layer resistivity and thickness

The second layer thickness varies from 2.30 to 200 m and the resistivity value from 1.3 to 1400 ohm-m. GHA, SAD1, SAD3, LON, HAN, KOL1, KOL3, KOL5, GHO2, GHO3, GHO4 have resistivity value higher than 100 ohm-m.

Third Layer resistivity and thickness

The thickness and resistivity of the third layer lie from 2.3 to 200 m and 0.6 to 500 ohm-m respectively. Most of the sites are found below 100 ohm-m except SAD1, KOL1, RAM4, GHO4 have resistivity values 130, 312, 405 and 500 ohm-m respectively.

Fourth layer resistivity and thickness

The fourth layer has thickness and resistivity in the range of 12.6 to 120 m and 1.2 to 2750 ohm-m respectively. Fourth layer showed the resistivity of SAD1, LON, KOL1, SEU6, RAG3, GHO1, GHO3, GHO4 higher than 100 ohm-m. Whereas SAD2, SAD3, KOL2, SEU9, SEU11, RAM5 have not detected any separate layer.

Fifth layer resistivity

Fifth layer of GHA, KOL4, KOL5, SEU3, SEU5, SEU7, RAG1, RAG2, RAM4, RAM6, GHO4 has resistivity value 3.5 to 23.1 ohm-m.

Geo-electric parameters

Generally, there is a variation of boundaries between the geologic section and the geoelectric section. It may be because the properties of resistivity layers and the individual layer of lithological characteristics or geologic ages are not coinciding on the same boundaries.

The three Geo-electric parameters were calculated using resistivity and thickness of the layer

1) The total longitudinal unit conductance (S) is

$S = h1/\rho1 + h2/\rho2 + h3/\rho3 \ldots\ldots$

2) Total transverse thickness (T) is

$T = h1\ \rho1 + h2\ \rho2 + h3\ \rho3 \ldots\ldots$

3) The coefficient of anisotropy (l) is

$l = \sqrt{(TS)}/H$

where h1, h2, h3……….. is thickness, and ρ1, ρ2, ρ3……….. is resistivity

Table 3 Geo-electric parameters obtained from Resistivity and Thickness

S. No.	Locations	S	T	l
1	GHA	1.73	8072.08	1.20
2	SAD1	0.20	14440.00	1.19
3	SAD2	1.37	4680.00	1.52
4	SAD3	0.13	10438.60	2.04
5	LON	2.87	5070.00	1.26

6	HAN	5.20	1329.10	1.38
7	KOL1	8.92	2499.68	1.33
8	KOL2	8.92	2160.00	2.06
9	KOL3	4.70	1686.60	1.82
10	KOL4	3.77	671.60	1.58
11	KOL5	4.03	1018.00	1.12
12	SEU1	92.94	697.71	1.89
13	SEU2	77.44	2219.00	1.97
14	SEU3	31.07	1869.85	1.36
15	SEU4	29.24	295.20	2.19
16	SEU5	24.85	294.20	1.91
17	SEU6	107.72	779.00	1.47
18	SEU7	24.98	1106.00	1.12
19	SEU8	2.65	339.00	2.31
20	SEU9	16.42	133.70	1.60
21	SEU10	45.46	1316.96	2.66
22	SEU11	37.81	176.00	1.34
23	RAG1	21.90	664.70	1.23
24	RAG2	36.89	422.56	3.20
25	RAG3	44.16	870.78	1.50
26	RAG4	51.54	513.40	1.05
27	RAM1	40.66	773.60	0.57
28	RAM2	22.00	76.30	1.93
29	RAM3	20.79	1385.60	1.75
30	RAM4	36.41	103.82	1.20
31	RAM5	43.39	183.30	1.56
32	RAM6	23.68	676.20	1.38
33	GHO1	0.09	1674.00	3.21
34	GHO2	5.10	4168.00	1.01
35	GHO3	6.09	3138.80	1.78
36	GHO4	0.23	74920.00	1.27
37	GHO5	1.18	2804.40	1.03

5. Discussion

It was already established that a region having a resistivity value between 20-60 ohm-m is a suitable site for potable water, water quality degrades when it goes below 20 ohm-m (Sharma, 1982; Prasad, 1984; Balasubramanian, 1986; Venugopal, 1988; Chandrashekar, 1988; Indira, 1988; Siddaraju, 1996; Nagaraju, 1996; and Mastan Rao, 1998). Total transverse thickness (T) measures the resistance in the direction transverse to the bedding. Whereas the total longitudinal unit conductance (S) measures the conductance parallel to the bedding. Total thickness can be interpreted in qualitative and quantitative manner. The increase in the T value shows the high thickness of a high resistivity value (Balasubramanian, 1986). S has been used for qualitative estimation of vertical electric sounding changes with total thickness. (Zohdy, 1969; Henriet, 1975; Worthington, 1977; Galin, 1979). A higher T value is associated to the high transmissivity and permeability of water. High 'S' values show deeper and more resistive basement. The transverse resistivity is found to be higher than longitudinal resistivity in heterogeneous medium. The increase of both T and S has a similar trend in high transmissivity aquifers with resistive base (Matzner, 1983).

The value of Aquifer anisotropy lies between 1.00 and 2.00 (Zohdy et. al., 1989). The high value of coefficient value of anisotropy shows the hardness and compaction of rock in the study area. A value between 1 to 1.5 is associated to be with the prospective groundwater zone. The low value of the coefficient of anisotropy is considered to be with a low water table fluctuation region (Keller et. al., 1966; Mukherjee and Kumar, 2022). The study area found anisotropic value between 1.0 and 1.5 in GHO2, GHO5, RAG4, KOL5, SEU7, SAD1, GHA, RAM4, RAG1, LON, GHO4, KOL1, SEU11, SEU3, HAN, RAM6, SEU6, RAG3 at thickness is to be associated with potable aquifer zone.

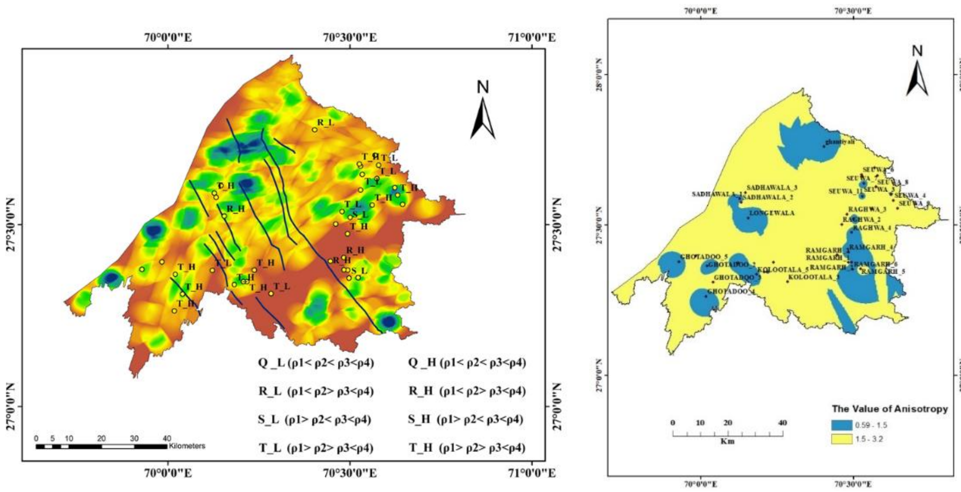


Fig. 22, 23 Map depicting lineament density, major faults along with resistivity curve type and coefficient of anisotropic map of the area

The following groundwater potential zones whose thickness are more than 10m are GHA (15.9), SAD (20), LON (24), SEU6 (120), SEU7 (6), RAM6 (42), GHO2 (15.2), GHO4 (10.4), GHO5 (30.4), thickness less than 10m are KOL5 (2.1), SEU3 (7), RAG1 (2.3), RAM4 (1.4), HANS (3.9), KOL1 (3.9). The potential aquifer of SEU11 and RAG4 has an unidentified layer below.

Conclusion: Geospatial and geophysical methods work almost everywhere. Geospatial methods provided surfaces like DEM, drainage density, and slope as well as subsurface information (to a meter) such as lineaments to infer possible sites for resistivity survey. Geophysical methods such as the resistivity method gave deep penetration into the subsurface for geoelectric anomaly further providing a resistivity layer with its depth. Most of the region is covered with a thick layer of sand over a silt or clay layer. The identification of the groundwater site was inferred after comparing it with lithology. The sites identified for groundwater exploration were GHO2,

GHO5, RAG4, KOL5, SEU7, SAD1, GHA, RAM4, RAG1, LON, GHO4, KOL1, SEU11, SEU3, HAN, RAM6, SEU6, RAG3. Most of the groundwater is developed around an impermeable clay layer.

Conflict of interest statement: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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