


Mapping Structurally Favourable Zones of Water Seepage Using Remote Sensing and Geophysical Methods in Western Rajasthan, India

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Abstract

The presence of cracks, joints, faults, fractures and lineaments and their interconnectivity influence the water movement in hard rock areas. The groundwater level in Jodhpur city, western Rajasthan, has been rising significantly over the past few years, and this has attracted attention due to the region's unfavourable impacts. In many parts of the city, particularly around popular markets, water levels have touched the ground. The rise in groundwater levels has caused water seepage in the basements of underground shops and houses throughout the city. Traditional field survey techniques require a lot of money and effort to map water seepage zones. In this study, subsurface signatures of linear features, faults and fractures were quickly and inexpensively mapped using a remote sensing methodology. Fracture zones that are prone to water seepage were identified using an electrical resistivity method. Based on meticulous analysis of satellite imagery, a number of minor and large lineament sets have been mapped, the majority of which cross over Kailana Lake-Takht Sagar and enter the city. According to the study of all available data, fractured zones exist, are linked by Kailana Lake-Takht Sagar, and act as conduits for water seepage. The presence of obvious lineaments also facilitates water seepage.

Keywords: Cross-section, Fracture zone, Groundwater, Lineaments, Seepage.

1. Introduction

The application of remote sensing technology is particularly effective for the resolution of groundwater problems due to the synoptic, repetitive, multi-spectral coverage of a terrain and the systematic delineation of distinct geomorphological units (Sahai et al., 1991; Isiortho and Nkereuwem, 1996; Mulder et al., 2011). Depending on the geographical resolution, the synoptic coverage aids in the local and regional delineation of lithological, geomorphological and structural elements. Such information is essential for planning and carrying out projects to address groundwater issues, particularly in inaccessible and hard-rock terrain. In addition, the integration of remote sensing techniques and field investigation has contributed to enhancing the mapping of geological and structural features (Mshiu, 2011; Tagnon et al., 2018; Hamimi et al., 2020). However, in recent years, initiatives for the management and development of water resources, surface hydrology, and hydrogeology have all benefited significantly from the usage of remote sensing techniques (Rao, 2000). Numerous researchers have reported using GIS and remote sensing to solve groundwater

problems like delineating and mapping groundwater potential zones (Dar et al., 2010; Machiwal et al., 2011; Suganthi et al., 2013; Manap et al., 2014; Elbeih, 2014; Shekhar and Pandey, 2015; Nejad et al., 2017; Mageshkumar et al., 2019; Raju et al., 2019; Bera et al., 2020; Bhattacharya, 2020; Al-Djazouli et al., 2020). In hydrogeological research, the integrated use of geophysical and remote sensing techniques has been extensively outlined by various researchers (Denne et al., 1984; Singh and Prakash, 2002; Rai et al., 2005; Srivastava and Bhattaycharya, 2006; Srivastava et al., 2012; Sharafi and Khazaei, 2013; Elmahdi and Mohamed, 2014; Dailey et al., 2015).

The majority of groundwater circulation occurs in hard rock areas because of secondary porosity, which is developed by faulting, fracturing, and lineament junction of the underlying rocks (Ali et al., 2012; Das, 2017; Bera et al., 2020). Water seepage is the most prevalent hydrogeological hazard for lakes and dams, especially those located over faulted and deformed structures (Al-Fares, 2011, 2014; Yadav and Pratap, 2015; Olasunkanmi et al., 2018; Al-Fares, 2019).

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Multi-temporal remote sensing data provides a powerful tool to detect and delineate water seepage by lakes or water loss in transportation through canal leakage (Chopra, 1989; Engelbert et al., 1997; Huang et al., 2009; Pratap et al., 2014;). The groundwater flow was estimated using the water budget equation for Mariout Lake, Alexandria City, Egypt (Kansoh et al., 2020). The groundwater flow pattern in the western Sand Hills of Nebraska was identified using the Landsat-7 ETM (Enhanced Thematic Mapper) image (Tcheroponov and Zolatrik, 2002). The use of remote sensing to detect seepage from irrigation canals and the visual interpretation of satellite images reveal the locations of confirmed seepage (Huang et al., 2009). Also, the high local groundwater inflow to Nosoud tunnel has been detected using satellite imagery data (Sharafi and Khazaei, 2013). The use of remote sensing to clarify the function of lineament characteristics in subterranean hydrodynamics that regulate groundwater circulation and storage (Takorabt et al., 2018). Remote sensing methods have been used to extract lineament characteristics, namely faults and joints, from the Atalla Shear Zone and its surroundings in Egypt's Central Eastern Desert (Hamimi et al., 2020). The data from observation wells, numerical modelling, and geophysical surveys were used to create a framework for understanding seepage at the Hidden Dam site near Raymond, California (Minsley et al., 2011). A groundwater seepage study was conducted using an electrical resistivity survey to investigate the potential groundwater seepage zones (Abidin et al., 2015; Kumar et al., 2021; Guo et al., 2022). The groundwater movement and occurrence in the Thar Desert of western Rajasthan, India, were studied using the remote sensing data to trace the paleochannels of the legendary river Sarasvathi Drishadvati and correlate older stream channels (Ghose, 1965; Ghose and Singh, 1975; Shankarnarayan et al., 1983; Kar and Ghosh, 1984; Kar, 1986). The remote sensing data is used to characterise groundwater prospecting zones and delineate the role of lineaments for the assessment of groundwater in a basaltic terrain in western Rajasthan (Khan and Mohrana, 2002; Bahuguna et al., 2003; Rajput et al., 2006; Javed and Wani, 2009). Remote sensing, GIS and modelling techniques were used to study

the influence of the effluent on groundwater in Pali City, western Rajasthan (Pathak et al., 2012). Chandrasekharan (1988) conducted the geoelectrical resistivity surveys for groundwater in western Rajasthan. Geoelectrical soundings were carried out by Shukla and Pandey (1991) to determine the best location for the development of a subsurface dyke to recharge the area, close to Jodhpur city. In the Jalore district of Rajasthan, Yadav and Abolfazli (1998) used geoelectrical sounding techniques with Schlumberger configuration to demonstrate the correlation between geoelectrical features and hydraulic parameters. Yadav et al. (2000) used geoelectrical sounding in the Jhanwar region of Rajasthan and Jodhpur district to identify the presence of potential zones of fresh groundwater.

This manuscript describes remote sensing and cost-effective geophysical approach to solve the adverse problem reported in the arid region in the Jodhpur City, Rajasthan India. The groundwater level has been rising in the city and covered 40% of the land area in the city. Due to the rise of groundwater level, causing seepage in underground of shops and houses in the city areas and weakening the foundations and reducing the lives of the buildings, erosion takes place. Keeping in view the above-mentioned groundwater problem, they are extremely pertinent to scientifically make an assessment of favourable fractured zones of water seepage. The remote sensing technique was used to identify the surface features such as lineaments and its ground truth verification by the use of geoelectrical method. The integrated remote sensing and geoelectrical methods have been proven a very successful in the detection of water seepage zone in the study area. The reason is that because the existing old geophysical technique use with remote sensing can solve the new problem.

In the present study, subsurface signatures of linear features, faults and fractures were mapped using a remote sensing methodology, and fracture zones that were favourable for water seepage were identified using an electrical resistivity method. On the basis of the layer parameters obtained from the geoelectrical sounding interpretation, geoelectrical cross-sections have been prepared in different directions. These cross-sections provide the clear picture of the

subsurface geological formations that help in delineating the probable zone of water seepage, weathered and fractured zones occurring at different depths in the study area.

2. Geology and location of study area

According to geological data, the study region is primarily composed of sedimentary rocks and a small portion of the rhyolite suite (Blanford, 1877; Paliwal, 1992; Paliwal and Rathore, 2000). The city of Jodhpur has a typical metropolitan backdrop and an unusual geomorphological environment. The historic walled city portion is situated on the lower slope of Fort Hill Ridge. In the S-E and S-W directions, the land eventually changes to plain alluvial terrain. A series of flat-topped hills with NE-SW inclinations of rhyolite, sandstone and shales constitute the research area. Rhyolite hills have a rough surface and an irregular relief, whereas sandstone/shale hills have an erosionally flat top. A few meters of capped sandstone can be seen on some of the rhyolite hills, showing a clear relationship between the contrasting rock formations of the two types. The Jodhpur group of sandstones and the Malani suite of igneous rocks make up the bedrock geology of the urban region. These rocks range in age from the Upper Proterozoic to the Lower Palaeozoic. Shale is interlayered with geological formations like the Malani rhyolite and Jodhpur sandstones in the city of Jodhpur. Due to the rhyolites extensive faulting, folding, weathering and fractures, the upper layer of the rock has become extremely porous. The city, which is located on the eastern side of Kailan Lake-Takht Sagar, is primarily made up of alluvium and rhyolite geological formations. Rhyolite that is heavily faulted, worn and fractured underlies the Kailan Lake-Takht Sagar (Sinha et al., 2002; Chandrasekharan and Navada, 2002). The Jodhpur sandstone and shale make up the largest portion of an ancient walled city. Sandstone and shale are severely deformed as a result of the neotectonic activity in the region. Significant hydrogeological formations in the study region include Jodhpur sandstone, Malani rhyolite, and quaternary alluvium. When the local water table is high, groundwater is present. Groundwater flow, dispersion and circulation are greatly influenced by sets of diverse joints, fractures, faults, beds of ash and clayey minerals in the research area.

The research region, which includes parts of Jodhpur City and its surrounding area, is located in Western Rajasthan, between the latitudes of 26° 13' N and 26° 20' N, and the longitudes of 72° 56' E and 73° 04' E. Jodhpur is the second-largest city in Rajasthan and was established on May 12, 1459, by the late Rao Jodhaji. It has a long history of water management. Numerous traditional water storage facilities, including jhalaras, ponds, baories (step wells), open wells, etc., can be found around the city. The Kailana Lake-Takht Sagar are the main reservoirs for the water supply and are well-connected to each other. The initial purpose of this reservoir was to store rainwater for the supply of drinking water. Numerous water supply plans have been put in place to fulfil the rising demand for water supply as the city continues to expand due to the multifold development, population growth and urbanisation. The water supply needs cannot be satisfied with the available surface water and groundwater resources. The Rajiv Gandhi Lift Canal (RGLC), which additionally connects to Kailana-Takht Sagar and continuously distributes water into this reservoir to meet the rising water requirements of the city. To fulfil the increasing demand for water, it is necessary to store more water and continually improve the water level in Kailana-Takht Sagar. Unexpected circumstances have led to rising water levels in some areas of the city as well as water seepage in the basements of bustling marketplaces and underground retail establishments. Houses in these places struggle consequently with moist walls, which weaken the foundations of homes and shorten the lifespan of the structures (Gupta et al., 2007). According to a previous study, the rising water level of Kailana Lake-Takht Sagar is the cause of groundwater seepage in the city (Sinha et al., 2002; Jigyasa, 2011; Yadav and Pratap, 2015; Kaur and Ramanathan, 2016; Pratap and Yadav, 2016). To identify favourable zones for water seepage and outline the fractured zones that operate as conduits for water seepage in the research area, accurate, quick and cost-effective investigations are applied in the affected area.

3. Methodology

The present study used the Geographical Information System (GIS) and ERDAS-

Imaging 8.6 software for satellite image processing. The methodology followed in the present study is illustrated in Figure 1. Thematic maps, such as lineaments and relief maps, were delineated using remote sensing data from Landsat-7 ETM (Enhanced Thematic Mapper) and Survey of India topo sheets Nos. 45F/3, 45F/4, 45B/15, and 45B/16 (Das, 2017). The data used for the mapping of structural lineaments was standard and multi-date coverage (Ali et al., 2012; Takorabt et al., 2018; Tcheroponov and Zolatrik, 2002). Apart from the remote sensing data, field surveys and relevant data were also collected from secondary sources. By visually interpreting the satellite imagery, thematic maps of the research area, including lineament and relief maps, were created. Thematic maps use pictures and terrain components to identify and delineate distinct units (Rao, 1995). The data obtained by remote sensing were cross-checked by geoelectrical techniques at a few selected sites.

The Terrameter SAS 300 resistivity meter and its accessories, made by M/s. ABEM Sweden, were utilized to collect the geoelectrical sounding data points using the Schlumberger configuration. Due to the weakening of the

resistivity meter readings at each step of the current electrode spacing, the field data was collected in segments that overlapped. As a result, the potential electrode spacing was raised, and two measurements of the same current electrode spacing were made: one for the old potential electrode spacing and the other for the raised potential electrode spacing. A total of 71 geoelectrical soundings, some recent and some older, were used. For those locations where sounding data could not be taken due to field restrictions, the Ground Water Department, Jodhpur, provided the old-sounding data. Figure 2 shows the location of these geoelectric sounding points.

On the log-log paper, the apparent resistivity values were plotted versus the half-current electrode spacing. There were two ways to interpret the field curves. First, by manually comparing the field curves to the master curves of the Rijkswaterstaat (1969) and the associated auxiliary point charts (Ebert, 1943). Second, a software was used to interpret and correlate the data. This interpretation reveals the resistivity and thickness of each layer. The available borehole lithology has been linked to the layer characteristics of geoelectrical soundings.

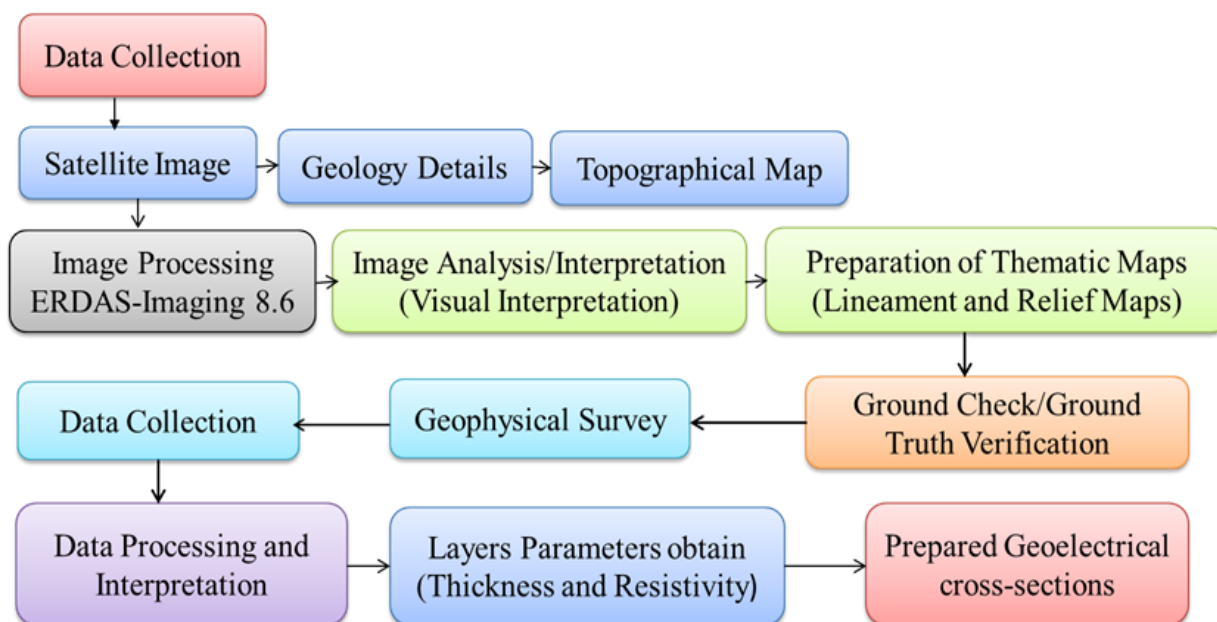


Figure 1. Flowchart showing the methodology used in the present study.

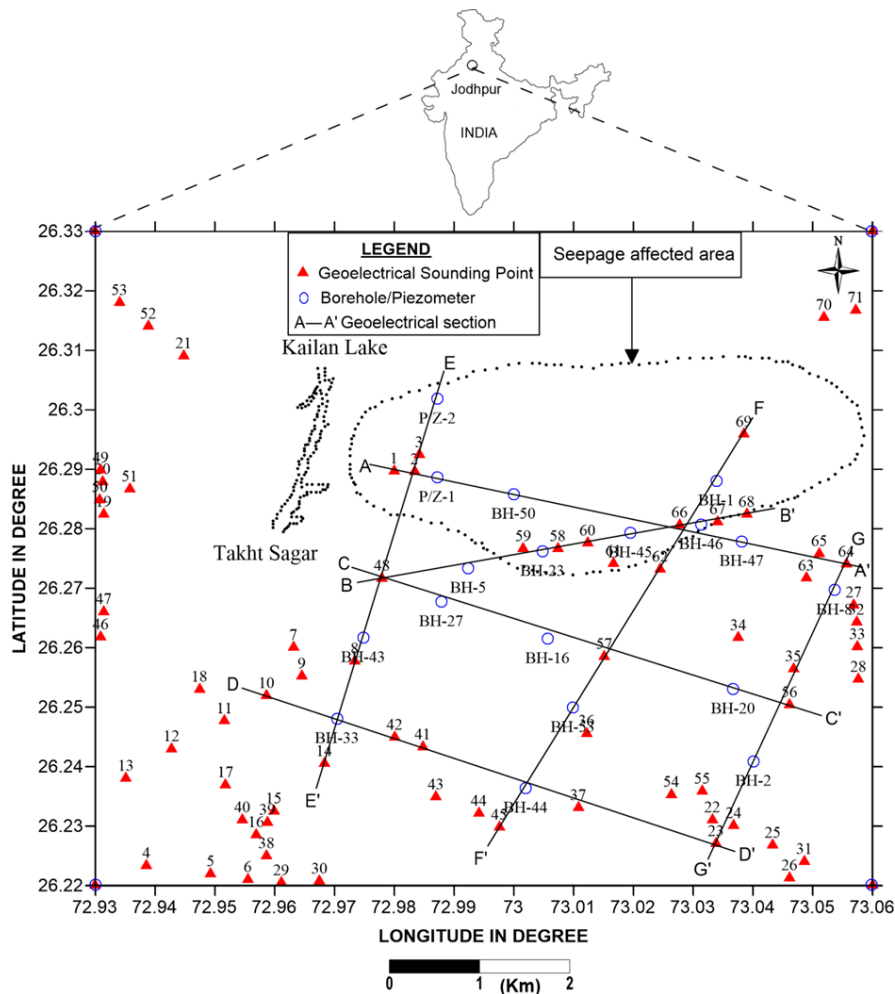


Figure 2. Study area showing geoelectrical sounding measurement.

4. Results and discussion

4-1. Lineament Map

A lineament is defined as a regional large-scale linear or curvilinear feature, pattern or changes in pattern that can be identified in a data set and attributed to a geological formation or structure (Qureshi and Hinze, 1989; Himabindu and Ramdass, 2003; Adiri et al., 2017). Lineaments provide the pathways for groundwater movement and are hydrogeologically very important (Sankar et al., 1996).

Based on the interpretation of satellite imagery, a number of lineament sets traversing NNE-SSW have been identified and presented in the Figure 3. Apart from them, large numbers of prominent joints traversing E-W direction and other sets in NW-SE, WNW-ESE and NNW-SSE directions are clearly shown in the Figure 3. The signatures of these lineament sets are not clear from the satellite image in the city area. It is expected that many of these joint sets

continue in the same direction in the city area below the ground surface.

The major lineaments are passing through the Kailana Lake-Takht Sagar and the general trend is in E-W directions. The Kailana Lake-Takht Sagar and other water bodies, hills and ridges are interconnected through the set of these lineaments. Several lineaments that cross in the NW-SE, WNW-ESE and NNW-SSE directions are shown in Figure 3. As a result, these lineaments have an impact on water flow and provide seepage zones.

4-2. Relief Map

Relief and hypsometry (frequency distribution of elevations) data are analysed and delineate the maximum relief (390 m) that occurs near the Kailana Lake-Takht Sagar and structural hills (in purple) shown in relief on the map (Figure 4). The study area is highly undulating in nature. High relief areas are characterised by the rhyolite hills near Kailana Lake-Takht Sagar, while low relief areas are covered by

quaternary deposits in the city. The relief map shows that elevations drop approximately 30 m in the water seepage area (a problematic area) in comparison to the Kailana Lake-Takht Sagar area. A gradual decline in the elevation from upstream to downstream is seen in the south and north-east directions on the relief map. The variations in the elevation are between 390 m and 107 m in the study area.

4-3. Geoelectrical Sounding (GS)

The studies of the geo-electrical sounding curves used both quantitative and qualitative methods. The interpreted geoelectrical sounding results are shown in Table 1. The VES curve obtained in the study area showed H, HA, HK, KH, QH and HKH types. The

interpreted VES results revealed three to five subsurface geo-electric layers delineated as surface soil, dry sand and kankar, shale, sandstone, fractured rhyolite, and compact rhyolite basement. The surface soils have apparent resistivity, which ranged from 23 to 780 ohm-m and depth ranges from 1.0 to 7.0 m, showing that they were made up of wind-blown sandy soil mixed with sand. Due to the various soil characteristics and varying levels of dryness and moisture, the surface soil resistivity values vary from place to place. Due to the high sand content of the surface soil, which acts as a transmission medium for groundwater flow, and the presence of weathered and fractured formations, which influence groundwater circulation in the study area.

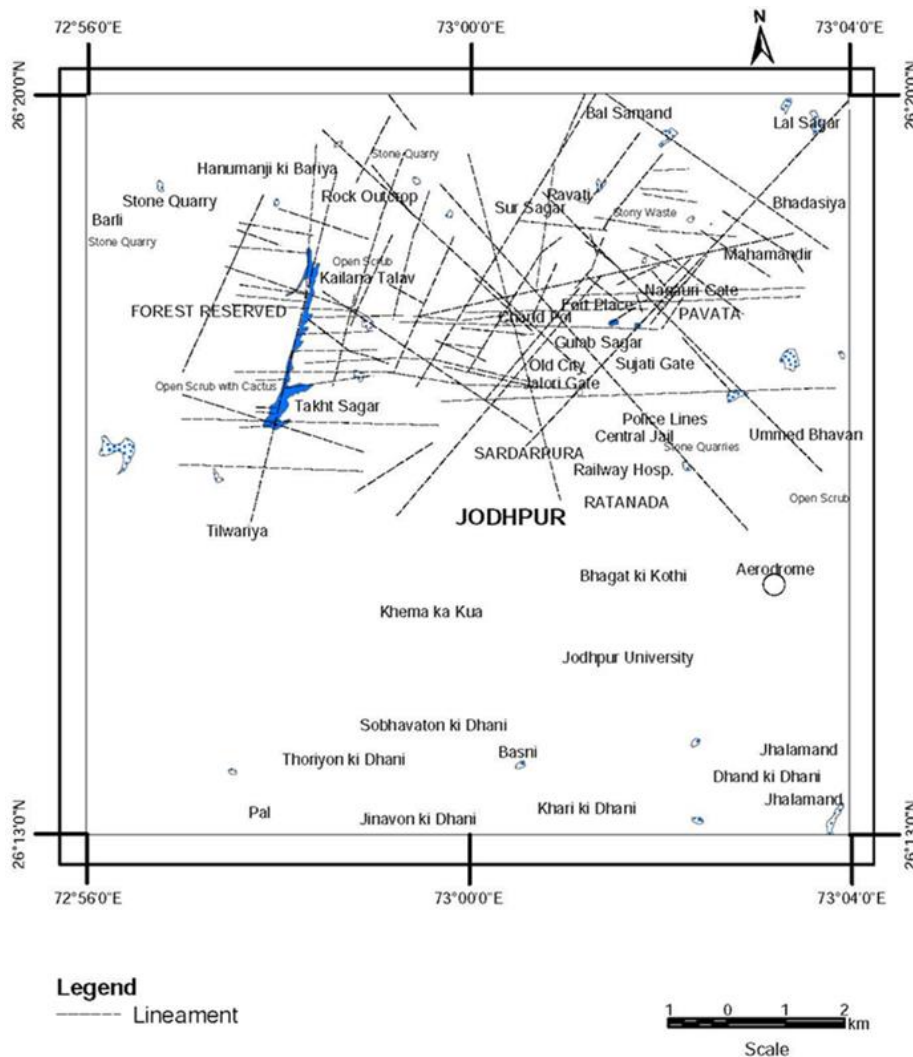


Figure 3. Lineament map inferred from ETM satellite image, showing the existence of lineaments and their interconnectivity.

Table 1. Interpreted results of geoelectrical soundings in terms of thickness and resistivity.

Sounding No.	Layer 1		Layer 2			Layer 3			Layer 4		Layer 5		
	ρ_1 (Ω -m)	h_1 (m)	ρ_2 (Ω -m)	h_2 (m)	ρ_3 (Ω -m)	h_3 (m)	ρ_4 (Ω -m)	h_4 (m)	ρ_5 (Ω -m)	h_5 (m)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)			
1		378	3.8	248	7.8	50	50.0	∞	-	-	-		
2		395	2.5	203	43.7	110	33.0	∞	-	-	-		
3		409	1.0	220	36.6	125	29.0	∞	-	-	-		
4		86	1.0	129	14.0	26	61.5	1160	-	-	-		
5		200	1.3	250	4.6	46	17.4	28	-	-	-		
6		120	1.2	180	4.8	17	34.0	85	-	-	-		
7		110	1.9	220	1.8	70	11.8	14	28.9	∞	-		
8		115	1.7	173	3.3	48	23.0	10	28.0	301	-		
9		130	1.0	20	6.0	18	66.0	190	-	-	-		
10		780	1.5	90	21.0	15	44.0	450	-	-	-		
11		90	1.6	180	17.6	26	100.0	600	-	-	-		
12		520	2.0	208	13.6	21	75.0	960	-	-	-		
13		140	3.0	210	12.0	14	35.2	200	-	-	-		
14		370	2.3	111	28.0	29	38.0	250	-	-	-		
15		56	3.0	120	6.6	46	60.9	11	26.5	50	-		
16		150	1.6	225	6.7	44	42.0	182	-	-	-		
17		120	2.2	185	6.6	34	72.0	170	-	-	-		
18		95	1.7	190	15.6	27	60.0	∞	-	-	-		
19		130	1.8	41	10.8	24	18.0	72	-	-	-		
20		170	1.2	110	14.4	680	-	-	-	-	-		
21		300	2.0	450	8.0	15	10.0	300	-	-	-		
22		125	1.6	36	12.3	25	19.0	85	-	-	-		
23		76	2.1	112	4.4	17	36.0	∞	-	-	-		
24		100	1.6	67	5.8	8	52.0	∞	-	-	-		
25		60	2.0	18	5.4	6	40.0	23	-	-	-		
26		160	2.0	104	8.2	11	46.0	47	-	-	-		
27		62	1.6	42	25.6	11	-	-	-	-	-		
28		23	1.2	12	9.6	23	-	-	-	-	-		
29		84	1.4	299	4.2	60	9.7	24	87.0	98	-		
30		52	2.1	130	11.3	22	98.0	88	-	-	-		
31		103	5.1	18	106.5	77	-	-	-	-	-		
32		170	1.4	68	6.1	91	26.2	14	63.8	9	-		
33		172	1.3	215	2.3	63	14.4	10	-	-	-		
34		45	2.0	157	7.2	18	71.1	300	-	-	-		
35		31	1.6	103	3.6	14	20.0	∞	-	-	-		
36		120	2.0	40	8.0	10	50.8	1200	-	-	-		
37		298	3.5	123	9.6	14	38.4	∞	-	-	-		
38		55	1.0	165	8.0	30	20.0	150	-	-	-		
39		36	1.8	108	12.8	31	87.5	102	31.5	156	-		
40		50	1.4	150	7.0	36	5.0	13	42.0	192	-		
41		54	1.3	162	3.9	60	22.5	21	56.5	330	-		
42		275	2.4	54	19.8	16	50.0	288	-	-	-		
43		103	4.5	68	9.0	38	6.0	19	58.0	344	-		
44		54	7.0	36	14.0	14	42.0	126	-	-	-		
45		40	2.0	120	4.0	34	18.0	12	48.0	∞	-		
46		90	6.8	36	20.4	96	2.7	47	26.4	4202	-		
47		280	3.2	93	9.6	34	36.0	1050	-	-	-		
48		110	3.0	106	2.0	140	7.9	125	20.0	500	-		
49		400	5.4	80	42.0	240	-	-	-	-	-		
50		340	1.1	113	4.4	65	5.2	126	-	-	-		
51		100	3.0	67	6.0	117	4.3	60	16.0	180	-		
52		134	3.1	5	5.9	237	-	-	-	-	-		
53		122	1.6	13	19.0	763	-	-	-	-	-		
54		62	1.0	93	4.0	30	11.0	15	56.0	31	-		
55		74	1.0	111	2.0	33	16.4	13	62.0	38	-		
56		130	1.0	260	2.0	70	5.2	26	20.0	180	-		
57		180	1.7	90	10.2	26	40.0	250	-	-	-		
58		170	2.0	85	26.0	24	54.0	210	-	-	-		
59		150	3.6	75	40.0	190	-	-	-	-	-		
60		40	2.0	20	6.0	13	48.0	∞	-	-	-		
61		48	1.4	72	11.2	7	72.0	660	-	-	-		
62		42	1.5	68	10.9	12	34.0	37	26.0	∞	-		
63		30	1.4	3	8.4	11	84.0	38	-	-	-		
64		50	1.8	70	6.5	14	21.9	∞	-	-	-		
65		85	1.2	38	4.4	57	10.5	28	42.0	127	-		
66		50	1.8	63	14.0	25	38.0	∞	-	-	-		
67		421	3.0	96	16.0	21	24.0	150	-	-	-		
68		140	4.0	120	12.0	20	46.0	∞	-	-	-		
69		140	2.0	93	32.0	10	3.6	∞	-	-	-		
70		200	1.4	20	22.4	400	-	-	-	-	-		
71		160	1.0	380	4.0	22	150.0	990	∞	-	-		

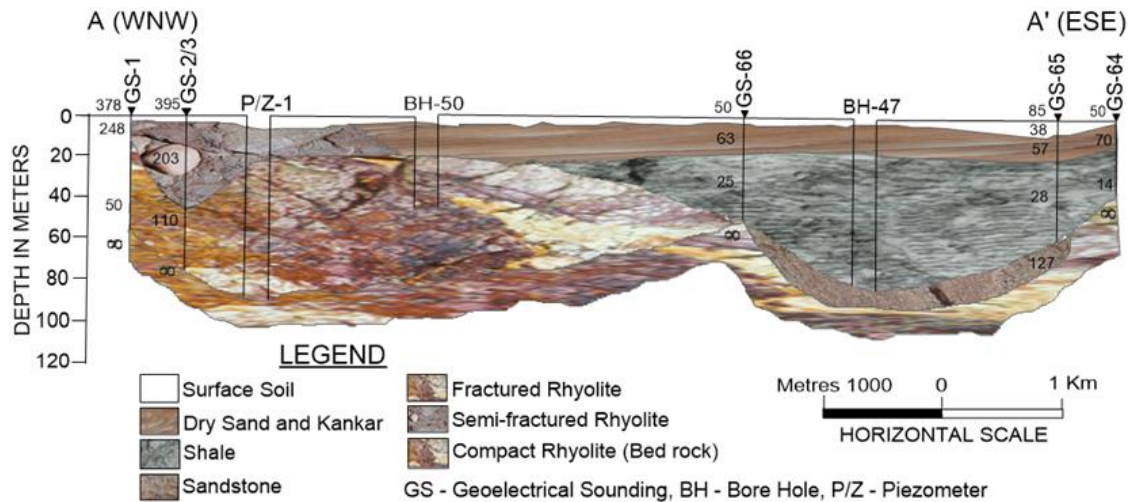


Figure 5. Subsurface geoelectrical cross section along profile A-A'.

4-5. Subsurface geoelectrical cross-section along profile B-B'

The subsurface geoelectrical section shown in Figure 6 was created using the data from the existing boreholes BH-5, BH-23, BH-45 and BH-46 as well as the results of GS-48, GS-59, GS-58, GS-66, GS-67 and GS-68. This cross-section also passes through the seepage zone and is oriented WSW-ENE. The resistivity of the surface soil ranged from 42-170 ohm-m and the thickness from 1-4 m. The variations in the resistivity values of the surface soil are due to the different compositions of the soil. The second geoelectrical layer is characterised by resistivity values from 63 to 160 ohm-m and a thickness of 3 to 40 m. It consists mainly of sand and kankar due to its thick sandy contents, which serve as the permeable

medium for groundwater seepage. The third geo-electrical layer consists of a mixed formation of fractured rhyolite encountered at GS-48, GS-59, GS-58, BH-5 and BH-23 on the westerly side, having resistivity 40-210 ohm-m and thickness 10-30 m, which supports the groundwater seepage. The GS-59, GS-58, GS-66, GS-67 and GS-68 revealed the shale formation has resistivity ranges of 20-24 ohm-m with varying thickness. An isolated patch of semi-fractured and sandstone was encountered at GS-48 and GS-67. The compact rhyolite basement at a depth beyond 80 m exists. There is a possibility that the groundwater will leak from the western side of the section upper part because it is composed of sandy, fractured and semi-fractured rhyolite formations.

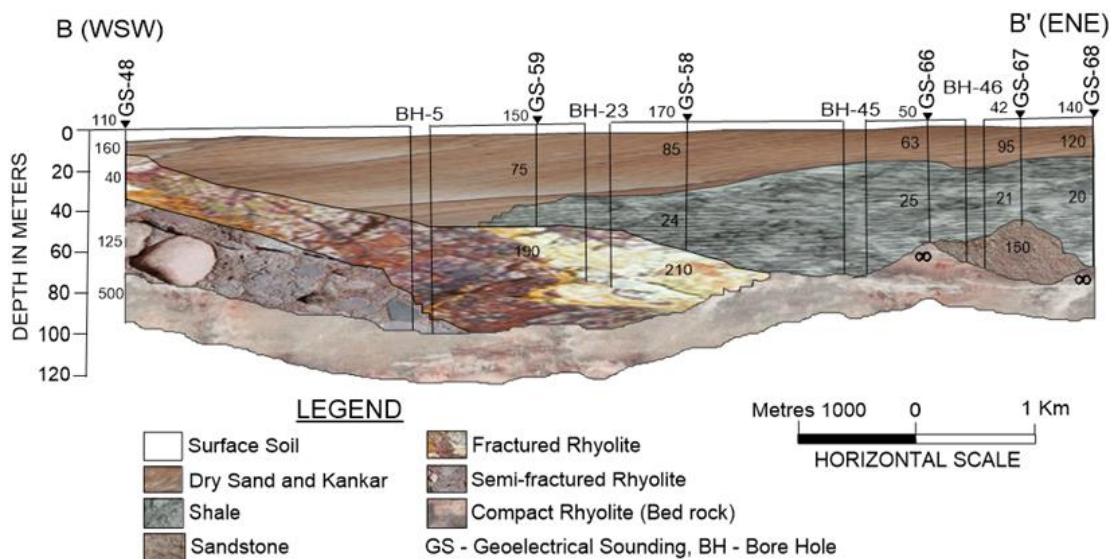


Figure 6. Subsurface geoelectrical cross-section along profile B-B'.

4-6. Subsurface geoelectrical cross-section along profile E-E'

The results of quantitative interpretation of four geoelectrical soundings (GS-2/3, GS-48, GS-8 and GS-14) were correlated with records of existing piezometers and boreholes (P/Z-2, BH-43 and BH-33) to prepare this section. Figure 7 shows the resistivity values of the various formations observed in the study area, as well as their thickness and depth from the top surface. This cross-section has a length of 7.4 km and is oriented in the NNE-SSW direction. There are four layers of stratification visible across the geo-electric cross-section. The section depicts the first layer, which is made up of surface soil with resistivity values ranging from 110 to 395 ohm-m and a thickness of 1 to 5 m. The second layer is composed of semi-fractured rhyolite with a resistivity of 203 ohm-m on the northern side and a sandy layer with varying resistivity values of 40 to 111 ohm-m on the southern side. The thickness of the second layer varies from 4 to 20 m. The third geo-electrical layer in this series is made up of fractured rhyolite on the northern side with a resistivity of 110–125 ohm-m and a thick layer of shale between BH-43 and GS-14 on the southern side with a resistivity of 10–29 ohm-m. Near the middle of the passage, both formations are squeezed out. The lingering presence of a semi-fractured zone and bedrock on the section's northern side are represented by the final layer. This semi-

fractured zone may contribute to the groundwater seepage.

4-7. Subsurface geoelectrical cross-section along profile F-F'

The section also covers a major part of the seepage region. The cross-section runs in the NE-SW direction and incorporates the results of GS-69, GS-66, GS-62, GS-57 and GS-45. Figure 8 was correlated with the lithological formation records of existing boreholes BH-1, BH-53 and BH-44. This cross-section consists of five geo-electrical layers and covers 8.8 km in length. The section displays the surface soil top layer with resistivity values of 40 to 180 ohm-m and a thickness of 1 to 6 m. The second layer is made up of dry sand and kankar with different thicknesses of 8 to 32 m, and its resistivity ranges from 34 to 93 ohm-m. Except for the central area, where sandstone of resistivity 26 ohm-m and on the northern and southern sides shale with resistivity values 10-12 ohm-m are present throughout this section. This stratum has a thickness range of 2 to 20 m. The isolated patch of semi-fractured rhyolite with a resistivity of 150 ohm-m is present at GS-57 in the middle of the cross section. The last geo-electrical layer is composed of compact rhyolite on the northern side and granite on the southern side of the section. The presence of sedimentary formations of sand, sandstone and a patch of semi-fractured rhyolite supports the groundwater seepage.

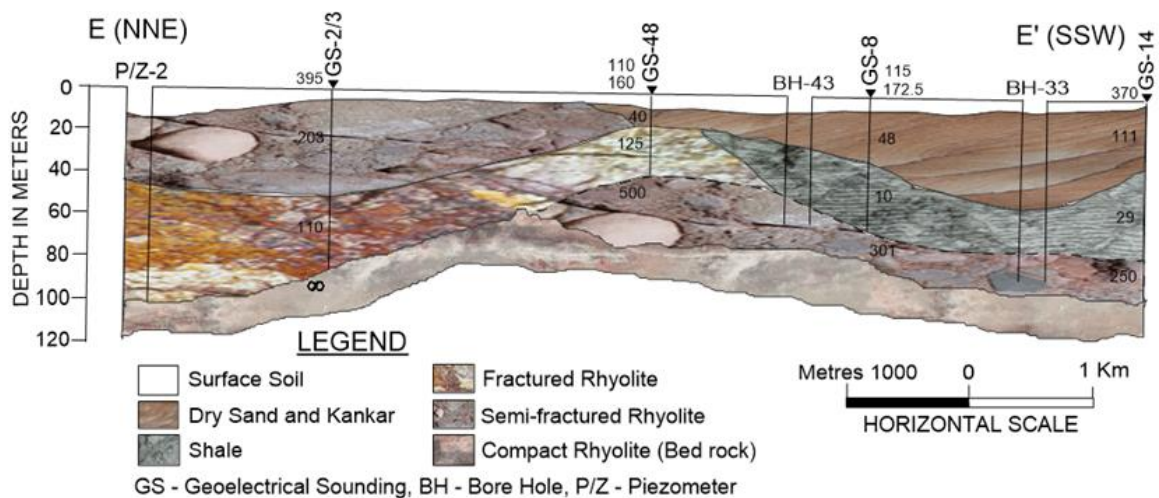


Figure 7. Subsurface geo-electrical cross-section along profile E-E'.

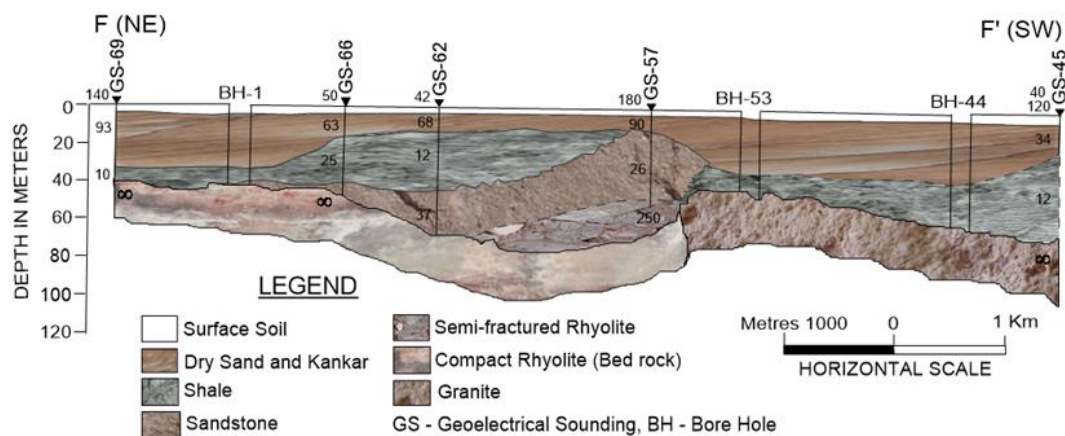


Figure 8. Subsurface geoelectrical cross-section along profile F-F'.

5. Conclusions

In this study, geo-electrical resistivity techniques were combined with a rapid, cost-effective remote sensing methodology to map structural features, faults and fracture zones that are favourable to water seepage. The interpretation of the satellite imagery reveals a number of minor and major lineament sets have been mapped and traversed in E-W, NW-SE, WNW-ESE, and NNW-SSE directions. The majority of the lineaments are interconnected and pass through Kailana Lake-Takht Sagar. These lineaments provide easy conduits for the water seepage in the area. The elevation drops throughout the study area play a crucial role in enhancing the water seepage. The geo-electrical cross-section delineates sandy, semi-fractured and fractured formations from the upper layer to greater depths in the region. Semi-fractured formations are frequently found immediately beneath the top soil layer, which penetrates down to a greater depth. In the study region, the interconnection of several major lineament sets and fractured zones through Kailana Lake-Takht Sagar was exposed to be a significant contributor to water seepage, according to the analysis of integrated data.

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