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Geophysical and hydrochemical studies for sustainable development of groundwater resources in northwestern part of Telangana State, India

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Studies have been carried out to assess groundwater potential using geophysical analysis and water quality indices in parts of Nyalkal and Zaheerabad Mandal, Medak District, Telangana State. As a part of the study, 50 groundwater samples were collected and 103 Vertical Electrical Soundings (VES) had been carried out. The water quality was assessed with respect to various major ion chemistry and trace elements. It is found that major ions and trace elements are within the permissible limits, except Al, Pb, and Zn metals, which slightly exceeded beyond permissible limits. However, the results of VES reveal that in some parts of the study area, the resistivity range for topsoil (26.61–930 Ωm), lateritic zone (453–738 Ωm), clayey/sandy clay layer (4.71–94.2 Ωm), weathered/fractured bedrock (60.5–928 Ωm) and weathered/vesicular/massive basalt (8.05–676 Ωm) are found with the formation of thick overburden and fractured basement. It is also found that the groundwater prospects are moderate to high depending on the extent of the weathering zone.

Keywords. Groundwater quality; geophysical; sustainability.

1. Introduction

Sustainability of groundwater becomes a challenging environmental and social issue in the Indian scenario. Whereas, in the past, the management of groundwater resources was based predominantly on the concept of available renewable resources. Today it is necessary to protect groundwater to balance the obstacles and maintain groundwater sustainability to meet the human and environmental needs. Groundwater assessments involve multiple approaches based on the type of interpretation leading to management strategies. Understanding of qualitative and quantitative variation in the groundwater system because of existing and proposed hydrologic significance is a base for their proper management. Tainting of the groundwater by residential, industrial effluents and agrarian movement is a significant issue in developing nations. The conventional techniques (histograms, trilinear, semi-logarithmic) manage a set of factors accountable for groundwater quality (Matthees 1982; Hem *et al.* 1989; Vishnu *et al.* 2014), the constraining values (action limits) for tainted soil might be lower than natural concentrations (backgrounds) over wide regions (Salminen and Tarvainen 1997; Sakram *et al.* 2015).

Hydrochemical assessment of groundwater frameworks is generally found in accessibility of data pertaining to groundwater quality (Aghazadeh and Mogaddam 2010; Sakram *et al.* 2018; Sreedhar *et al.* 2018a), relies upon physical and substance dissolvable elements because of disintegration from rocks and manmade wastes bringing about a complex groundwater quality, it is unequivocally subject to bedrock, lithology and atmosphere. However, may likewise be affected in parts by contamination, especially from farming and mechanical sources. The most significant farming contaminations are abundant utilization of composts and pesticides; however, it is perceived that manure and pesticide applications are not as concentrated as in numerous western countries. Phosphate and potassium fertilizers are likewise utilized, however, versatility of these in the soil is considerably less than that of nitrate. Another effect of contamination is probably going to be a high concentration of total dissolved solids (TDS).

Overall, groundwater quality relies upon the extent of precipitation and water recharge, association between the rock and water, in a spread of time result with aquifer system (Appelo and Postma 2005; Vishnu *et al.* 2014; Narsimha and Sudarshan 2016). The significance of the quality of water in individuals has sporadically pulled in a lot of intrigue. In fast-growing nations like India, roughly 80% of all maladies are understood to be identified with the consumption of poor water quality and unhygienic surroundings (Olajire and Imeokparia 2001). The over-abstraction of subsurface water had numerous impacts on all water resources. Groundwater sources are exhausting continuously in several zones with an irregularity among recharge and discharge. This has come into an intense water deficiency with groundwater as the main option. Inadequacy and dependableness in groundwater in the region related to considerable change in groundwater chemistry and quantity.

Geophysical studies are important to portray sub-surface of the earth basically to outline water-bearing locations and help in locating groundwater zones of recharge and discharge. A wide scope of geophysical study systems includes electric, electromagnetic, gravity, magnetics, ground penetrating radar (GPR), and seismic strategies are accessible for examination of sub-surface topography. The decision of the geophysical technique depends on physical property differentiate and logistic support in the region. Electrical and seismic strategies are broadly utilized for groundwater applications. The simplicity of activity and practical utilization of electrical resistivity technique has turned out to be prominent for groundwater investigation particularly in India. The direct current (DC) electrical resistivity system has been broadly used to picture geoelectric structure of shallow subsurface earth (Zohdy *et al.* 1974; Parasnis 1986; Giao *et al.* 2003; Kumar *et al.* 2007; Dhakate *et al.* 2008, 2012). Electrical profiling (EP) method was used to study horizontal impacts of varieties in the sub-surface (Giao *et al.* 2003). A resistivity model got from the reversal of 1-D information brings about poor goals particularly for maximum depth limits and give point vertical data. Then again two-dimensional electrical resistivity tomography (2D-ERT) method has the point of interest over traditional resistivity and contemplated by numerous researchers (Batayneh 2001; Daily *et al.* 2004; Adepelumi *et al.* 2006; Kumar *et al.* 2010; Robert *et al.* 2011). One of the chief preferences of the multi-terminal resistivity tomography method bears an unmistakable perspective on geoelectrical changes inside regolith which promptly identify porosity and permeability in vertical profile through regolith in crystalline rocks (Owen *et al.* 2005). Low-recurrence electrical techniques for subsurface portrayal and checking in hydrogeology is clarified in ongoing study and exhibit subsurface portrayal and groundwater stream (Revil *et al.* 2012; Abdulaziz *et al.* 2012).

The aim of the study is to survey degrees of water quality as for normal centralizations of elements in the region, to study the relationship between contaminated components and their spatial occurrence as well as to distinguish potential pollution zones. The subsequent target is to recognize groundwater potential utilizing geophysical procedures in the region.

2. Location of the study area

The study area lies in the south-western part of Telangana State, 100 km away from Hyderabad City, comprising of 23 villages falling in Nyalkal and Zaheerabad Mandals located between latitude 17°45′–17°50′N and longitude 77°30′–77°40′E falling in toposheet number 56 G/9 and 56 G/10. The topographic elevation of the study area ranges from 553 to 665 m above mean sea level (amsl) (figure 1).

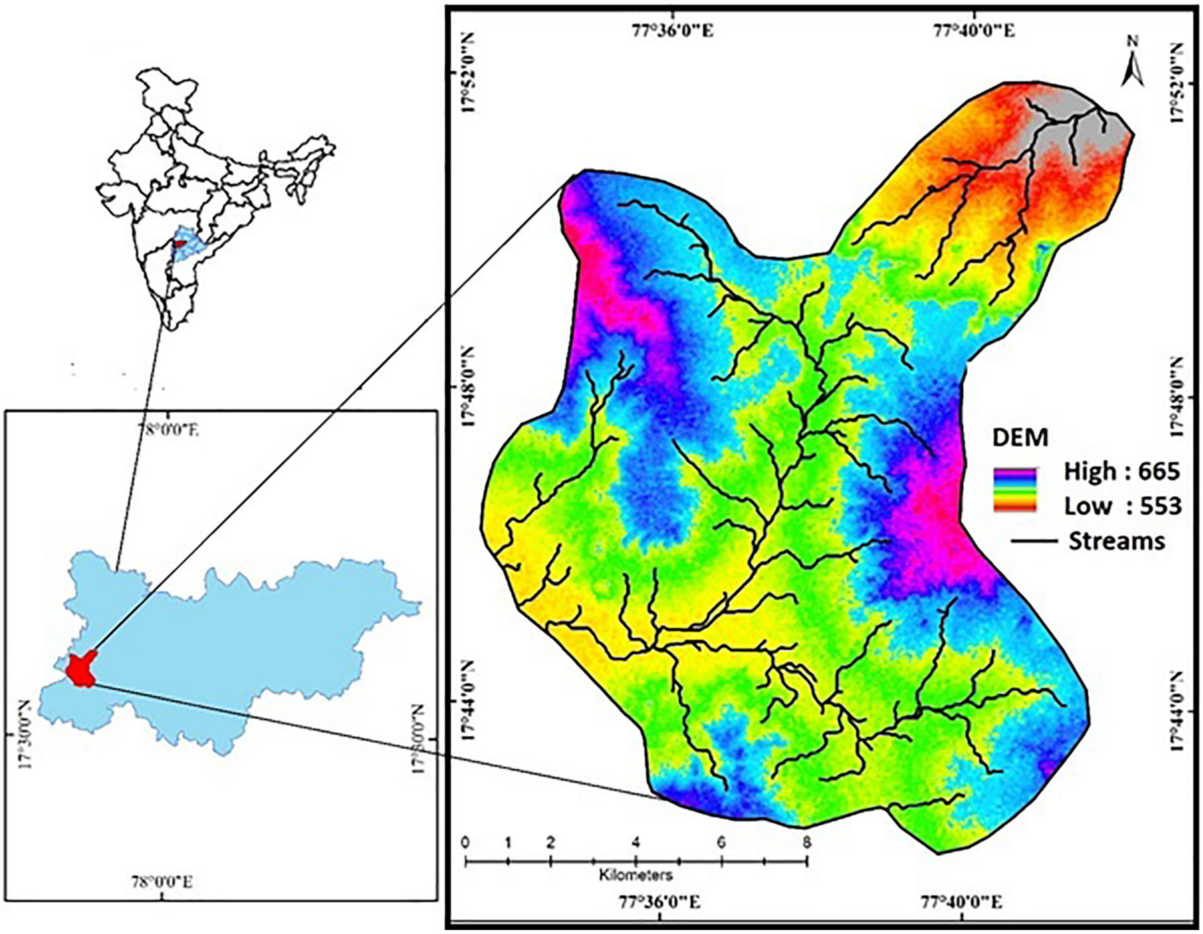

Figure 1. Key map of the study area showing drainage pattern and topographic elevation.

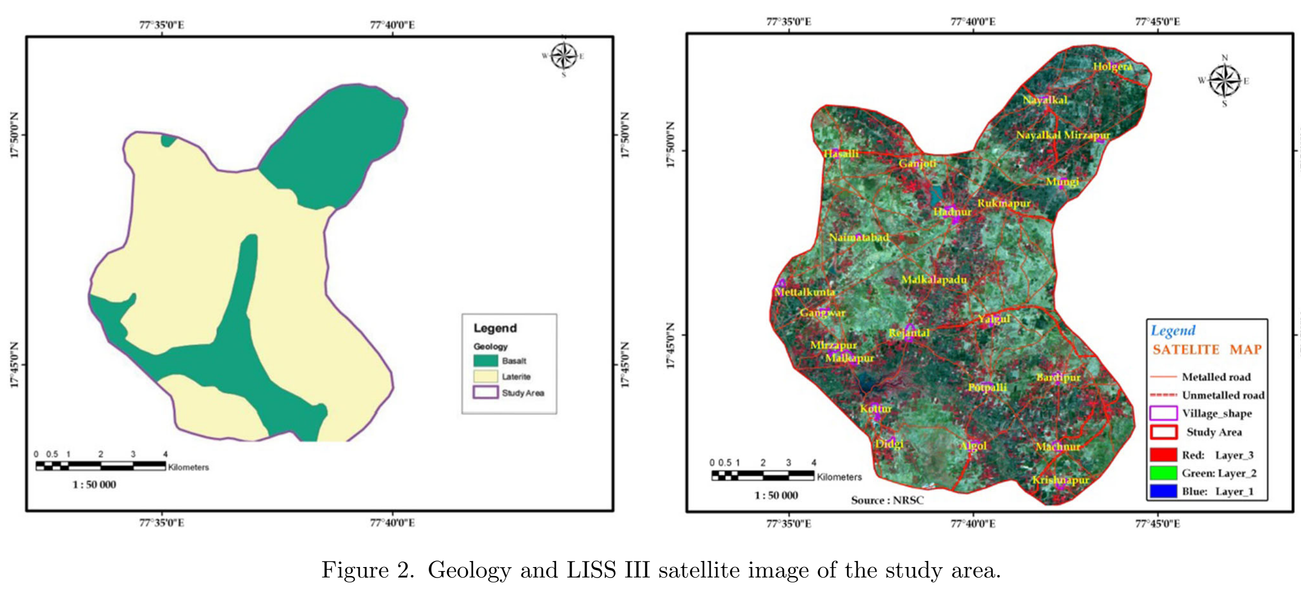

Figure 2. Geology and LISS III satellite image of the study area.

3. Geology and hydrology of the study area

Geologically the region comprises of traps and laterites. These rocks are hard-massive to foliated (resembles the skin of elephant endured) and very much jointed. The soil in the region observed fine black alluvium and reddish to brown in shading. The soil is porous and permeability high with respect to downpour, which can cause extensive surface stream and disintegration. Traps occurring

Table 1. *Statistical summary of groundwater sample for major ions and comparison with WHO (2004) standards.*

Sl. no.	Parameters	Min (mg/l)	Max (mg/l)	Average (mg/l)	WHO (2004) standards (mg/l)	Exceeding permissible limits	Within permissible limits
1	pH	6.67	8.9	7.48	6.6–8.5	2%	98%
2	EC	86.91	900.16	255.05	–	–	
3	TDS	55.62	576.1	163.23	500	2%	98%
4	TH	20	265	126.60	< 200	8%	92%
5	Na^{2+}	0.13	2.63	0.91	250	–	100%
6	K^{+}	4	64	8.04	10	2%	98%
7	Ca^{2+}	6	59	27.36	100	–	100%
8	Mg^{2+}	1	45	14.74	50	–	100%
9	CO_3^{2-}	9	108	22.19	10	76%	24%
10	HCO_3^{-}	109.8	732	278.44	500	2%	98%
11	Cl^{-}	46	461	136.57	200	16%	84%
12	SO_4^{2-}	1	132	16.43	200	–	100%
13	NO_3^{-}	5	32	14.15	50	–	100%
14	F^{-}	0.13	2.63	0.87	1.5	2%	98%

Table 2. *Statistical summary of groundwater sample for trace elements and comparison with WHO (2011) standards.*

Parameters	Min	Max	Mean	Std. dev.	WHO (2011) (μg/L)	No. of samples	Samples exceeding permissible limits (%)
Al	30.16	386.98	105.5	74.51	100–200	17	34
As	0.47	3.78	0.95	0.58	10	nil	nil
B	105.86	1359.7	253.61	170.16	2400	nil	nil
Ba	0.06	53.93	12.09	7.95	700	nil	nil
Co	0.18	2.38	0.44	0.34	–	–	–
Cr	5.2	61.6	11.61	8.47	50	1	2
Cu	4.76	93.15	19.32	12.96	2000	nil	nil
Fe	66.44	520.45	134.94	66.48	300–1000	nil	nil
Li	0.68	10.73	1.78	1.50	–	–	–
Mn	3.12	119	16.14	18.77	–	–	–
Ni	5.72	258.97	27.86	39.87	70	2	4
Pb	5.11	50.22	13.48	9.58	10	26	52
Se	4.52	34.85	7.92	4.66	40	nil	
Sr	0.9	788.13	206.89	171.84	–	–	–
Zn	18.74	427.05	91.28	78.14	50	32	64

within the region of Nyalkal show vesicular and non-vesicular structures. The top-soil spread is a fine-created leftover soil of traps and laterites. The non-vesicular huge units are alluvium of fine-grained, thick and conservative. Certain spots show columnar and spheroidal structures and normally show fine-created joints within different regions. The vesicular kind of basalts is exceptionally altered which offered to ascend to laterite. In the region, around 9 flows of traps observed, initial seven flows not endured and show up as basaltic nature, though eighth and ninth flows totally endured and modified to laterite. Accordingly, laterite occurs as a top-cover over basalts as flatlands around 600–660 m (amsl). They have open spaces regularly loaded up with yellow-red clay material. A portion of lithomarge denotes separation between traps and laterite. The lithomarge appears silica in nature and displays dark colour to green shading with lathery touch and difficult to break and also called as ‘SapaMurram’ in local terminology.

Hydrogeological, aquifers of the region are covered by traps, laterites and alluvial deposits. The traps include a sequence of volcanic rock flows (nearly horizontal in nature) separated by intratrappean beds, wherever every flow contains 40–70% of large volcanic rock within lower zones and 30–60% vesicular basalt in upper zones (Madhnure 2001; Sakram *et al.* 2019). The weathered thickness was found between depths of 6 and 29 m, and joints and fractures depth reduce within granitic environment. Sediment deposits occur on the Godavari stream courses with 12–30 m thickness, comprising clay, silt and gravels and occasionally cobbles that bear productive aquifers (Madhnure 2001; Sakram *et al.* 2019). In the present study, geological mapping was done using IRS-1C, LISS-III image, using image processing software ERDAS for better exposition of hydrogeological features. GIS package ARC-GIS (ARC-Map) was used for mapping features. Basalts exhibit a greenish tone with a coarse texture and laterite show yellow tone (figure 2).

4. Materials and methods

4.1 *Hydro-geochemical investigation*

Fifty groundwater samples were gathered from bore wells of the study region in non-reused Polyethylene bottles (2 L). The temperature, electrical

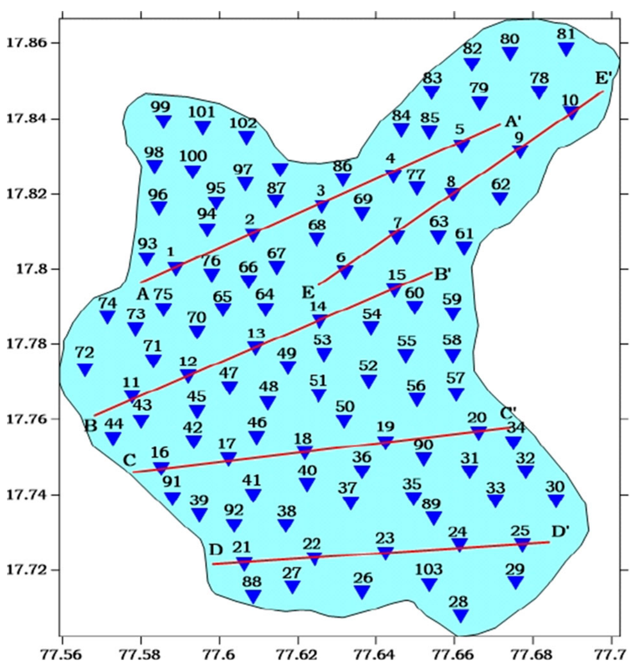

Figure 3. Profiles along with the vertical electrical soundings conducted in the study area.

conductivity, and pH were resolved infield because of their unstable nature with separate meters. Total hardness (TH) as $CaCO_3^{2-}$ and calcium (Ca^{2+}) were examined titrimetrically, utilizing standard EDTA. Magnesium (Mg^{2+}) was figured, taking contrast among TH and Ca^{2+} values. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{2-}) were evaluated by titrating with $H_2SO_4^-$ Sodium (Na^+), and Potassium (K^+) was estimated by a flame photometer (Model-Mediflame 127). Chloride (Cl^-) was assessed by standard $AgNO_3^-$ titration. Sulphate (SO_4^-) was estimated by spectrophotometer (Model-Spectronic 21). Nitrate (NO_3^{2-}) and fluoride (F^-) were measured utilizing ion particular cathodes (Model-Orion 4 star). Total dissolved solids (TDS) were determined from specific conductance (EC) utilizing empirical formula (Richards 1954). The statistical summary of analyzed groundwater samples for major ions and trace elements is given in tables 1 and 2.

4.2 *Geophysical investigation*

Geophysical information incredibly helps in finding the groundwater potential in any hydrogeological arrangement. The property and thickness of overburden acquired from geophysical overview at the area can yield a groundwater potential model of higher reliability quality and exactness. However, variations in electrical resistivity of different segments litho units in a geologic arrangement rely upon numerous components including type of rocks and soils, penetrability, degree of satiety and nature of the saturating fluid and digenetic cementation factors. Wenner technique was utilized to recognize groundwater potential points, where four electrodes are set in a line, and a realized flow is gone through two extreme electrodes, the potential contrast estimated between two inward terminals gives a proportion of the resistivity of the ground. The estimation of resistivity 'ρ' is estimated by the formula:

$$\rho = (V/I) \times 2\pi a \quad (\text{in } \Omega\text{m}),$$

where V is voltage (potential) measured in millivolts between two inner electrodes, and I is current measured in milliamperes passed into ground, a is the distance between consecutive electrodes and 2π is constant. Since $V/I = R$, resistance (in Ωm), the formula may be expressed as:

Table 3. *Interpreted results of VES carried out in the study area (ρ is resistivity in Ωm, h is layer thickness in m).*

VES no.	Longitude	Latitude	ρ_1	h_1	ρ_2	h_2	ρ_3	h_3	ρ_4
1	77.58844	17.80064	26.6	2.06	4106	4.33	117523		
2	77.60848	17.81012	45.1	2	88.8	1.03	1739		
3	77.62663	17.81716	34	2.06	4741	4.33	95230		
4	77.64478	17.82583	15.5	2.16	1529	16.1	9.15		
5	77.66157	17.83396	8.05	2.08	453	33.8	1593		
6	77.63123	17.80064	52.1	2	534	11.7	4079		
7	77.64649	17.81175	57.9	12.9	65.5	1.27	1618		
8	77.65941	17.82069	36.6	3.85	12.6	5.31	12494		
9	77.67647	17.83233	9.97	2.01	87551	112	1783		
10	77.69001	17.84208	214	2	108	21.8	4610		
11	77.5776	17.76651	11.2	2	348	26.1	4149		
12	77.59196	17.7722	86.4	3.81	44.1	5.23	6156	25	94.2
13	77.60875	17.78005	64.7	2	22.9	20.1	14999		
14	77.62555	17.7871	31.2	18.4	19.2	12.3	11728		
15	77.64451	17.79468	58.7	4	36	9.67	22084		
16	77.58519	17.74755	51.1	13.5	60.6	1.37	21628		
17	77.60198	17.75053	930	10.8	133	8.62	1244		
18	77.62148	17.75815	676	20.3	336	41.9	135901		
19	77.64261	17.75432	186	6.31	928	2.65	862		
20	77.66645	17.75649	79.6	6	4458	14.3	85809		
21	77.60607	17.72196	266	69.3	25319				
22	77.62423	17.72395	253	7.97	71.3	52.3	6343		
23	77.64263	17.72494	547	8	93.6	60	15587		
24	77.66154	17.72743	157	2.45	39.9	4.04	128	45.3	56991
25	77.67721	17.72718	146	4	199	74.9	20621		
26	77.63758	17.77914	84.6	4.5	28.9	5.19	158		
27	77.61791	17.71654	794	2.1	46.3	4.11	1301		
28	77.66183	17.70802	2620	4	152	55.8	7658		
29	77.67592	17.71753	56.9	2	5328	4.97	157		
30	77.68576	17.7385	39.1	2	67.5	26.3	43726		
31	77.66412	17.7467	29.5	2	110	3.64	26.4		
32	77.67822	17.74571	4269	14.2	329				
33	77.6697	17.73817	179	3.58	42.8	5.26	779		
34	77.67592	17.75423	366	2.41	30.5	4.11	694		
35	77.65003	17.73916	684	2	20.7	1.48	1935		
36	77.63659	17.74637	35.7	2	2269	1.65	185		
37	77.63331	17.73752	504	7.9	82.9	47.8	20116		
38	77.6166	17.73162	109	4	48.5	20.5	506		
39	77.59464	17.73457	138	2.3	33.4	6.54	63.8		
40	77.6225	17.74244	22.9	2	586	3.35	19.5		
41	77.60841	17.74047	20.1	5.15	17.7	0.496	1124		
42	77.59333	17.75423	403	6	207	75.6	24594		
43	77.58022	17.75915	51.6	10.8	243	54.7	28853		
44	77.57334	17.75587	48.9	10.8	322	38.2	11595		
45	77.59366	17.76243	49.4	3.54	72.7	33.2	18863		
46	77.60906	17.75522	61.7	31.7	25844				
47	77.60251	17.76898	102	6	34.5	16	29629		
48	77.61234	17.76505	30.8	6.37	102	47.4	16565		
49	77.61725	17.77423	24	2	576	3.97	39.6	13.9	16528
50	77.63233	17.75981	27.2	2	482	2.88	16	9.34	13220
51	77.62545	17.76735	30.5	2	713	2.96	21.6	10.1	13414
52	77.6379	17.77029	55	2	534	2.8	15.5	9.03	27413
53	77.62676	17.77718	142	4	2518	64.1	687		

Table 3. *(Continued.)*

VES no.	Longitude	Latitude	ρ_1	h_1	ρ_2	h_2	ρ_3	h_3	ρ_4
54	77.63889	17.78504	171	3.25	22.6	5.63	43328		
55	77.64741	17.77783	274	5.2	41.8	16.9	13287		
56	77.65003	17.76636	32.7	2	692	3.73	51.3	11.1	1971
57	77.65986	17.768	15.4	5.3	15.4	0.59	31686		
58	77.65954	17.77783	23.1	4	308	112	9303		
59	77.65954	17.78832	9.89	2	8065	5.95	65.6		
60	77.6497	17.79062	96.7	7.32	36.6	18.5	13032		
61	77.66244	17.80635	16.7	2	444	3.34	23	10.6	11062
62	77.67166	17.81946	11.427	2.06	5091	4.59			
63	77.65593	17.80864	32.4	2	966	110			
64	77.61168	17.78963	67.5	2.69	41.4	6.87			
65	77.60087	17.78966	174	2	22.6	3.23			
66	77.60775	17.7975	222	6.16	23.3	21.2			
67	77.6143	17.8011	120	5.36	38.2	28.1			
68	77.62479	17.80864	10.4	2	151	3.42	9.9	7593	
69	77.63626	17.8152	22.1	2	112	3.72	11.3	15008	
70	77.59431	17.78439	194	6	139	62			
71	77.58317	17.77619	8.15	2	43882	5.55			
72	77.5658	17.77423	364	8	273	70.9			
73	77.57825	17.78504	6.21	2.05	934	4.42			
74	77.57104	17.78832	4.76	2.05	801	4.43			
75	77.58546	17.78963	4.71	2.04	14428	66			
76	77.59759	17.79881	13.8	2	2472	2.15			
77	77.65036	17.82208	11.4	2	413				
78	77.68182	17.84699	12.2	2.08	1477	4.65			
79	77.66642	17.84437	12.1	2	39.5	2.75			
80	77.67396	17.85781	8.26	0.6	32.5	3.58			
81	77.68838	17.85945	43.9	2	850	3.39	10.8	5196	
82	77.66445	17.85486	35.3	2	217	2.7	48.5		
83	77.65396	17.8483	253	4	76.2	12.5	9268		
84	77.64643	17.83781	129	20.5	5878				
85	77.65396	17.83749	145	2	99.8	17.9	20519		
86	77.63135	17.82405	92.1	20.6	36539				
87	77.6143	17.81848	139	4	75.6	7661			
88	77.60841	17.71359	34.1	2	87.9	28292			
89	77.65429	17.73424	63.1	4.07	47.8	8.61	120072		
90	77.58808	17.73916	89.8	20.4	41916				
91	77.58776	17.73916	164	5.44	66.3	12	49985		
92	77.60349	17.7326	191	27.9	77579				
93	77.58153	17.8034	83.4	4	135	12.5	48747		
94	77.59726	17.81094	53.1	6.08	79435				
95	77.59923	17.81848	62.2	6	2184	75.6	81412		
96	77.58415	17.81684	65.5	6	1048	75.6	24267		
97	77.60611	17.82372	2844	6	223	64.7	917		
98	77.5835	17.82732	610	6	158	72.9	28292		
99	77.58579	17.84011	1135	8	155	70.9	34947		
100	77.59267	17.82667	17	2	214	46.3	23102		
101	77.59595	17.83814	173.5	4	164	13.5	6636		
102	77.60644	17.83585	309	33.6	957				
103	77.65364	17.71589	48.8	2	2686	6.67	138	21.2	23089

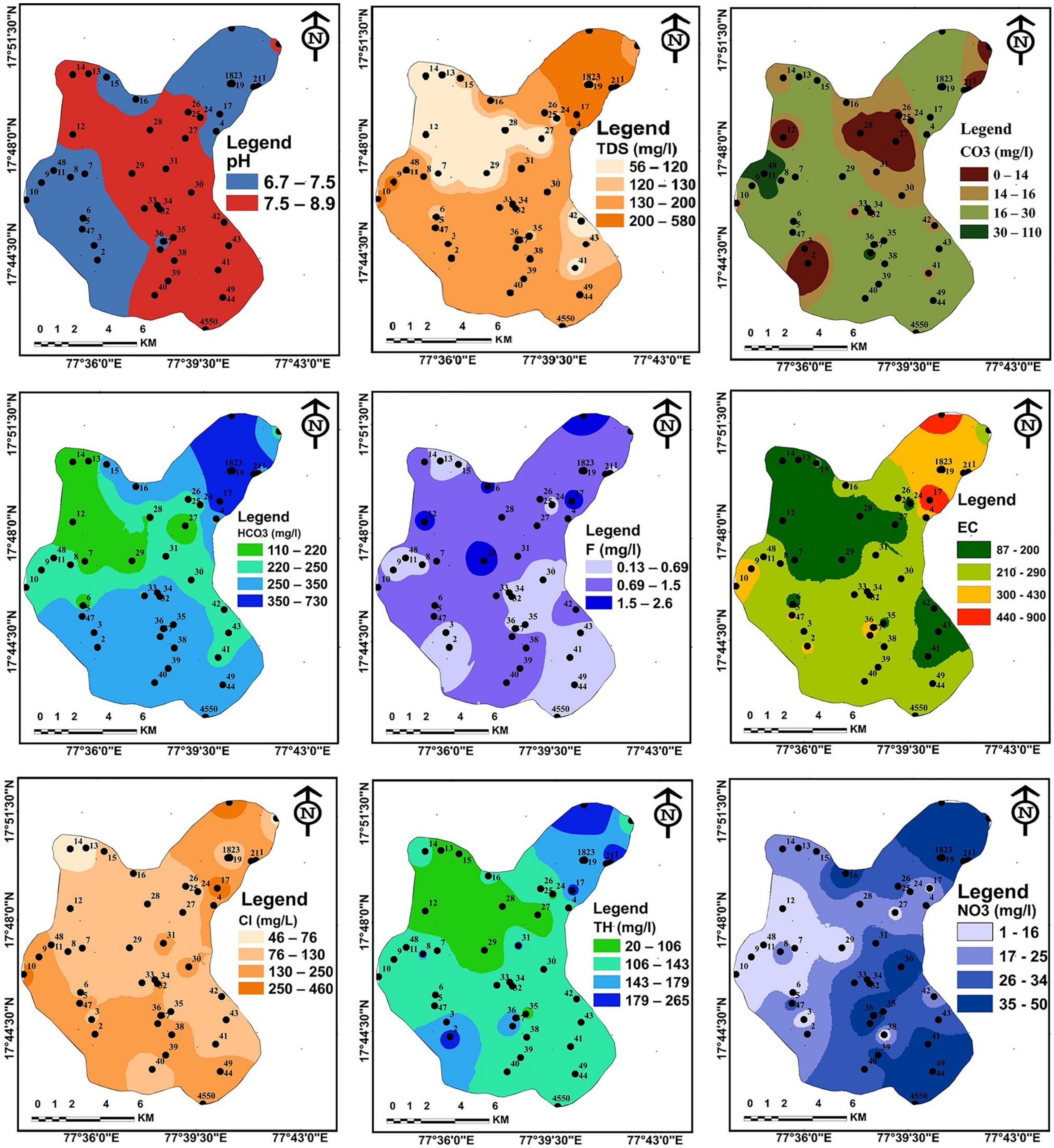

Figure 4. Distribution map of pH, TDS, CO_3^{2-}, HCO_3^{2-}, F^-, EC, Cl^-, TH and NO_3^2 in the study area.

$$\rho = 2\pi a R \ \ (\text{in } \Omega\text{m}).$$

The interpreted layered earth model is deciphered utilizing IPI2 WIN programming, to decrease interpretation error as far as possible (Barker 1989). Geo-electric segments were found from deciphered information. Every geoelectric layer relates to the inferred lithological property. The subsurface order fluctuates starting with a single geoelectric layer then onto the next. The electrical resistivities differentiate over lithological divisions to depict geoelectric cross-sections (Schwarz 1988).

Total 103 Vertical Electrical Soundings (VES) using Wenner configuration were carried out using DDR-III Resistivity Meter (IGIS make) with

Table 4. *Resistivity ranges of different sub-surface formation.*

Resistivity ranges (Ωm)	Sub-surface/lithology formation
0–20	Clayey layer
20–50	Hard murram
50–120	Semi-weathered to fractured rock
100–250	Fractured rock
> 250	Hard rock

(Source: Ramanuja Chary 2012).

maximum current electrode dispersing (AB/2) have the greatest spread of 180 m (figure 3). Initial curve matching techniques were adopted for getting initial layer parameters (Orellana and Mooney 1966). Further, interpretation was done using IP2WIN software. The final interpreted layer parameters are given in table 3. Based on interpreted VES results, the resistivity ranges of different sub-surface layers were calculated and given in table 4.

5. Results

5.1 *Hydro-geochemistry*

The statistical summary of analyzed parameters of 50 groundwater samples for major ion and trace elements is shown in tables 1 and 2. pH ranges from 6.67 to 8.9; EC ranges from 87 to 900 μS/cm with average of 255.05 μS/cm at 25°C; TDS 56–576 mg/l with average of 163.23 mg/l; Ca^{2+} ranges from 6 to 59 mg/l; Mg^{2+} ranges from 1 to 45 mg/l; Na^{+} ranges from 0.13 to 263 mg/l with average of 0.91 mg/l and K^{+} ranges from 4 to 64 mg/l with average of 8.04 mg/l; TH 20–265 mg/l; HCO_3^- 109.8–732 mg/l; Cl^- 46–461 mg/l; SO_4^{-2} 1–132 mg/l; NO_3^- 5–32 mg/l; F^- 0.13–2.63 mg/l with averages of 278.44, 136.57, 16.43, 14.15, 0.82 mg/l, respectively. The loads of major ions are in order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ and $HCO_3^{2-} > Cl^{-} > NO_3^{2} > SO_4^{-} > F^{-}$ (table 1). The trace elements showed Al ranging from 30.16 to 386.98 μg/L, 34% of samples

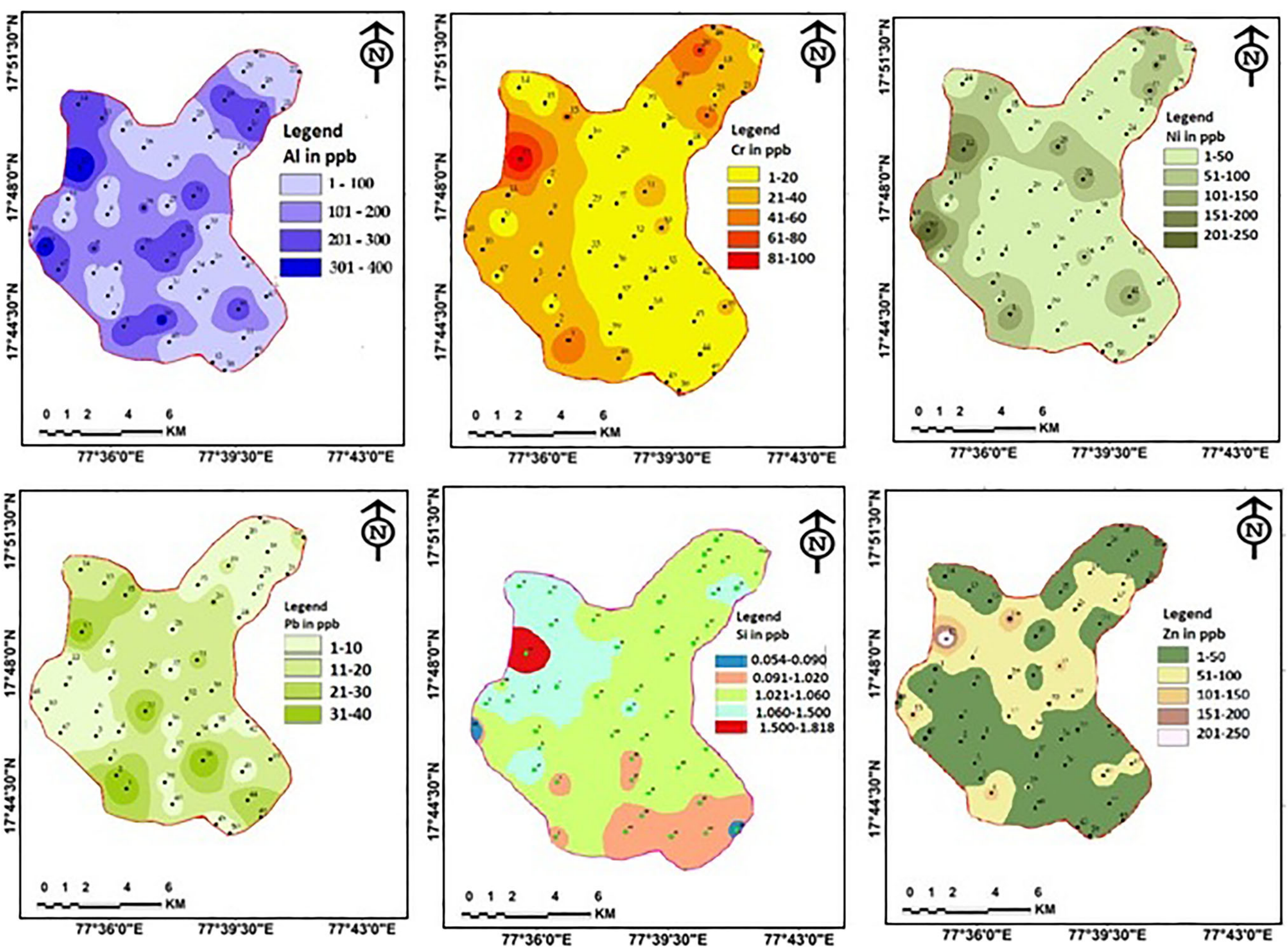

Figure 5. Distribution map of trace elements of groundwater in the study area.

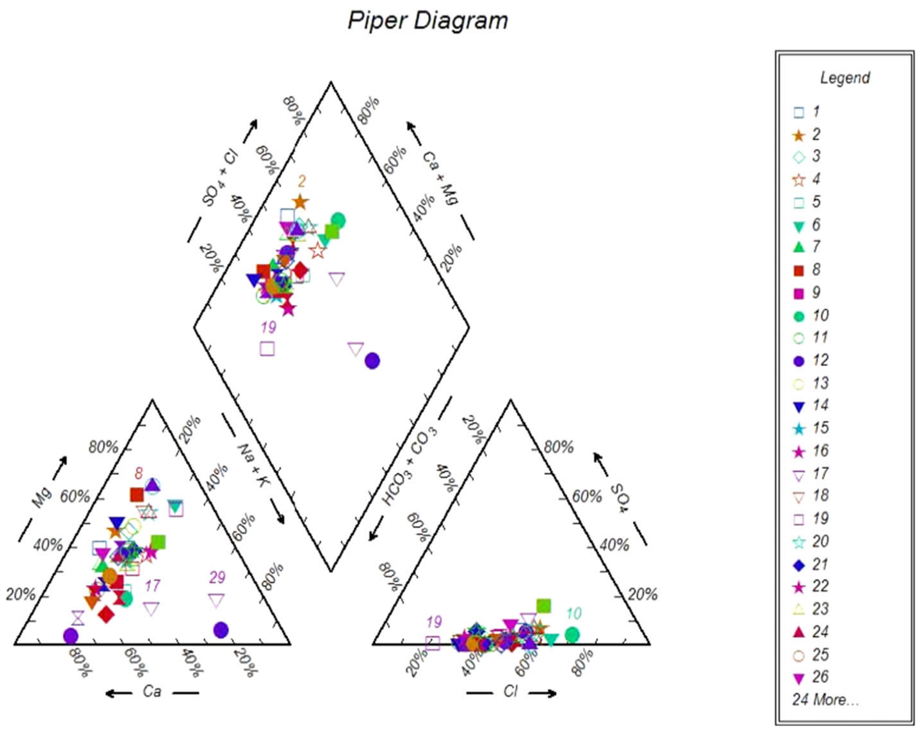

Figure 6. Trilinear diagram (after Piper 1944) in the study area.

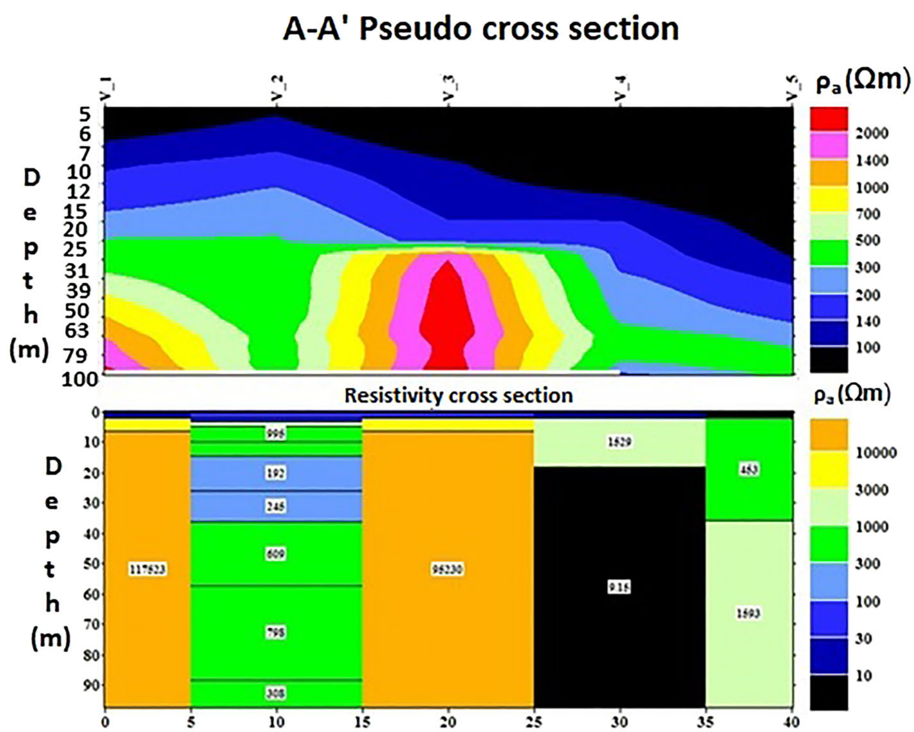

Figure 7. Geophysical pseudo cross-section A–A′.

exceeding permissible limits (WHO 2011). Ni ranges from 5.72 to 258.97, 52% samples exceeding permissible limits. Pb ranges from 5.11 to 50.22, 52% samples exceeding permissible limits, and Zn ranges from 18.74 to 427.05, 64% of samples exceeding permissible limits, remaining are within

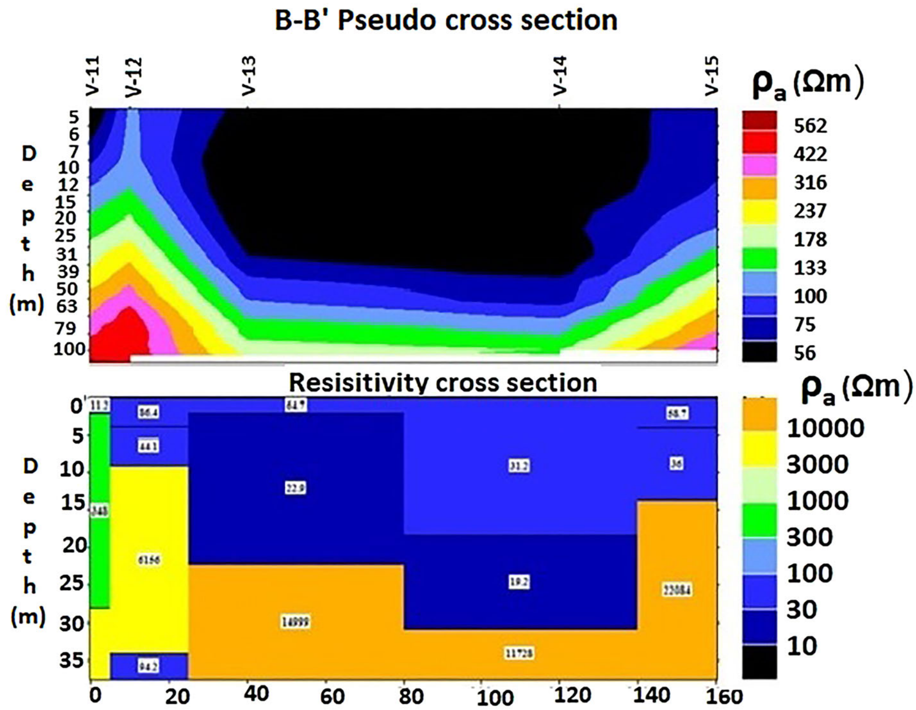

Figure 8. Geophysical pseudo cross-section B–B′.

the permissible limits (WHO 2011). The spatial distribution maps of major ions and trace elements are shown in figures 4 and 5.

The hydrochemical fundamental elements of groundwater can be comprehended by plotting cations mobile phase and anions mobile phase (Piper 1944) (figure 6). Facies are prominent parts of various types having a hereditarily related framework. The plot demonstrates that a greater part of groundwater samples fall in the area of Na^+–Cl^- category by Ca^{2+}–Na^+–Cl^- and Ca^{2+}–Cl^- types. From the plot, it is seen that alkalinity (Na^+ and K^+) surpasses the basic globe (Ca^{2+} and Mg^{2+}) and solid acids surpass frail acids. By and large, groundwater chemistry is commanded via soluble base and acids.

The major part of samples is well within possible permissible limits with few exceptions pH, EC, TDS, TH, Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, Cl^-, SO_4^-, NO_3^2, and F^-. TDS in all samples are within limits with the exception in sample from Mungi Village. Spatial distribution of TDS, differentiated based on excellent (> 300 mg/l), poor (< 900 mg/l) shows popular of region abstaining lower TDS suitable for drinking purposes. High TDS in water may create terrible taste (Spellman and Drinan 2000). The pH of groundwater differed from 6.64 to 8.9. Ninety-eight percent of groundwater samples are found within the permissible limit. Chloride concentration differed from 46 to 461 mg/l, 84% of samples are within permissible limit, exception in Mungi (461 mg/l), Metalkunta (312 mg/l), Nyalkal service station (316 mg/l), Krishnapur (202 mg/l). Elevated chloride in water gives delectable taste to water because of the enduring of rocks, infiltration from the anthropogenic source. Water hardness is caused principally by the presence of cations and anions in water (Sadashivaiah *et al.* 2008). Calcium and Magnesium are within the permitted limit. Total hardness discusses to effect with soap and scale formation, the capacity of water to promptly increase in the boiling point of water form lather with soap. Nitrate in the region are within the permissible limits of WHO, the suitability of groundwater for cultivation system relies on its mineral constituents.

The most significant criteria for making a decision about water quality is the concentration of total salt estimated by the conductivity of electricity (EC) and sodium/alkali hazard normally communicated as absorption of sodium ratio (SAR) and percent sodium (%Na^+). Richard (1954) characterized groundwater based on electrical conductivity, 100% of the samples belong to excellent water class under range 10. SAR evaluate the extent of Na^+, Ca^{2+} and Mg^{2+} ions in the sample and its utility for cultivation purpose. At the point when sodium value is high, because of Ca^{2+} and Mg^{2+} in clay particles decreases the soil permeability (Srinivasamoorthy *et al.* 2009). Subsequently, sodium concentration plays a significant role in assessing groundwater quality for the irrigation water system. The SAR values for groundwater samples vary from 0.18 to 0.70 meq/l, suggested that groundwater in the region could be excellent for water irrigation system (Richards 1954).

It is seen that among the groundwater samples of the region, about 72% fall under C1S1 class representing low salinity-low sodium waters, 26% fall under C2S1 class showing medium salinity and low sodium waters and 2% of the samples fall under C3S1 class representing high salinity and low sodium water. Electric conductivity influences total salt concentration and soil salinity and consequently influencing the yield of the crop and its resistance consequently.

5.2 *Geophysical interpretation*

Hydro-geologically, the aquifer of the region is confined to traps, laterite and alluvium. The Deccan traps involve a sequence of basaltic magma flows (about flat in nature) isolated by red, dark or green bole as intratrappean beds, where each flow includes 40–70% of huge basalt in the lower zones and 30–60% vesicular basalt in the upper zones (Madhnure 2001; Sakram *et al.* 2013; Sreedhar *et al.* 2018b). In rock joints, cracks and fissures, due to enduring and faulting, create secondary porosity for aquifers. The endured thickness was found between depths of 6 and 29 m and joints and fractures diminish with depth in the granitic region. Alluvium dump occurs along the Godavari River track with 12–30 m thickness, containing clay, silt and gravels and irregularly cobbles that bear good aquifers (Madhnure 2001; Sakram *et al.* 2013, 2019).

A total of five cross-sections A–A′, B–B′, C–C′, D–D′ and E–E′ comprising of 103 Vertical Electrical Soundings (VES) was drawn for deciphering the sub-surface information and heterogeneities in the hard rock terrain (figure 3). The objective of the quantitative interpretation of resistivity data deciphered a range of three–four geo-electric succession: topsoil, laterite, sandy clay and weathered/fractured/vesicular basalt/massive basalt/weathered/fractured fresh bedrock (table 3). The electrical resistivity ranges across various lithological units are presented in table 4. The topsoil has resistivity values range from 26.61–930 Ωm, lateritic horizon (453–738 Ωm), clayey/sandy clay layer (4.71–94.2 Ωm), this prospect is target for hand wells and dug wells. Resistivity values of

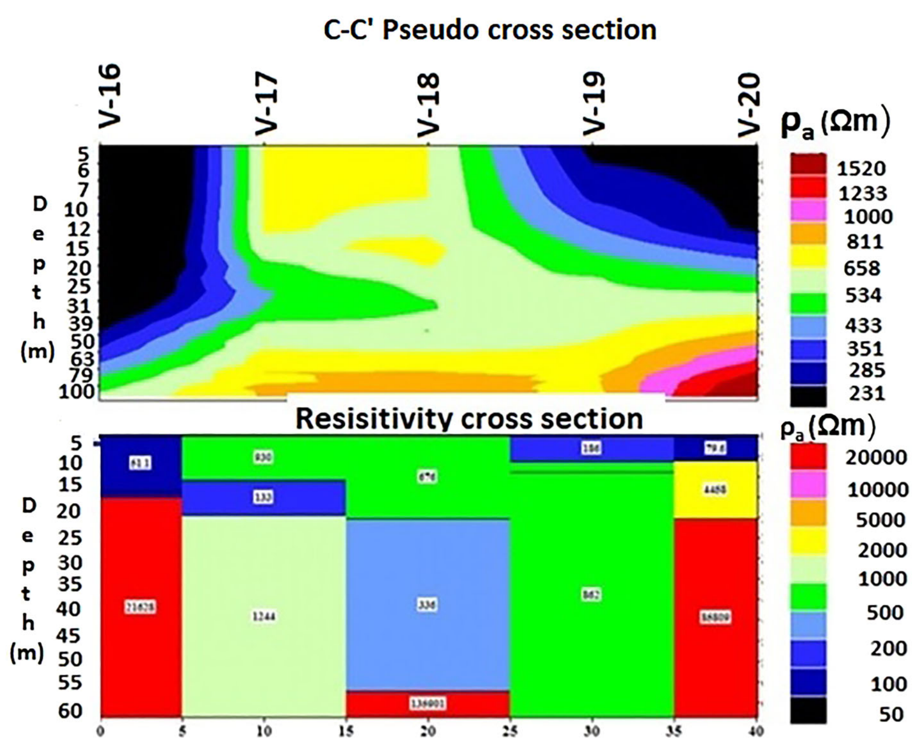

Figure 9. Geophysical pseudo cross-section C–C′.

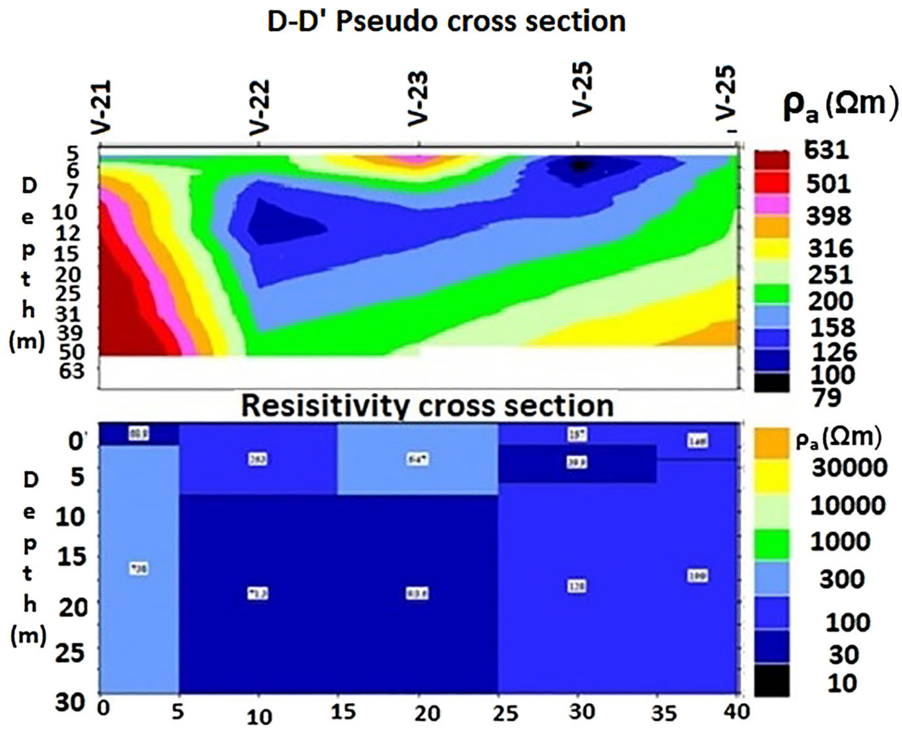

Figure 10. Geophysical pseudo cross-section D–D′.

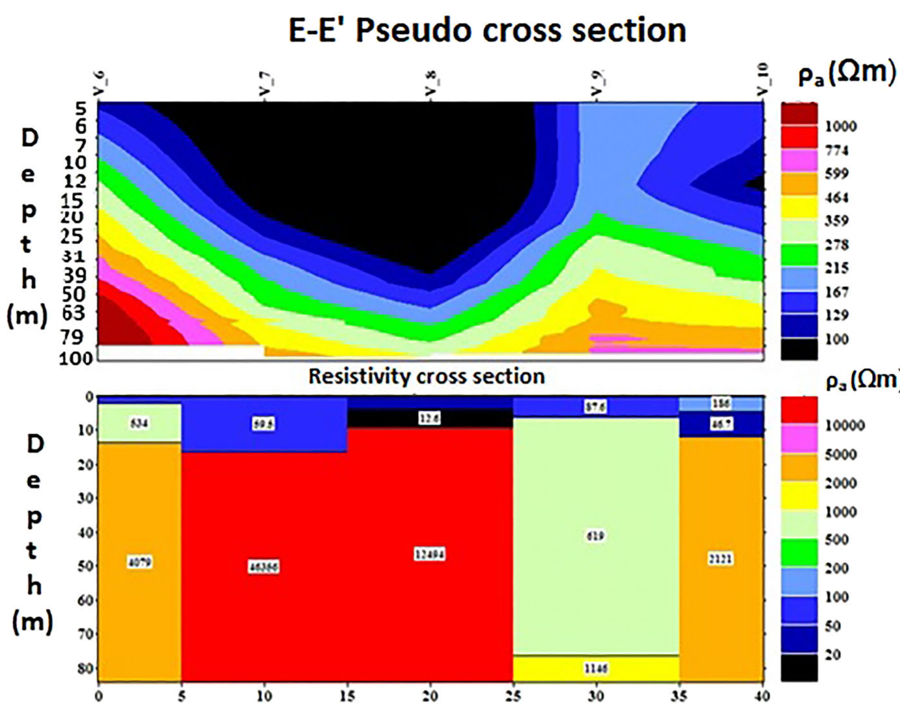

Figure 11. Geophysical pseudo cross-section E–E′.

weathered/fractured rock layer range from 60.5 to 928 Ωm and weathered/vesicular/massive basalt ranges from 8.05 to 0.676 Ωm.

A–A′ geophysical pseudo section was drawn using VES nos. V1, V2, V3, V4 and V5 showing 20–200 Ωm resistivity up to 20 m indicating that the subsurface have weathered and fractured formation. After this depth, the pseudo section shows a resistivity range of 300–1000 Ωm indicating hard massive jointed basalt formation up to a depth of 100 m except at VES no. 3 (figure 7). The pseudo section B–B′ represented by VES nos. V11, V12, V13, V14 and V15 depicting very thick weathered/fractured formation with resistivity of 42–133 Ωm up to a depth of 80 m in the center part of the pseudo section, while hard rock with resistivity >500 Ωm was observed at VES No. V11 (figure 8). The pseudo section C–C′ represents VES nos. V16, V17, V18, V19 and V20 representing resistivity of >200 Ωm up to 40 m and 15 on the left and right side, whereas in the center part shows the resistivity >500 Ωm with the basement as hard rock (figure 9). D–D′ pseudo section was drawn by using VES nos. V21, V22, V23, V24 and V25 showing a low resistivity of 79–200 Ωm in centre part up to a depth of 50 m indicating a highly weathered/fracture formation which is good for groundwater prospecting. Top of the pseudo section shows high resistivity of >500 Ωm indicating a boulder formation, while the left portion of the section shows a resistivity >300 Ωm indicating a jointed basaltic formation (figure 10). Similarly, E–E′ pseudo section was drawn by using VES No. V6, V7, V8, V9, and V10. A thick zone of low resistivity of 100–167 Ωm seen in the middle of the pseudo section up to 40 m indicating weathered formation, below this a semi-weathered/fractured zone of resistivity 215–278 Ωm was seen followed by hard rock formation with high resistivity (figure 11).

Stacked isopach map of overburden and basement resistivity maps revealed thick overburden, and fractured basement in few areas. High resistivity values (930, 676, 547 and 284.4 Ωm) topsoil in VES points 17, 18, 10 and 23 due to embedding of boulders at VES points and bedrock zone resistivity range (60.5–135901 Ωm). An iso-resistivity map of region demonstrates generally low resistivity towards endured or fissured rock layer and zones through moderate in height resistivity towards deciphered fresh bedrock (Olorunfemi and Olorunniwo 1985) though zones with either thick overburden or endured/fractured basement are outlined having medium yield while regions with slight overburden and high bedrock resistivity (fresh basement) as low groundwater potential zones. So as to guarantee the greatest and enduring yield, boreholes are best referred to regions where the regolith could be maximally drilled (Lenkey *et al.* 2005). The hydrological properties of traps are complex. Dependable groundwater bodies are often confined to near-surface weathered and jointed zones. Partly weathered traps form good aquifers, while in highly weathered form they become black cotton soil, which is impervious. In the case of massive basalts, groundwater occurs in

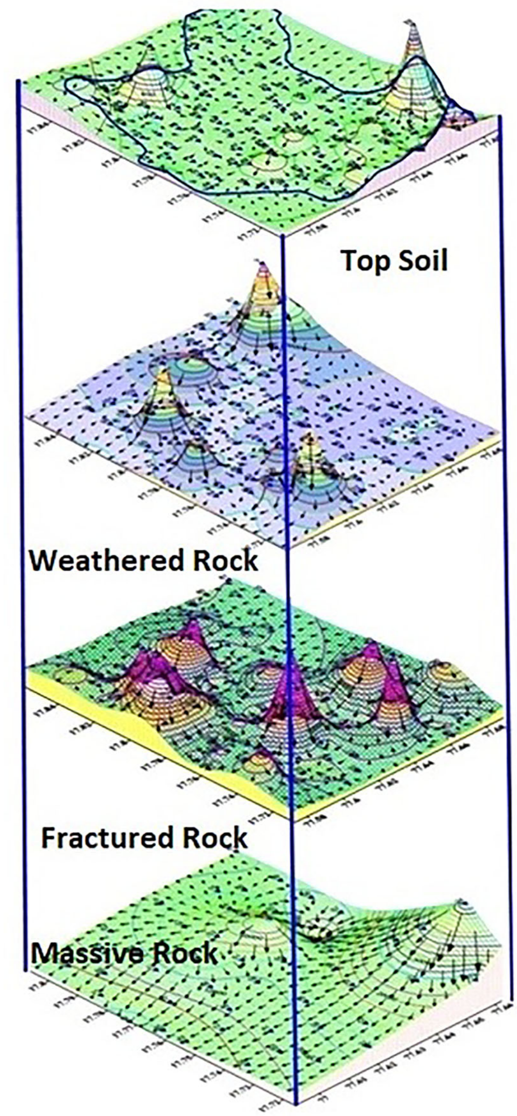

Figure 12. Iso-resistivity maps showing top soil, weathered and fractured thickness for further groundwater prospects in the study area.

joints and crevices. Vesicular basalts act as good aquifers when vesicles are interconnected and are not filled with secondary minerals like calcite and zeolite quartz. The basic controlling point in the region, observed from geophysical survey and litho-log at the time of drilling indicates good weathered zone with proper depth and ash bed/intratrappean/tuff beds were encountered, there was good yield in wells and failure cases have only massive basalt or clay formation. The iso-resistivity map of overburden, indicate high and low zones overburden thicknesses relate basement ridge and basement valley separately. The stacked iso-resistivity map utilized to create a groundwater source map of the region (figure 12).

6. Conclusion

Integrated studies using hydrochemical and geophysical investigation were conducted in parts of Medak District, Telangana. The water quality analysis results of major ions and trace elements show good water quality except for few samples exceeding the permissible limit. However, the parameters like TDS, TH, K^+, CO_3^-, and Cl^- exceeds the concentration of permissible limits of 2%, 8%, 2%, 76% and 16% of the total samples. While, trace elements concentration exceeds the permissible limit in Al, Pb, Zn and Cr. The elevated concentration was due to anthropogenic source in the study area. Piper plot reveals that the groundwater was Ca^{2+}–Na^+–Cl^- and Ca^{2+}–Cl^- types. Majority of the sample falls under C1S1 class and few sample falls under C2S1 category representing low to medium salinity. Geophysical investigation reveals that the area was consisting of three–four geo-electric subsurface formations consisting of soil/alluvium, laterite, fractured/jointed basalts and massive bedrock. The groundwater prospects are more in the area having thick overburden and jointed and fractured hard rock. Vesicular basalts also act as good aquifers when vesicles are well interconnected. The iso-resistivity map of overburden, indicate high and low zones, overburden thicknesses relate basement ridge and basement valley separately and can be utilized to create groundwater source map of the region. North-western and eastern part of the study area was moderately covered by thick overburden overlie on endured or fractured bedrock distinguished have most potential possibilities and outlined for good groundwater yield. This study helps to identify the best feasible points for groundwater exploration, which in turn helps the society to abstract potential wells in the study area. Furthermore, the less groundwater potential zones identified will be made more potential by adapting groundwater recharge system. This also benefits in improving the water quality.

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Author statement

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