

Delineation of groundwater potential zones using geo-electrical surveys in SSW part of Yeleru river basin, East Godavari District, Andhra Pradesh

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ABSTRACT

Data of 40 Vertical Electrical Resistivity soundings covering an area of about 144 square kms located in SSW part of Yeleru river basin, East Godavari district provided by Andhra Pradesh state Ground Water department was analyzed to delineate potential sources of ground water, its extent and depth of water table. The study revealed mainly a three layer subsurface with top layer consisting of clay/lateritic gravel, followed by the sandstones. The general geology of the study area is Rajahmundry sandstone. Saturated sandstone with a resistivity range of 10-50 Ω m extending to a maximum depth of approximately 135 m forms the major aquifer, while layers with less than 10 Ω m may be possibly due to high clay content and hence poor aquifers. The fence diagrams and geoelectric sections reveal potential aquifers in the northern part of the region dominated by a thickness of 21-50m with a small patch showing a thickness above 50m and clay dominated zones in the southern part of the region, which are unevenly distributed. Thus, the study provides vital clues on the distribution and thickness of the aquifer, which helps to decide the type of well to be built (dug well, bore well) in future groundwater exploration/ exploitation programs.

Key words: Yeleru river basin, Vertical Electrical Soundings, Groundwater potential zones, Fence diagram, geo electric sections.

INTRODUCTION

Yeleru River is one of the major streams in East Godavari district. The basin area covers different geological formations like Flood plains, Rajahmundry sandstones, Tirupati sandstones, Charnockites and Migmatite group of rocks including Deccan traps. The present study is confined to the Rajahmundry sandstone formations in the basin area. This study area located between 17.00° to 17.13° N latitudes and 82.00° to 82.17° E longitudes spread over an area of 144.224sq.km (Figure 1) covers the villages around Peddapuram mandal, which is an irrigation command area. The major crops in the area are Tapioca, Rice and Sugar cane (Groundwater Brochure, 2013). The topography of the area varies from 33 to 81m above mean sea level. The average annual rainfall of the district is about 1280 mm (East Godavari district web portal), of which more than half contributed by South-West monsoon. Figure 2 shows the total annual rainfall during six years (2009-2014). This chart also indicates total maximum rainfall of 1909 mm during the year 2010 (much above annual average of 1280 mm), which decreased from 2012 onwards touching a low of 632 mm in 2014. This has resulted in decline in groundwater levels in all the three study blocks with maximum difference in Ramesampeta from 5.29m in the year 2013 to 12.62m in 2014. Due to the heavy demand of water for irrigation, people looked for deeper groundwater to meet their requirements.

Among all the geophysical methods the resistivity techniques especially the Vertical Electrical Sounding (VES) method is widely used for investigating subsurface layer parameters and groundwater potential (Jagadeswara Rao, 2003; Hardianshah and Abdul Rahim, 2013). This method was found suitable for hydro-geological surveys in sedimentary rocks (Kelly and Stanislav, 1993; Hadi, 2009). In sedimentary rocks, the resistivities of the interstitial fluid are probably more important than that of the host rock. Resistivity for sandy material is about 100 Ω m and decreases with increasing clay content to about 40 Ω m and the values decrease further to 1-10 Ω m for those more typical of clay (Reynolds, 1987a; Majumdar and Das, 2011). In the present study, a detailed investigation has been made to identify the ground water potential zones in the study area using electrical resistivity sounding data.

Hydrogeology of the Study Area:

Groundwater in the study area occurs under phreatic and semi confined conditions and the hydro geological regime of the area is influenced by the Yeleru River. There are three observation wells, which have been monitored for six years from 2009 to 2014 during both pre monsoon and post monsoon. These three open wells show depths of water level of 24m at Peddapuram, 16m at Ramesampeta and 8m at Katravulapalli. As the infiltration rate is high in sandstone formations, the depth to water level has been

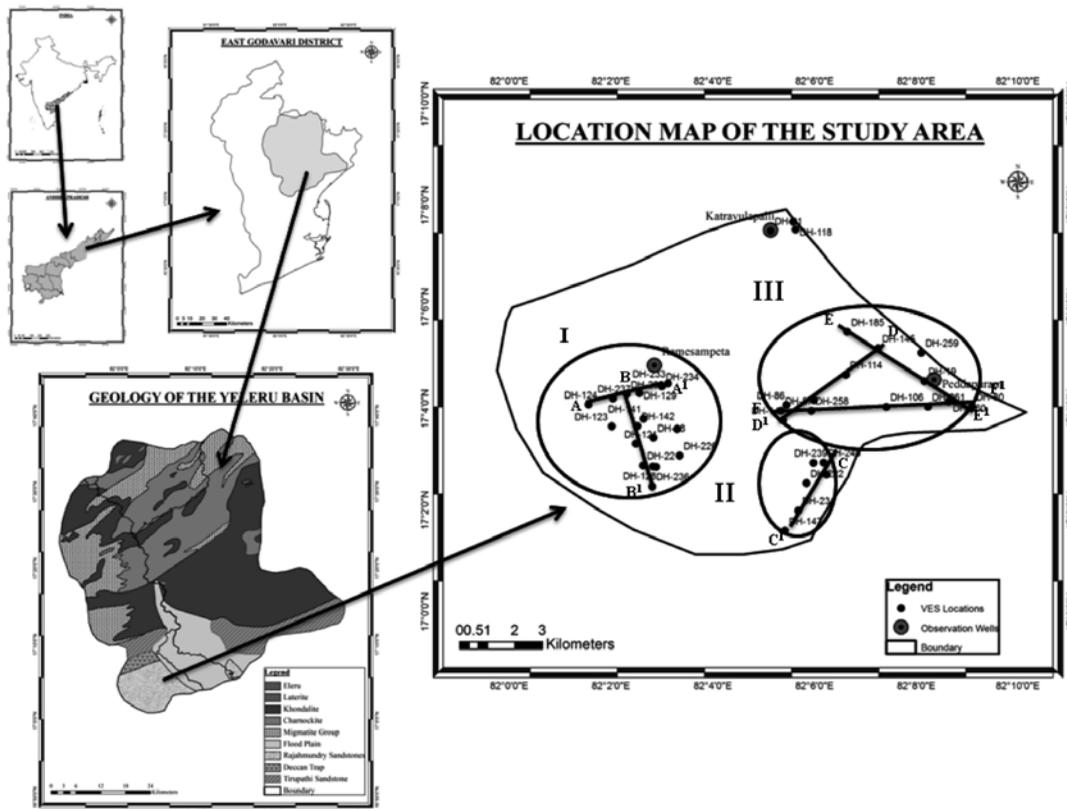


Figure 1. Location map of the study area.

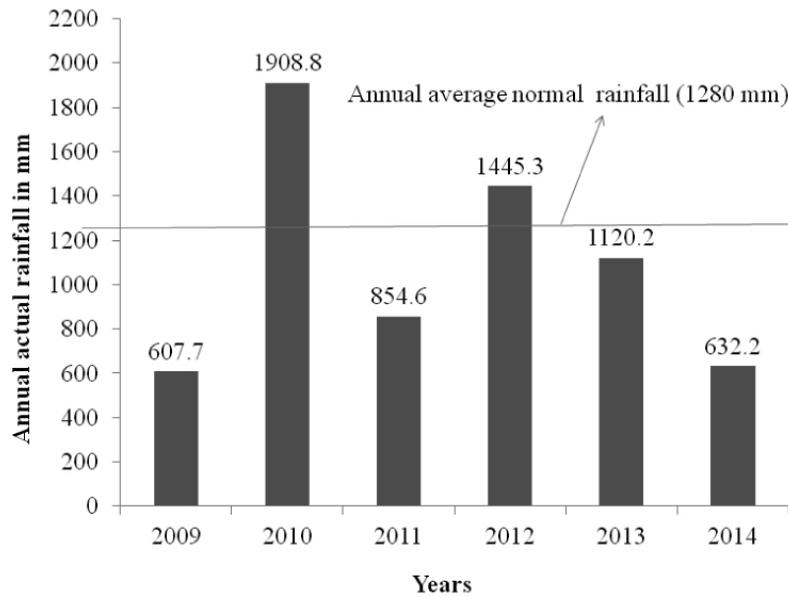


Figure 2. Actual annual rainfall of the district (2009-2014).

raising abruptly during post monsoon in all wells (Figure 3). Very Shallow water levels were clearly observed during post

monsoon of 2010, 2012 and 2013 wherein the water levels in these three years were much deeper during pre-monsoon.

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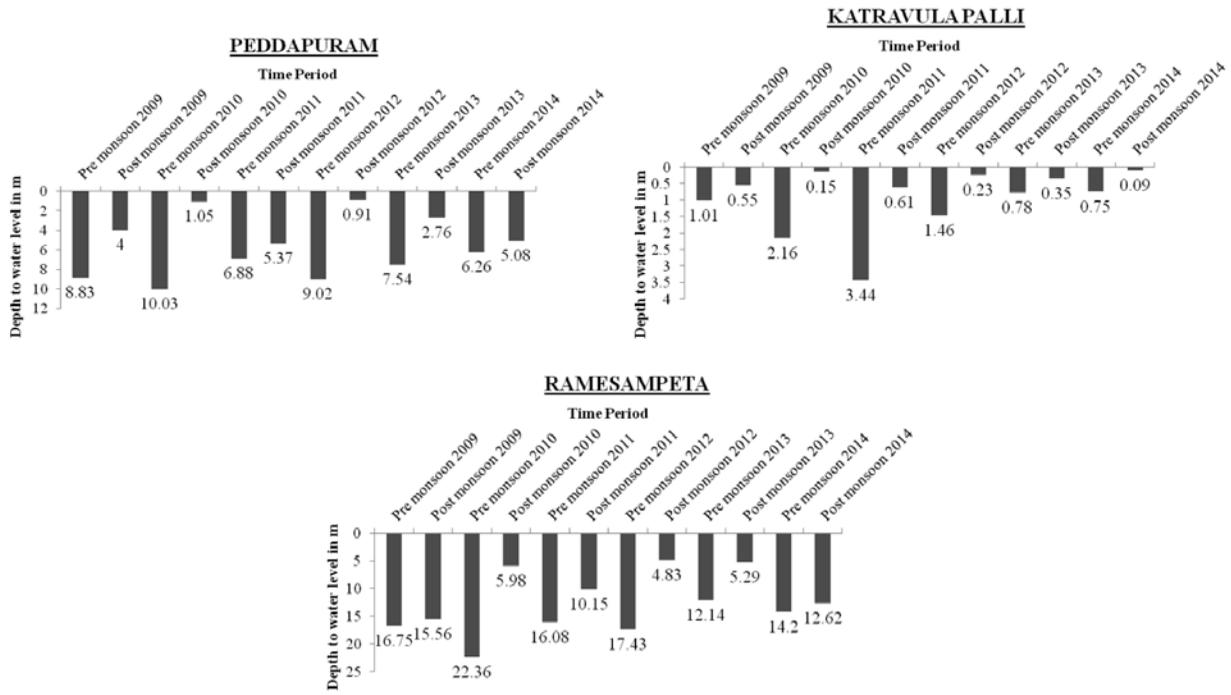


Figure 3. Depth to water levels in dug wells during the period 2009-2014 (Pre and Post monsoons) at three locations Peddapuram, Katravulapalli and Ramesampeta.

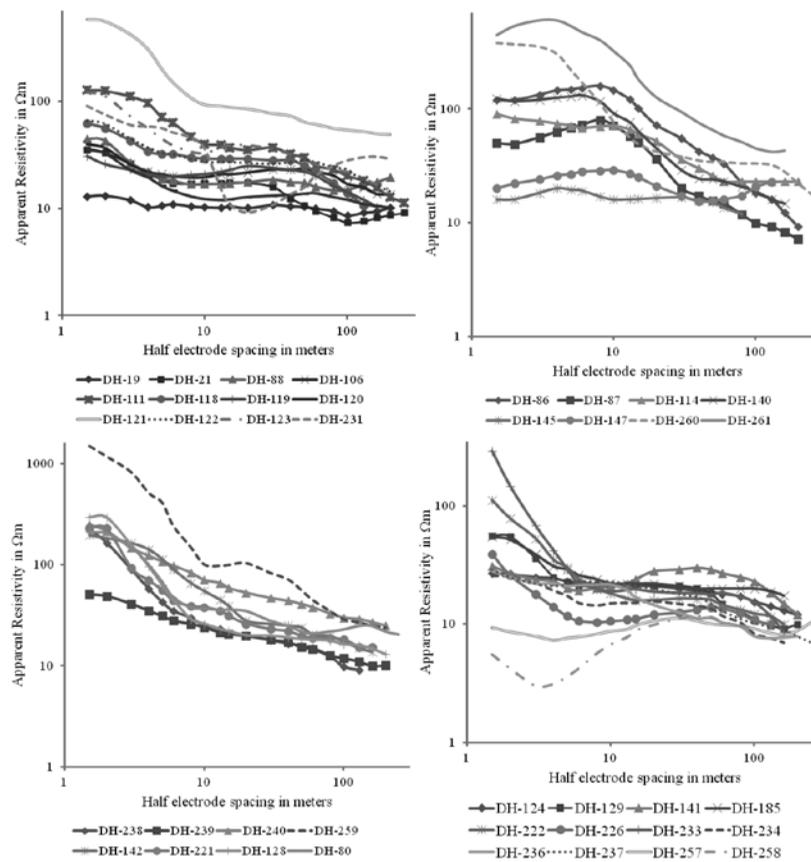


Figure 4. Vertical Electrical Sounding curves (40 nos.) of the study area.

Table 1. Interpreted Results of the vertical electrical soundings.

Code	Longitude	Latitude	Elevation	Resistivity (Ω m)					Thickness (m)				Total Thickness(m)
				1st Layer	2nd Layer	3rd Layer	4th Layer	5th Layer	1st Layer	2nd Layer	3rd Layer	4th Layer	
DH-19	82.136	17.0757	41	17.7	10.2	4.6	18.9		0.9	50.8	31.9		83.6
DH-80	82.1517	17.0674	41	279.5	34.3	8	71.6	12.1	1.4	19.7	14.9	30.6	66.6
DH-86	82.0908	17.0678	54	102.9	249.8	42.3	8.4		1.5	3.7	36.5		41.7
DH-87	82.089	17.066	56	66.1	204.2	41.2	8.2		0.6	5.2	37.2		43
DH-88	82.0473	17.0571	60	72	16	25	8	30	1	10	15	30	56
DH-106	82.1235	17.0673	53	55	19	26	10		1	10	40		51
DH-111	82.104	17.045	40	142.2	34.1	10.9			2.1	41.8			43.9
DH-114	82.1103	17.0778	45	89.3	70.4	20.5	39.4		1	10.5	111.6		123.1
DH-120	82.0471	17.0477	58	39.9	11.1	15.3	8.7		1.5	11.7	39.4		52.6
DH-121	82.0414	17.0551	65	645.8	80.3	46.6			1.8	26.7			28.5
DH-122	82.055	17.06	66	76.4	26.5	7			1.3	77.8			79.1
DH-123	82.0336	17.0609	64	147	26	100	24	13	1.4	5.5	4	45	55.9
DH-124	82.026	17.068	72	27	20	11			2	42			44
DH-128	82.0482	17.0476	56	470	38.5	19	9.1		1.2	3	75.4		79.6
DH-129	82.0427	17.0717	77	142	21.2	4	20		0.8	37.4	44.9		83.1
DH-140	82.0897	17.0628	54	82	261.1	26.7	12.1		1	2.3	39.8		43.1
DH-141	82.044	17.0634	67	30	13	35	7		1.5	3	50		54.5
DH-142	82.042	17.061	67	200	50	23	10		2	8	60		70
DH-145	82.1208	17.0865	45	12	35	10	25	10	1	1.5	5.5	15	23
DH-147	82.0903	17.0266	33	21.8	32.4	6.3	40.9		2	14.1	21		37.1
DH-185	82.1107	17.0919	53	83	23	20	10		1	12	123		136
DH-221	82.0438	17.0481	63	411.2	39.1	18.6	7		1	10.4	120.8		132.2
DH-222	82.0974	17.0422	46	128.8	17.1	9			1.2	46.5			47.7
DH-226	82.0558	17.0513	60	57.5	9.3	13.9	7		1	5.6	60.6		67.2
DH-231	82.0947	17.0332	35	151.5	61.1	3.8	102.3	15.1	0.5	5.1	11.4	50.9	67.9
DH-233	82.052	17.075	77	396.9	19.3	2.5			0.9	88.7			89.6
DH-234	82.05	17.074	77	27.6	14.5	4.9			1.5	54.7			56.2
DH-236	82.0469	17.0412	61	38.5	21.4	9.7	6.8		0.5	9.3	44.3		54.1
DH-237	82.034	17.07	80	48.7	21.7	14.4	6.9		0.5	15.1	26.6		42.2
DH-238	82.0385	17.0714	81	368.9	40.3	16.8	5		0.9	3.8	45.3		50
DH-239	82.0997	17.0489	43	60	22	10			1.5	20			21.5
DH-240	82.103	17.049	41	251.7	62.8	26.7			1.6	17.7			19.3
DH-257	82.0999	17.0695	42	9.3	6.6	13.7	6.2	29.6	1.4	4	21	103.1	129.5
DH-258	82.099	17.066	43	8.4	1.7	16.9	4.8		0.8	1.7	28.1		30.6
DH-259	82.135	17.085	35	1547.3	99.3	23.1			1.7	22.5			24.2
DH-260	82.144	17.069	46	377.5	36.3	4.9			2.9	114.1			117
DH-261	82.1372	17.0673	55	391.9	727.9	95.8	39.8		0.8	3.3	19.7		23.8
DH-21	82.0857	17.125	44	47.2	16.6	5.4	20		1	24	84.7		109.7
DH-118	82.0938	17.1255	42	79.6	29.3	6.8			1	38.5			39.5
DH-119	82.093	17.128	39	30	18	32	8.5		1	6	23		30

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Table 2. Resistivity ranges of Sandstones.

S.No.	Resistivity in Ωm	Formation
1.	<10	Saturated Clay
2.	10-50	Unconsolidated/Saturated Sandstones
3.	51-250	Top soil/Dry sands/Consolidated sandstones
4.	251-1550	Lateritic gravel

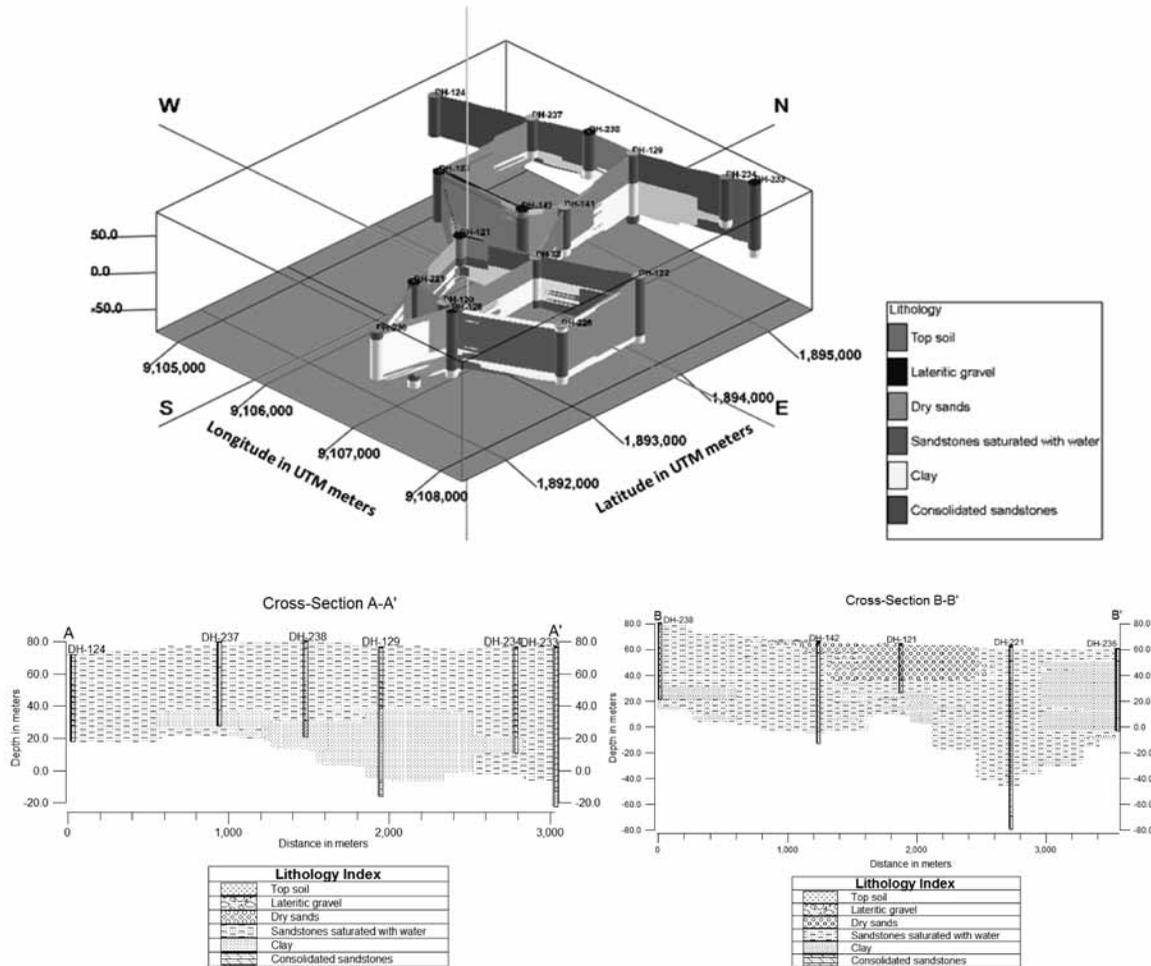


Figure 5. Top figure is the fence diagram for region-I, Bottom two figures are the lithologies along the geo-electric section AA` and BB` of Figure 1.

METHODOLOGY

Electrical resistivity data of 40 Vertical Electrical Soundings (VES) using Schlumberger array with maximum of half-current electrode spacing varying between 100-250 m are initially interpreted with theoretical curves prepared by Orellana and Mooney (1966) for having preliminary understanding of the true resistivities and thicknesses of the subsurface layers of different composition. The shapes of the curves indicate 3-5 layer subsurface patterns

corresponding to Q, HK, KH, QH, KQ, QQ, HKH, QHK, HKQ and KHK (Figure 4). These curves have been interpreted with the inversion technique using RESIST program (Vander Velpen and Sporry, 1993) based on the criteria of flexibility and user friendliness to process the data with Wenner, Schlumberger and Dipole-Dipole arrays. The results obtained from partial curve matching technique were given as inputs for RESIST program. The inversion of the resistivity data is based on the Marquardt-Levenberg technique. The layers resistivity and thicknesses of all the

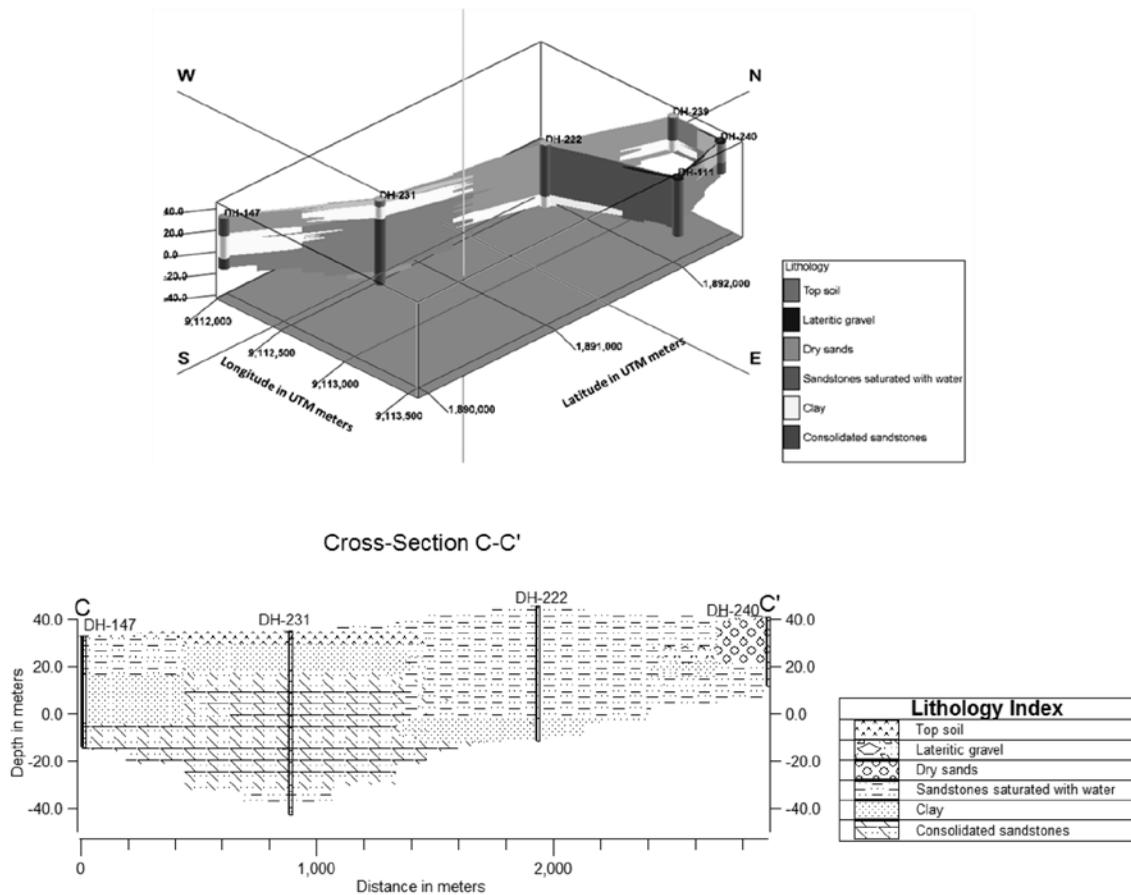


Figure 6. Top figure is the fence diagram for region-II, Bottom figure is the lithology along the geo-electric section CC` of Figure 1.

sounding curves determined with RESIST program are given in table-1.

Sub Surface Lithology:

Based on the interpreted resistivity values, geology of the area and lithology of the three observation wells, the subsurface lithology is classified broadly into clay, consolidated and unconsolidated sandstones and gravel (Reynolds, 1997; Hasan et al., 2013). The resistivity ranges of these formations are shown in table 2. In some pockets of the study area, dry sand is observed in the top layer. Most of the curves initially show descending trend with an exception of a very few curves with a high second layer resistivity. Such a trend could probably be due to dry sandy/lateritic gravel layer followed by a steep fall in the third layer resistivity (~41-42Ωm) with a larger thickness of approximately 36-37m (DH86 and DH87), which could be a potential zone of groundwater. The top layer consists of sand/sandy loam/dry soils/lateritic gravel with a thickness of 0.5 to 2.9m with an average thickness of 1.7m underlain by saturated sandstones at many places. In addition to this, clay formations (very low resistive less than 10 Ωm) were

identified at a few locations in deeper layers. Sounding data inferred the thickness of saturated sandstones varying between 10 – 135m (maximum at DH-185).

The study area is divided into three regions (I, II & III in Figure 1) and fence diagrams have been generated based on the lithology of the observation wells and resistivity values (table 2) for each region separately, for better view of the lithology. Fence diagrams for regions-I, II and III are drawn based on 17, 6 and 14 soundings, respectively. For each region, soundings located along straight lines are connected for drawing geoelectric sections (AA`, BB`, CC`, DD`, EE`, FF`), based on the resistivity values. All these fence diagrams and sections are shown in Figures 5, 6 and 7.

Discussion of Region-I: Fence diagram for this region (top of Figure 5) covering an area of about 17.4 square km is drawn on the basis of layer resistivities and thicknesses of 17 VES data. By looking at this figure, one can easily infer that bed rock is not reached at any of the sounding points in spite of the sounding spread extending to 250m (AB/2). Saturated sands of Rajahmundry sandstones, which form a major aquifer (resistivity range 10-50 Ωm) occupy maximum area of the region and extend to a maximum depth of 50m below

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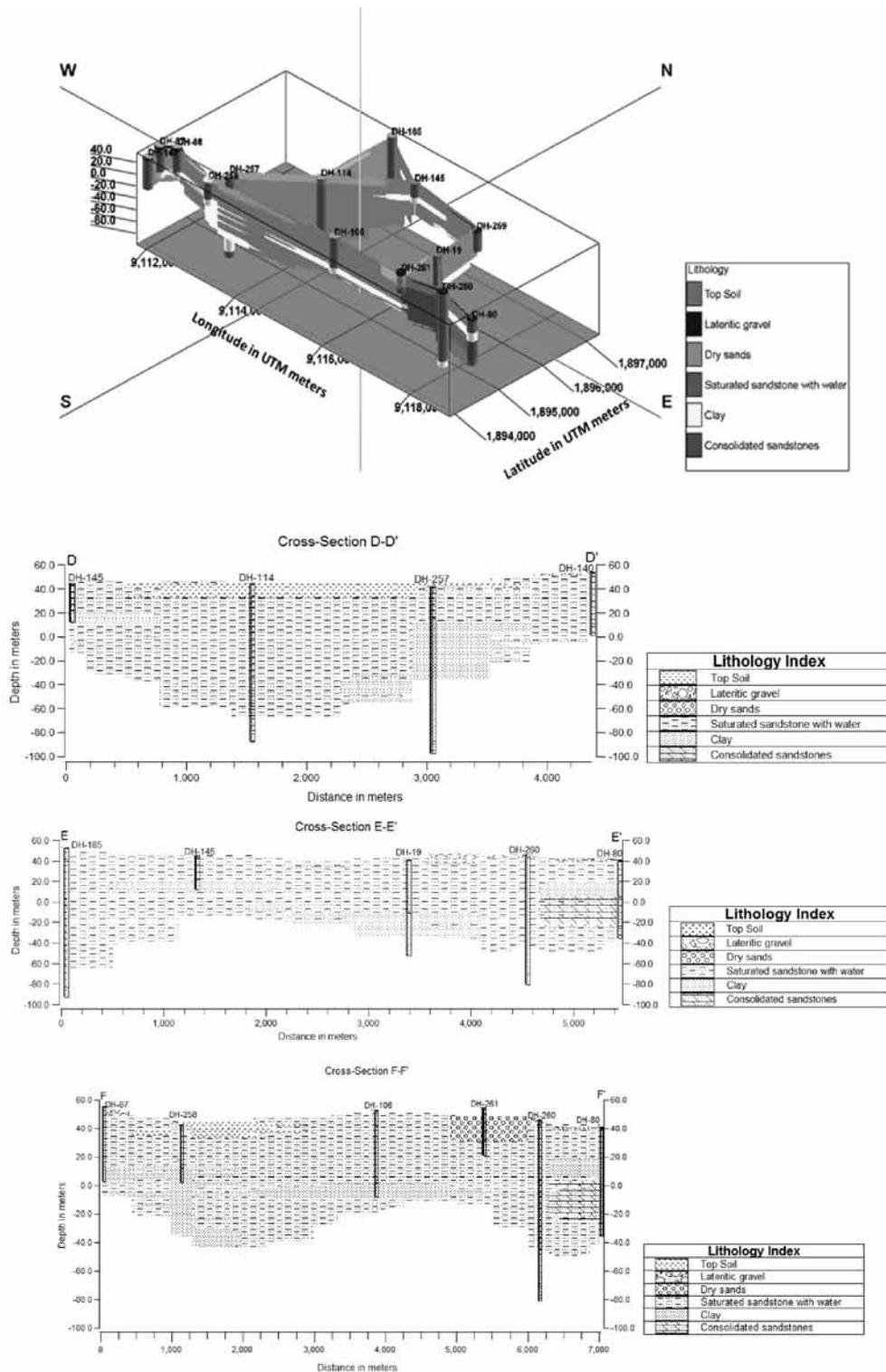


Figure 7. Top figure is the fence diagram for region-III, Bottom three figures are the lithologies along the geo-electric section DD', EE' and FF' of Figure 1.

mean sea level (DH-221). Open well dug at Ramesampeta in this region up to a depth of 16m also shows sandstone.

Bottom diagrams of Figure 5 are lithological sections along profiles AA' and BB' of region-I (Figure 1).

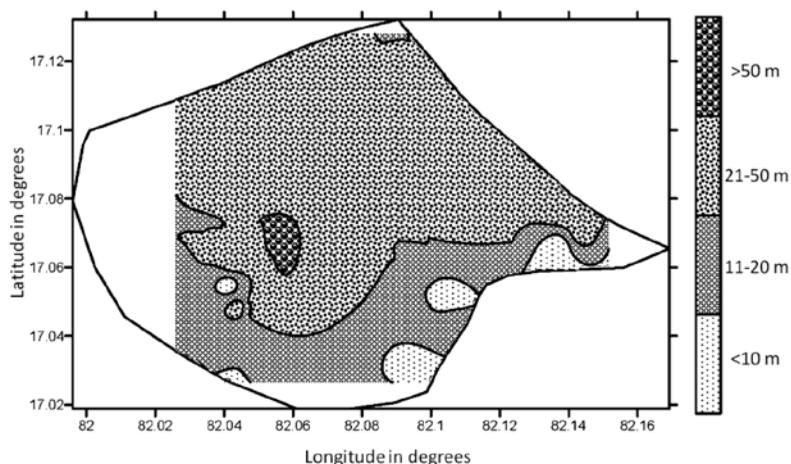


Figure 8. Spatial distribution of the saturated sandstone ($10\text{-}50 \Omega\text{m}$) of varying thicknesses.

Section AA': The topography of this section varies between 72 and 77m above mean sea level (amsl) along W-E direction. Two major formations viz. saturated sandstones followed by saturated clay have been inferred along this section. The thickness of the clay zone ($<10 \Omega\text{m}$) varies in the range of 10–50m, found at depth of 40m below ground level (bgl) with 10m thickness at a distance of 600m from A (West) and increasing towards A' (East) with maximum thickness at distance of 2 km from A. Above this zone, saturated sand ($10\text{-}50 \Omega\text{m}$) is encountered with an average thickness of approximately 30-40m, over a length of 3km along AA'.

Section BB': The length of this section is 3.6km and runs along N-S direction with surface topography decreasing from 80 m amsl on the northern side (B) and 60m amsl on the southern side (B'). Saturated sandstone is inferred at most of the locations with few locations revealing dry sand as top layer at 2 km from B (DH121) and clay zone with a thickness of 50m at a depth of 10 m bgl located on southern most part of the section (DH236). The thickness of aquifer (saturated sandstone) is about 60m extending to a distance of about 1 km (DH142) towards south from B (DH238). The depth to this aquifer is approximately 1 m bgl.

Discussion of Region-II: The fence diagram of this region (top of Figure 6) covering an area of about 5.34 square km is based on the resistivity and thickness values of the different layers of the subsurface from 6 VES data. It can be inferred from this fence diagram that two thirds of the fence area is occupied by saturated sandstones, while one third is covered by consolidated sandstones (high resistive).

Section CC': This section of 2.9 km (bottom of Figure 6) revealed aquifer (saturated sandstone) along a length of about 800-900m having thickness of 30- 40m. This unconfined aquifer is located from a distance of 1.4 km from the point C (DH147) and at the sounding point DH222. The region occupied by consolidated sandstones

and clay (from Point C to approximately 1.4 km) in some parts of this section is not suitable for ground water exploitation.

Discussion of Region-III: 14 electrical resistivity soundings (VES) were carried out in this region covering an area of about 31.91 square km. The maximum surface elevation from the mean sea level is approximately 50m. The subsurface lithology is depicted in the fence diagram (Figure 7 top) based on the lithology of the well near DH19 (Peddapuram). Entire region is covered by saturated sandstones as can easily be observed from the fence diagram, with an exception at few locations where clay and consolidated sandstones are revealed.

Section DD': The length of this section (bottom of Figure 7) is about 4.3 km. Dominant formation along this section is saturated sandstone covering the entire length of the section with the exception at DH257, where the thickness of this formation is very less. This is underlain by a thick clay zone. The sandstone (saturated) is a good aquifer with thickness varying from 20m at DH257 to a maximum thickness of 90m at DH114 along length of approximately 2.8 km from D along this section.

Section EE': The distance between E and E' is 5.3 km (bottom of Figure 7). Most of the region is characterized by saturated sandstones, with an average thickness of around 40m. At few locations, clay deposits (10-20m thick) embedded into this formation (DH145, DH19 and DH80). Clay zone of 20m underlain by the same thickness of consolidated sandstones (high resistive) is observed in between the sounding locations DH260 and DH80, extending over a length of 800 m at a depth of 20 m bgl.

Section FF': This sections runs to about 7.0 km in the W-E direction in which saturated sandstones with an average thickness of 50m over a length of 6.0 km are the

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major formation along this section. At some locations, this formation is exposed onto the surface (DH87 and DH106) and at other locations (DH261) it is overlain by dry sand of 20m in thickness over a length of 800m and top soil of 10 m thick at DH258. Thus, this sandstone aquifer of 50m thick is undulating over a length of 6.0 km with patches of clay pockets at a few locations (DH258 and DH106) at a depth of 40 m bgl. The presence of clay may play a big role in the yield of the wells. However, at the end of the section (DH260 - DH80) clay and consolidated sandstone together with a thickness of 40m is delineated. EE` and FF` join at this point. Along this section ground water potential is revealed in the region from DH87 and DH260.

Summary

The three fence diagrams and the lithology along the six geoelectric sections reveal the geometry, thickness, spatial and depth extent of sandstone aquifer. In addition to aquifer, zones of clay and consolidated sandstone are also inferred from these geoelectric sections. The aquifer thickness map based on the thicknesses of the saturated sandstone (figure 8), inferred poor aquifers in the southern most parts of the study area as revealed by smaller thickness, whereas, towards northern and central parts, the thickness of the aquifer is around 50 m and could yield good amount of water. The major aquifers are delineated along the sections AA`, DD` and FF`. Along DD` the layer with maximum thicknesses of 90m extending over a length of 1.4 km may be due to a very good source of groundwater. Thus, the study plays a key role in delineating the aquifer and clay zones, which helps to decide the type of well and depth to be drilled in future groundwater exploration/exploitation programs.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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