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Geophysical Monitoring for the Prospects of Groundwater in the Hard Rock Terrain Regions along the Thandava River Basin

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Authors' contributions

This work was carried out in collaboration of the authors. Author KKK designed the study, correlated the results and made the draft. Author YI made the literature review, sample collection and assessments. Both the authors read and approved the final manuscript.

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ABSTRACT

The occurrence, movement and control of groundwater, particularly in hard-rock areas, are governed by different factors such as topography, lithology, and structures like fractures, faults and nature of weathering. An attempt was made in the present study to investigate the extent of the influence of structures such as fractures and thereby delineate the nature of subsurface lithology with the help of electrical resistivity method. Vertical Electrical Soundings by Schlumberger array configuration were recorded in fifty stations of the study area. The choice of the sampling stations in, around and along the basin made the study the first of its kind in the area. The huge sample number made ease of the interpretations with reliability in establishing the geomorphology of the area around the river basin. Groundwater potential zones were delineated with the present status of the reserves. The lithological segregation of the hard rock terrain stands reference for future studies besides suitability of the area made the study in announcing the challenges to be faced for sustainability.

Keywords: Vertical electrical sounding; groundwater; potential zones.

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1. INTRODUCTION

According to Lewis [1], it is possible to image the subsurface quickly and inexpensively through the application of various nonintrusive surface geophysical methods. Electrical resistivity studies have been extensively used in groundwater geophysical investigations because of the correlation that often exist between electrical properties, geologic formations and their fluid content [2,3]. Schwartz and McClymont [4] and Stollar and Roux [5] reiterate that the variations in apparent resistivity in the area can often be related qualitatively to geological features. Delineation of aquifers is the pre-requisite for assessment of regional/local groundwater potential. In view of present, which include the river basin study, earlier integrated studies were reviewed in an attempt to draw significant anomalies and approaches to be followed.

Delineation of aquifers and subsequently their groundwater potential assessment were carried out in different part of India by using different geophysical, geological, geochemical, remote sensing and GIS methods depending on the local hydro-geological conditions [6,7,8,9]. In fact, studies like these carried in assessment of groundwater had obviously used one interpretation, courtesy of various factors. The present resistivity survey was carried in 50 locations along the Thandava reservoir during June 2011 along with soil sample collection.

1.1 Study Area

The Thandava river basin extends over an area of 909.48 Km^2. The basin has a maximum length from North to South of 49.88 Km between latitude 17 º 50′ and 17 º 15′ North and maximum width from East to West of 21º 5′ between longitude 82 º 17′ and 82 º 45′ East. This basin covers water of Visakhapatnam and East Godavari districts of Andhra Pradesh state. The basin is surrounded by Sabari sub-basin of Godavari in north and Varaha river basin in the east, Bay of Bengal in the south and Pampa and Yeleru in the west. The upper reaches and most of the eastern portion lie in Visakhapatnam district and the lower portion and western side lies in East Godavari district. About $2/3^{rd}$ of the catchment lies in the former district and the balance lies in the later district.

Topographically the Thandava River rises in Eastern ghat hill ranges and enters Bay of Bengal. The basin is surrounded by hills almost all around except in the southern, which is plain. The entire catchment's consists of undulating country, a series of ridges and villages interspersed with low hill ranges. Large flat areas are not available in this basin. The Northern and Western sides of the basin are hilly with dense forests. Particularly the Northern hilly range is the area of heavy rainfall. The slopes of these hills are covered with thick jungles and in some places mixed with bamboo. The Eastern portion of the Thandava basin is generally flat and of low elevation. The coastal belt is sandy. The map of the study area is shown in Fig. 1a and resistivity stations were shown in Fig. 1b.

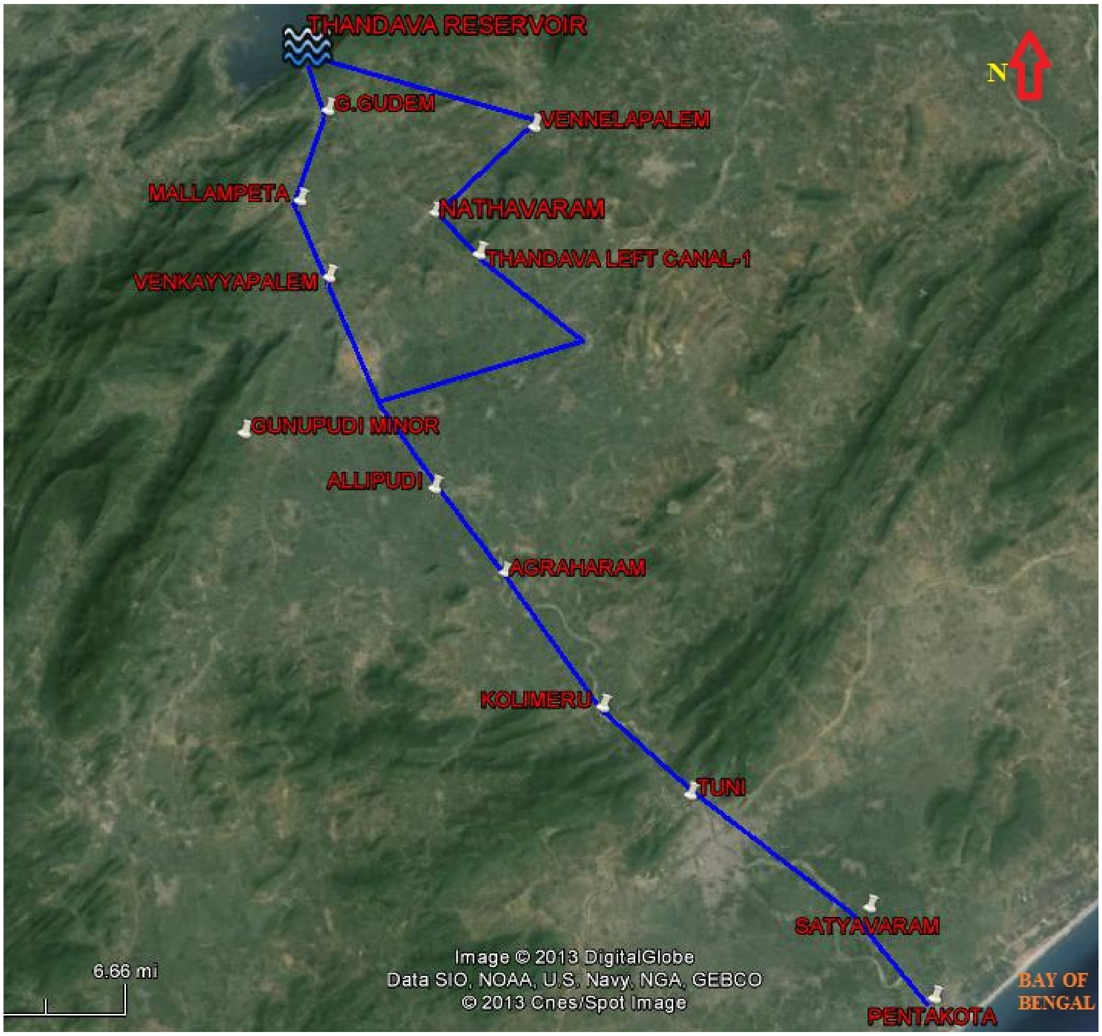

Fig. 1a. Map Of The Study Area

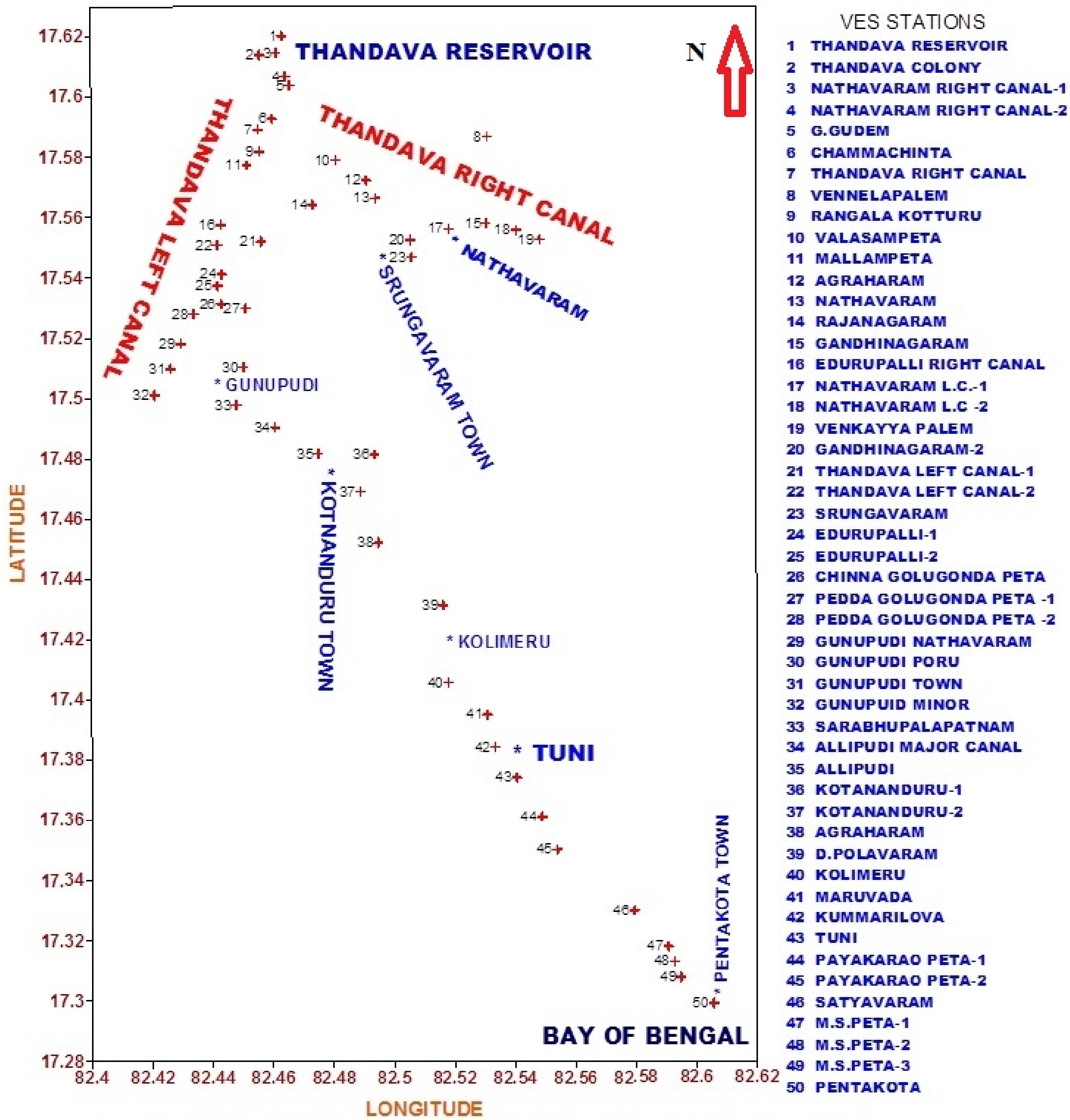

Fig. 1b. Vertical Electrical Sounding Stations Along The Thandava River Basin

2. METHODOLOGY

The ease and accuracy of any study or work for instance depend largely upon the planning made prior to collection of the samples. The plan includes the location of sampling sites and parameters to be analyzed, methods of data collection and also the handling procedures. Sampling points should be such that, they represent the existing environment [10]. A trail run before the execution made the things to be sorted out and means in collection at the ground level, where there were significant deviations in the reality and the hypothetical assessments made were quite evident and thus made the work to be carried in smooth manner.

The station's latitude and longitude were obtained by using GPS (Garmin) at the site. The values of coordinates were cross checked using topo sheets of the respective districts (District Ground Water Board). After the finalizing the number of sample sites, the total distance of the two districts were broken into parts of possibility for collection based on the time of journey, travel route, feasibility for collection etc. along with the onsite changes from time to time in accordance with the ground realities. The rainfall data of the area for five years had been collected from the groundwater department assessments at two rain gauge stations for relative understanding along with the present results.

3. RESULTS AND DISCUSSION

According to Scheidegger [11], water is an important agent in the formation of landforms and thus geophysical assessment of an area invariably signifies the potentiality of groundwater. The electrical resistivity of rock is a property, which depends on lithology and fluid content and depends on many factors, chief among these are the mineral content, texture, moisture content, salinity, fissures and fractures of geological formations. The resistivity values of rocks vary depending upon the presence of secondary porosity such as weathered, fractured and joints.

Surface electrical resistivity surveying is based on the principle that the distribution of electrical potential in the ground around a current-carrying electrode depends on the electrical resistivities and distribution of the surrounding soils and rocks. Schlumberger method [12,13] was used in the present study to obtain the resistivity. The resistivity survey was carried for 50 locations along the Thandava River Basin during June 2011. The Schlumberger soundings were carried with maximum current electrode spacing (AB) 400 m (AB/2 = 200 m). The field data acquisition was generally carried out by moving two or four of the electrodes used, between each measurement. Data from resistivity surveys are customarily presented and interpreted in the form of values of resistivity. The resistivity was obtained from the equation $R_a = \pi R (AB)(AB)/4(MN) = \pi R a n (n+1)$, where AB is the distance between the current electrodes, MN is the distance between the potential electrodes and R is the resistance read on the MiniRes. MN can also be designated a and the distance between a current electrode and the nearest potential electrode designated as na. The resistivity values at various thicknesses are given in Table 1.

It was expected that based on the resistivity values the lithology, weathered, fractured pattern, depth to basement and resistivity variations would be evaluated. As different values of the resistivities at various depths indicate the different formations based on the local geomorphology and geology. The soil and alluvium layer is underlain by weathered shale and the weathered shale is underlain by fractured shale. It was observed that resistivity soundings falling under high-density lineament zones provide favorable results when compared to soundings that fall under other zones. Moderate-to-good yields are tapping from weathered zones, where no fracture zones are present. In these, the thickness of alluvium followed by weathered shale's is greater, and the percolation of the groundwater in the unconsolidated material led to the formation of the moderate to good yields without presence of fractured zones.

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Table 1. Vertical Electrical Soundings Along The Thandava River Basin

S.No.	Sampling Stations	Resistivity (µm)			Thickness (m)		
		µ1	µ2	µ3	m1	m2	m3
1	THANDAVA RESERVOIR	25.61	29.54	141.2	1.42	17.9	55.26
2	THANDAVA COLONY	142	4029.7	407.7	1.35	7.99	-
3	NATHAVARAM RIGHT CANAL – 1	37.02	13.16	19.02	1.12	1.91	9.42
4	NATHAVARAM RIGHT CANAL – 2	39.59	7.28	599.8	1.58	10.9	10.83
5	G.GUDEM	23.61	176.2	62.5	4.84	12.5	41.82
6	CHAMMACHINTTA	177	25.81	81.61	2.84	14.9	36.4
7	THANDAVA RIGHT CANAL	10.69	183.4	45.15	0.96	2.18	15.47
8	VENNELAPALEM	38.63	137.5	514.4	9.04	12.2	52.89
9	RANGULAKOTTURU	203.8	150.2	161.9	2.33	3.72	42.1
10	VALASAMPETA	137.7	25.85	192	1.36	12.3	5.74
11	MALLAMPETA	59.12	92.63	20.85	1.09	6.88	45.62
12	AGRAHARAM – 1	331.8	6332.6	1252.5	0.69	8.24	-
13	NATHAVARAM	14.28	22.9	2267.8	1.41	48.8	-
14	RAJANAGARAM	33.52	5.27	522.2	3.47	16.8	-
15	GANDHINAGARAM	45.95	66.17	508.4	2.22	7.73	19.89
16	EDURUPALLI RIGHT CANAL	19.42	6.08	602.5	4.64	11.9	6.09
17	NATHAVARAM LEFT CANAL – 1	154.4	17.61	48.35	3.64	41.6	-
18	NATHAVARAM LEFT CANAL – 2	125.1	236.6	534.2	1.52	7.39	-
19	VENKAYYAPALEM	287	61.17	2892	3.73	39	-
20	GANDHI NAGAR	51.01	24.87	50.44	1.94	16.6	42.6
21	THANDAVA LEFT CANAL – 1	126.8	186.9	42.32	0.71	2.12	7.62
22	THANDAVA LEFT CANAL – 2	15.37	9.53	79.31	1.71	18.1	29.49
23	SRUNGAVARAM	30.75	37.3	3693.4	1.3	60.9	-
24	VEDURUPALLI – 1	50.91	179.1	338.3	1.57	6.15	61.81
25	VEDURUPALLI – 2	72.87	7214.5	72.87	0.65	0.15	7.95
26	GOLUGONDA PETA	130.7	54.57	59.25	2.4	1.46	71.5
27	PEDA GOLUGONDA – 1	99.53	237.8	21.29	1.37	3.65	26.39
28	PEDA GOLUGONDA – 2	161.8	79.59	702.9	5.12	25.4	46.93
29	GUNUPUDI NATHAVARAM	180.3	603.2	22.25	1.08	3.41	8.7
30	GUNUPUDI PORU	103.1	438.8	304.1	1.41	2.21	16.62
31	GUNUPUDI TOWN	27.96	10.26	22.77	1.78	9.11	13.3
32	GUNUPUDI MINOR	12.49	10.73	166.47	1.08	11.6	26.25
33	S.B.PATANAM	109.3	66.5	55.27	1.55	16.5	50.31
34	ALLIPUDI MAJOR CANAL	10.52	3.44	260.9	1.28	7.3	-
35	ALLIPUDI	29.77	25.96	56.36	0.66	258	4.75
36	KOTNANDURU – 1	40.81	13.08	83.34	1	14.7	32.04
37	KOTNANDURU – 2	55.51	10.35	875.8	2.2	12	-
38	AGRAHARAM – 2	26	120.7	11953	2.59	43.8	-
39	D.POLAVARAM	8.2	50.22	30.22	1.99	9.94	53.46
40	KOLIMERU	28.46	4.68	199.1	1.08	20.3	12.27
41	MARUVADA	19.54	245	2.47	0.9	1.68	3.27
42	KUMMARILOVA	160.1	41.27	4086.1	4.66	50.3	-
43	TUNI	10.01	25.58	35.52	1.49	10.9	5.1
44	PAYAKARAO PETA – 1	349.7	46.27	3.96	1.33	6.23	43.08
45	PAYAKARAO PETA – 2	14.31	4.58	217.7	1.55	9.59	-
46	SATYAVARAM	5.34	2.3	13.11	1.47	6.27	21.63
47	M.S.PETA – 1	47.29	168.1	5.43	1.75	9.82	36.38
48	M.S.PETA – 2	13.67	6.82	10.48	2.28	4.61	29.26
49	M.S.PETA – 3	69.1	124	6.48	1.34	6.84	31.14
50	PENTAKOTA	0.0126	0.0118	-	1.35	-	-

In some cases though the fracture zone is not present, yields are high, maybe due to the presence of high alluvium thickness and the weathered zone, and also recharge from the adjacent canal sources of the river. Some areas are devoid of fractures and alluvium zones with low yields during rainy season and dry up during summer season. Whereas areas covered with high alluvium and more fractured zones are abundant with rich resources groundwater. These areas show much lower resistivity values compared with rocky regions. It was apparent that the primary porosity is clear within the geology but, groundwater occurrence is mainly due to the secondary porosity, i.e. weathering, joints, fissures and fracture/lineaments. Most of the wells located in this zone yield a good quantity of water. The high resistivities are located over topographic high at the southern and northeastern portions of the study area. The wells located in high resistivity zones give relatively poor yields. The major part of the basin constitutes the values relating to pediplain with moderate and plain weathering. The thickness of piedmont zones increases from northern area to southern areas of the present river basin, where the apparent resistivity values are found to decrease in the same direction. The alluvium consists of pebbles, gravel, sand, silt and clay, ranging in thickness from 2 to 26 m occurring from a northern direction of the study area and presence of coastal plain to deep.

The average soundings curve does confirm that the curve begins to descent, after the last measured data point. Shows the presence of fractured bedrock at a depth of about 4 m and subsequent depths showed that the bedrock is in fact fractured sandstone due to local stresses. It is very difficult to predict the characteristics and orientation of these fractures. This may not be a good aquifer. The plots flat shape for the minimum, which apparently narrows down the possible range for the value of the true resistivity of the conductive layer, above bedrock, to about 35 m. These preferred orientations of deep-seated fractures are responsible for the groundwater potential zones in the study area and this is ably assisted from the torrential rainfall in these parts in comparison with the limited in others. However, in areas where such information is not available or is rather scanty it is difficult to infer either the thickness of the alluvial column or the presence of granular zones in the subsurface formations, particularly in the marginal areas where marked irregularity of the basement topography and a wide variation in the nature of the sediments are usually observed.

Basing on these it is a segregation of three zones in the study area as a Pleistocene coastal belt, the central zone and Northern part of the basin formed by Archean type rock and khondalites and the remaining portion is unclassified crystalline which also belongs to Archean group. The northern of the area is topographically is narrow longitudinal valleys, formed by the discontinuous recent hill ranges of Archean complex as basement for the younger formations which are occupying the Southern part of the area. The younger sediments are fringing at North, with the hard, compact crystalline rocks whereas, towards South these are concealed mostly by thick veneer of alluvial and Gondwana sedimentary formations. The high resistivities are located over topographic high at the southern and northeastern portions of the study area. The wells located in high resistivity zones give relatively poor yields. The geomorphology of basin is shown in Fig. 2 and groundwater potential zones are shown in Fig. 3.

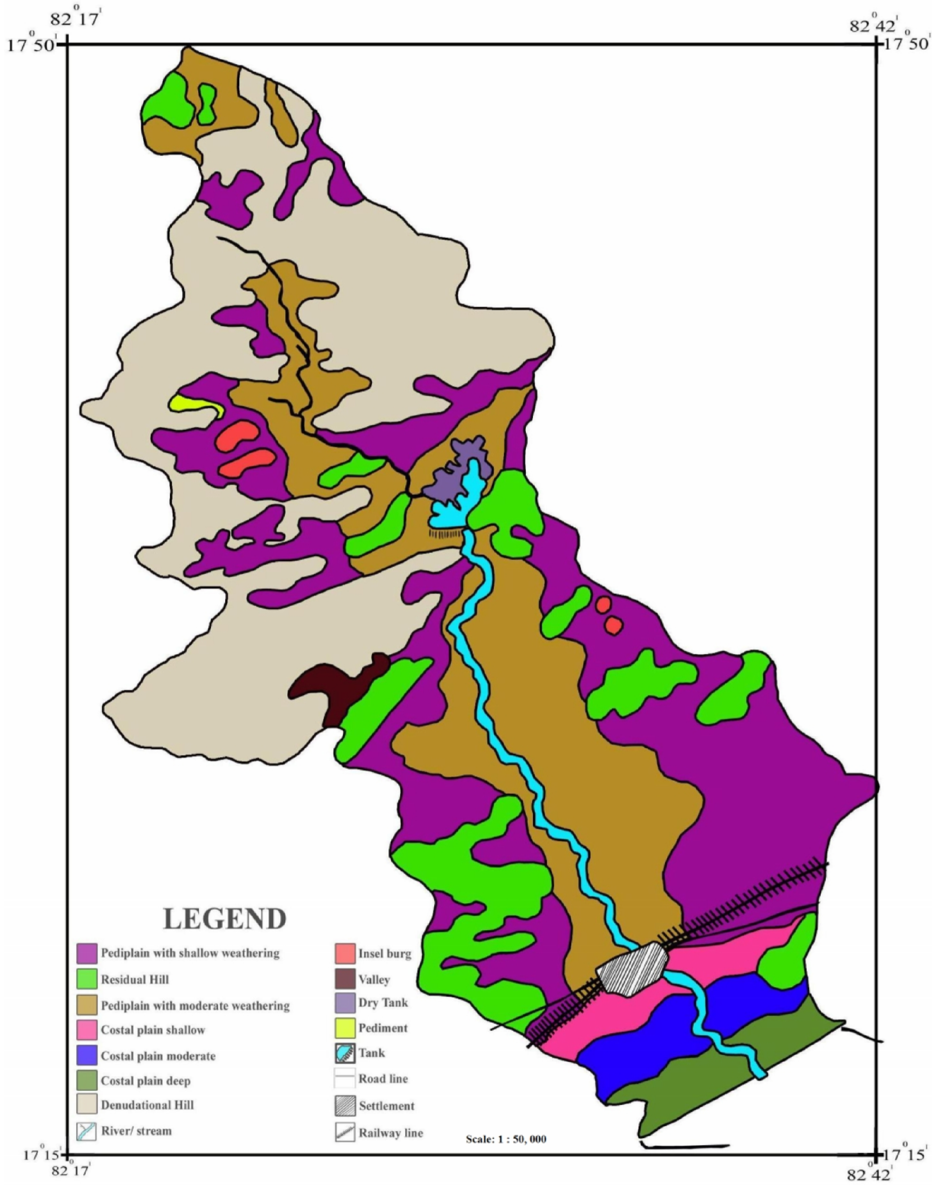

Fig. 2. Geomorphology Of The Thandava River Basin

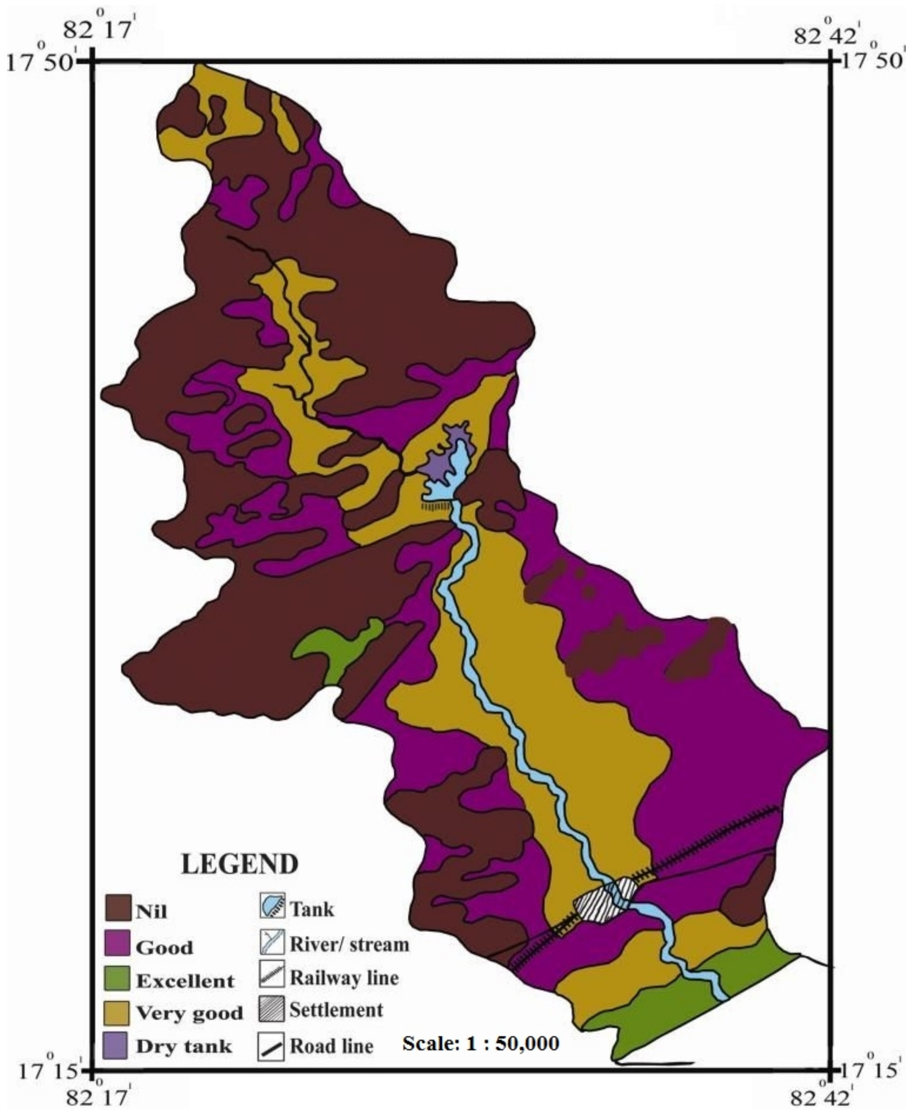

Fig. 3. Groundwater Potential Zones Along The Thandava River Basin

3.1 Geological Assessment

The soil/aquifer samples (28) collected at some of the points were thoroughly analyzed for the differentiation and origin basis in and around the river basin. Table 2 is the summarized results of the testing grain size and its outcome in assessing the local geology and the possible sources and their types in the study area. Soils differ in their capacity for crop production and suitability for irrigated agriculture. Their physical and chemical properties which determine this capacity and suitability are governed by several factors operating singly and collectively geological, topographically, climate, agronomies and biologically. The behavior of sub soil-waters also plays an important part in the final outcome. Under natural conditions, there is a soil-water crop relationship peculiar to each area.

Table 2. Results Of Soil And Aquifer Samples Of The Thandava River Basin

S.No.	Sampling Station	Place	Cumulative Weight Percent Retained in Sieve Size (mm)						Passed Through 0.075	Geology*
			5.60	2.00	1.00	0.50	0.25	0.075		
1	Tuni	Aquifer	--	0.90	12.87	61.28	88.68	97.93	99.251	FMS
2	Satyavaram-1	River Bed	0.90	13.40	43.91	76.76	92.06	98.67	100.114	MS
3	Satyavaram-2	River Bed	--	0.45	3.30	42.85	90.41	98.86	99.126	FMS
4	Srirampuram	River Bank	--	4.55	8.48	12.70	26.06	93.58	99.196	STS
5	Peddirajupalem	Aquifer	0.32	1.22	4.28	27.52	79.07	99.77	99.797	FMS
6	Payakarao Peta	Aquifer	0.50	2.65	21.20	68.70	91.96	99.37	100.000	MS
7	Gopalapatnam	Aquifer	--	0.75	8.70	61.56	91.33	99.84	100.000	MS
8	Rekhavanipalem	Aquifer	5.45	14.85	27.66	59.91	88.21	99.87	99.983	MS
9	Kumamrilova	River Bed	--	1.87	11.68	72.23	93.38	99.94	100.000	MS
10	Kummarilova	River Bank	1.97	10.27	14.92	23.38	52.44	95.59	99.315	FS
11	Manivada	Field	1.55	11.91	21.93	45.44	70.07	96.94	99.301	FS
12	Nandivampu	Field	--	--	--	2.32	8.58	90.89	99.574	STC
13	D.Polavaram	River Bed	5.92	20.82	41.25	72.67	90.57	99.37	99.790	CS
14	Sitarampuram	River Bed	--	1.30	4.90	31.01	77.51	99.71	99.723	FMS
15	Guntapalli	River Bank	--	0.45	1.15	4.70	45.00	95.60	99.700	STC
16	Kollimeraka	Field	4.01	10.43	17.80	39.61	74.14	98.01	99.326	STC
17	Kollimeraka	River Bed	--	0.30	2.15	14.70	59.91	99.03	99.138	STC
18	Atikivanipalem	Field	7.52	17.19	25.42	44.38	72.91	99.59	99.293	MS
19	T.Jaganadapuram	Field	9.90	31.15	39.21	53.07	69.20	97.85	99.974	MCS
20	Surapurajupeta	River Bed	--	5.25	24.12	54.29	85.15	99.01	99.449	MCS
21	Agraharam	River Bank	1.35	15.61	23.26	74.92	89.68	99.95	110.000	MCS
22	Kakarpalli	River Bed	2.52	9.92	23.18	67.03	93.48	99.28	99.289	MCS
23	Kakarapalli	River Bank	12.35	23.92	29.18	54.03	63.73	95.79	100.047	MCS
24	Kotanaduru-1	River Bed	1.43	9.90	20.88	55.05	88.51	99.49	99.803	M S
25	Kotnanduru-2	River Bed	26.25	61.17	76.93	88.63	94.79	99.45	99.954	VCS
26	K.Mallavaram	Aquifer	--	1.65	2.98	23.79	81.34	99.74	99.852	FMS
27	K.Agraharam	River Bed	1.92	14.67	42.95	80.20	95.46	99.11	99.488	M S
28	K.Agraharam	River Bank	--	3.89	6.99	14.22	38.51	94.57	99.225	FS

***FMS = Fine to Medium Sands; FS = Fine Sands; MS = Medium Sands; MCS = Medium to Coarse Sands; CS = Coarse Sands; VCS = Very Coarse Sands; FS = Fine Sands; SC = Sandy Clay; STC = Silty Clay; STS = Silty Sands**

There are mainly three types of soils in this river basin. They are i) Red Loamy soils in the upper reaches of the basin ii) Red Sandy soils in the interior and iii) Coastal sands and alluvial soils in the coastal belts. The extent of these soils in the basin with respect to the total area is 63.80% (582.00 Sq. Km) of Red Sandy, 29.2% (265.89 Sq. Km) of Coastal Sands & Alluvial and 7% (63.89 Sq. Km) of Red Loamy. Red sandy soils cover the largest area (interior) in the basin. The regions occupied by acid granite, gneiss, quartezite and feldspar, with only subordinate rock types rich in iron and magnesium bearing minerals, gives particularly to red soil, but at places yellow to grey or even black colored soils. Some red colored soils are of different constitution having been derived from the surface – cropping of laterized rocks or from limestone formations. This type of soil, though frequently red in color not always necessarily so, and the color is not due to a high percentage of the iron content. Texturally, red soils comprise course sandy loams, medium fine sandy loams, fine sandy loams and loams. The deep red soils exhibit a sandy loamy texture at the surface, loamy composition in the deeper layers. The soils usually are friable and light textured, sufficiently permeable to be well drained, have water retainability, negligible, salt content seldom, exceeding 0.2%, a low base status and are almost free from lime concentration and carbonates etc., these soils are deficient in exchangeable bases. They are different in nitrogen and organic matters but, have sufficient potash and lime. The extent of available phosphate is generally low to sufficient. Because of they are being friable, well drained and easily manageable and are capable of withstanding heavy moisture saturation without detriment to crop growth.

The sandstones present in the study area belong to the Upper Jurassic age and that of the Tirupati standstone (Goundwana group). The general character and distribution of these would be the intercalation of clay and sandstones, brown in color. These are generally suitable for light tube wells with a discharge of about 30,000 liters per hour and these groundwaters are in general good. Coastal sands and alluvial soils occur in the coastal belt of the Thandava basin. Alluvial souls are as a rule, of sedimentary type and are found in the deltaic areas and on the coastal belt belong to the Recent type. They are formed by annual depositions of rich silts brought down by rivers. On the basis of texture, these soils can be silty loams, clay and rarely sandy loams. They are generally well drained and being inherently fertile. They respond well to irrigation and generally give high crop yields, but at some, there have been reports of saline patches at various depths along the coast.

4. CONCLUSIONS

Interpretation of the VES tests indicates the presence of an alluvial aquifer that mainly consists of sand and clay. The resistivity of the aquifer between 30 to 140 ohm-m showed the increasing value, which indicated the existence of fresh groundwater. The geological structure can be summed up as, the coastal belt as Pleistocene, the central zone and Northern parts with Archean type rock and khondalites, with the remaining as unclassified crystalline correlates with the other results. These are correlated to the presence of the Red and mixed soils, which predominantly exist in this basin. Their permeability and low water holding capacity react favorably to the application of irrigation water, as they are friable, well drained and easily managed.

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COMPETING INTERESTS

Authors declare that there are no competing interests.

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