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Original Research Paper

Geochemical Assessment of Groundwater Along Thandava River Basin, Andhra Pradesh, India

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ABSTRACT

Groundwaters under the influence of the river basin and of the reservoir sources undergo vibrant fluctuations due to various geochemical and geophysical characteristics along with seasonal impacts. To understand these influences, a geochemical assessment was made to reveal the groundwater quality and other geophysical characteristics. 117 water samples were interpreted for two seasons along the Thandava River basin. All the major cations, anions along with physical characteristics were assessed. The correlation of geophysical and geochemical parameters revealed the factors controlling the groundwater quality along the basin and in and around the reservoir. An in-depth assessment was also made for the geochemical evolution and flow pattern of the groundwater to understand the geomorphology of the basin and for the recommendations to be made for the safeguard of this natural resource unaffected from various anthropogenic activities in and around the basin and the reservoir.

INTRODUCTION

Groundwaters influence the prosperity of human civilization since ages. Groundwater along river basin regions maintained its quantity and quality for all kinds of purposes over the years. The idea of weathered, fractured and freshwater basements along with local environment would enhance these chances in any given area. But settlements in due course and overexploitation without management made groundwater to suffer in maintaining its basic characters. Reasons might not be limited but vigilance in time might restore or reduce the onslaught and, thus, safeguard the futuristic needs. Assessments of groundwater involve multiple approaches basing on the type of interpretation and thus status leading to management strategies. An understanding of the quantitative and qualitative changes in groundwater system because of existing and proposed hydrologic stresses is a prerequisite for their proper management.

Delineation of aquifers is the prerequisite for assessment of regional/local groundwater potential. Delineation of aquifers and subsequently their groundwater potential assessment were carried out in different parts of the country by using different geophysical, geological and geochemical methods depending on the local hydro-geological conditions (Rai 2009). Geochemical studies on the Dankar, Thinam and Gete lakes in the Spiti valley of Higher Himalaya was carried out to understand the nature of lithology and the type of weathering at the source (Das & Dhiman 2003), geochemistry and quality assessment was reported by Singh et al. (2007) and hydrogeological and hydrochemical study on Kali-Ganga was also reported by Asad et al. (2001).

Groundwater studies involving integrated approach reported mainly basing on the geophysical dominance assessments relating to areas in and around the present study area include, mathematical modelling basing on resistivities by Vinod Rao & Gurunadha Rao (2006), integration of geoelectrical and pumping data by Subba Rao (2003), and electrical resistivity surveys by Sagar & Nagamalleswara Rao (1989) have applied in Varaha River basin. In fact, studies like these carried in assessment of groundwater potential or for the matter of any other had used only one interpretation. But from comprehensive and thus by making use of water supply to meet the ever-increasing demands for domestic, agricultural and industrial uses makes more benefits. Consumption of water has increased in manifold results, scarcity of water supply and deterioration of water quality is seen in many parts of the world and to a larger extent in India. To cope up with such problems, it was the nation's endeavour to promote the activities of sustainable development, management and governance of water resources to achieve the goals of safe and secured water supplies and to maintain the pace of developments in agricultural and industrial sectors. In assessment, development and management of surface/ground-water resources to meet the demands of water supply from available water resources, the present novel approach of integrated assessment is carried out. Review of these, revealed the respective interpretations being dominant rather than a comprehensive study and which might not be needed, if focused on for a particular characteristic study. But, at the same time, multiple parameter analysis with integrated interpretation would always reveal an overall scenario of better understanding and thus leading to confirmation rather than speculation. The present survey was carried in 117 locations along the Thandava reservoir during June 2010 along with soil sample collection. The 117 water samples were collected in the pre and postmonsoon seasons of the same year.

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°50' and 17°15' north and maximum width from east to west of 21°52' between longitude 82°17' and 82°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 2/3rd of the catchment lies in the former district and the balance lies in the later district.

Thandava River flows over the Chintapalli, Narsipatnam, Tuni and Yelamanchili taluks for a length of 99.7 km. The Thandava River rapidly falls to +1000 in its first 9.5 km reach. After travelling about 14.4 km, it receives a tributary Sapegedda kalva, Lower down Peddagadda lanka, another tributary flowing in westward direction falls in to Thandava, after the later traversing a distance of 19.3 km from its origin. The level at this confluence is +6502. After travelling another 10.4 km, a small tributary from west comes and joins the river, the bed fall in this reach works out to about 1 in 264. At about 40.2 km of its traverse, a minor tributary formed by the small streams *viz.*, Dharagedda and Chittampadugedda and Gorrigedda, join the Thandava flowing in southward direction. After 4.8km confluence, another tributary Addakalagedda joins the main river from the west. Lower down after 11.2 km another tributary from west Sarugudugedda taking its origin in Sarugudu forests falls in Thandava River. After this there are no streams worth monitoring that join the Thandava River. This reach is flat, and the average bed slope is mild until the river enters the Bay of Bengal at Pentakota in Visakhapatnam district.

Topographically, 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 part which is plain. The entire catchment 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 forests 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 sampling stations of groundwater samples, resistivity stations, soil samples and rain gauge stations are shown in Fig. 1.

Criteria of sample collection: 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 analysed, methods of data collection and also the handling procedures. Sampling points should be such that, they represent the existing environment (APHA 1995). The discussions with the Groundwater Board prior the sample collections and before the finalizing of the number, parameters to be analysed, mandals to be covered, district topographical marking of the stations, etc., had made meaningful effects at various stages of the work in the study area. 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 actual work to be carried out in smooth manner.

Problems can occur during or after sampling which may drastically change the sample composition from its true form, as natural waters are of great matrix of dynamic phases. These are due to a variety of causes, the principal among which are contamination and loss of substance due to precipitation, complex formation, adsorption or ion exchange on the container wall. Compounding these difficulties is the main task in sampling. The chemical composition of the rock formations, though is expected to reflect an average trend in the variations with a small region of a rock formation, often poses a constraint in arriving at acceptable averages. This is mostly due to differential P-T conditions at the time of formation. One has to consider such constraints existing in different geological settings before arriving at average or compositions of rock formations and their contributions to groundwater quality. At the same for taking resistivity reading, it would not suit the same as it will be expensive as well as a laborious exercise.

Electrical conductivity and pH provide an integrated

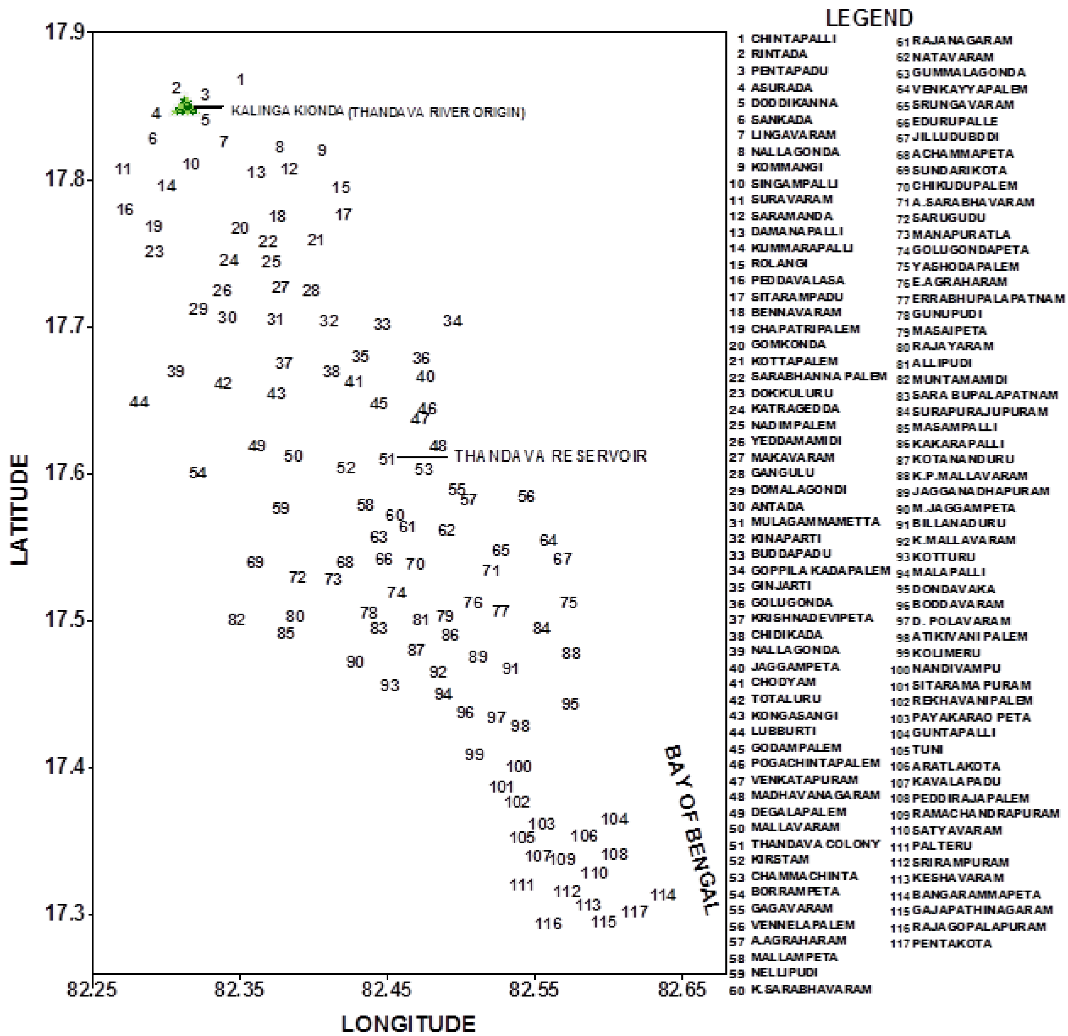

Fig.1: Sampling stations along Thandava river basin.

characteristic of the ionic composition and its thermodynamic state. Keeping this in view water samples collected from cluster of wells located in the same geological formation and similar hydrological setting were collected and analysed in the field for the above two parameters. Subsequently, based on the average values and their relative variations and the geological, geomorphologic and geo-hydrological characteristics (even though resistivity values might alter even for small differences in geological areas), the well which possesses EC and pH hydrogeological values close to that of a general average trend of the cluster, has been identified as a sampling location. Wherever significant anomalies were present in a local scale, an attempt was made to identify the reasons for such anomalies before they are eliminated from sampling. However, locations of specific geological, hydro geological significance and stations in vicinity of industrial units were given importance in sample collection.

During the entire study, care was taken in identifying the nearest possible source to the river path of a particular area and at the same time it should be a potable source of the local people. A minimum of 1 km distance and a maximum (depending on potable source in the area) of 3km distance was maintained between the sampling stations. In all the cases, the sample source selected is a public open or bore well or that of a privately owned, but used by the locals as potable sources were only considered. In some cases, both open and borewell waters were collected for comparative study, as these areas are spread over large distances coming under the same station. Municipal sources, even in the absence of groundwater source for drinking water, in any area has not been considered for sample collection, as these are generally supplied with pre-treatment. As the the investigation is already planned to carry the assessments through geophysical and chemical analysis, the collection of the soil samples was taken at the site itself. As the result, not the same number of samples of soils was taken as those of the water, but were rather sufficiently and representatively for the study area.

Groundwater samples were collected in three litre capacity polythene bottles having double stoppers. Prior to the collection, the well cleaned sample bottles were rinsed thoroughly with the sample water having been collected and filled to neck, avoiding bubbling and closed to air tight. In case of borewell water collection, water was collected only after considerable quantity was discarded after pumping. In open wells water from a depth of about one meter from the upper surface of water was collected and was labelled. The station's latitude and longitude were obtained by using GPS at the site. The values of coordinates were cross checked using topo sheets of the respective districts (District Ground Water Board). After finalizing the number of samples collected, 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. Collected water samples were brought to the laboratory and stored in dark to avoid major chemical alterations (Golterman et al. 1978) and analysed on the next day. The rainfall data of the area for five years was collected from the groundwater department assessments at two rain gauge stations.

RESULTS AND DISCUSSION

The water samples collected were analysed for both physical and chemical properties. The samples were analysed for pH, electrical conductance (EC), total dissolved solids (TDS), bicarbonates (HCO_3^-), chlorides (Cl^-), fluorides (F^-), phosphates (PO_4^{3-}), sulphates (SO_4^{2-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+).

Groundwaters had pH in the range of 7.12 to 8.52 in pre-monsoon, and 7.12 and 8.70 in the post-monsoon seasons. These values indicate the dominance of the alkaline waters in these areas and thus signify the general nature of the groundwaters to be in line with prescribed values for all uses, either for drinking, agricultural or industrial purposes etc. The electrical conductivity values of the water samples ranged from 178 to 4828 in pre-monsoon and 562 to 4280 μSiemens/cm in post-monsoon respectively. The higher values in some cases can be attributed to the presence of high bicarbonate and chlorides in those areas. The concentrations of TDS ranged from 110 to 3093 in pre-monsoon and 294 to 3428 mg/L in post-monsoon seasons respectively.

The concentration of the cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) in the investigated area range from 8 to 272, 4 to 272, 6 to 680 and 1 to 175 mg/L respectively in the pre-monsoon season, and 20 to 226, 14 to 154, 24 to 560 and 01 to 110 mg/L in post-monsoon season. The anionic (HCO_3^-, Cl^-, SO_4^{2-}, F^-, PO_4^{3-}) concentrations in the groundwater samples of the area range from 40 to 722, 9 to 1018, 1 to 284, 0.12 to 1.64 and 0.001 to 1.206 mg/L in the pre-monsoon season, and 80 to 702, 42 to 872, 2 to, 415, 0.10 to 2.12 and 0.001 to 1.66 mg/L in post-monsoon season respectively. A statistical summary of the chemical analysis data in the pre and post-monsoon seasons is given in Table 1.

The highest temperature recorded in this basin is 47.2°C in June, and lowest is 14.4°C in December. During May, as generally considered for the summer season month, the temperature ranges from 27.6°C to 37.3°C and for monsoon and winter months ranges from 24.4°C to 31°C and 19.1°C to 27°C respectively. Rainfall average at Kotananduru and Tuni rain gauge stations for the last five years was 3.5 and 4.8 m respectively.

Geochemical evolution of groundwaters: To identify the geochemical evolution and sources of dissolved salts in groundwaters, Piper's trilinear diagram (Piper 1994) was used. The diagram is the combination of the percentages of the total meq/L of cations and anions. The chemical data of the pre-monsoon season that in the percentage mode of all the groundwater samples in the study area fall in zone 5 are 23.93% and the stations which include these are the 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 20, 27, 28, 29, 30, 31, 41, 47, 89, 92, 94, 97, 107 and 112.

The samples fall in zone 7 constitute 31.62%, and are present at sampling stations 21, 25, 33, 34, 35, 37, 38, 40, 46, 53, 63, 64, 65, 67, 68, 69, 70, 71, 72, 73, 76, 77, 78, 79, 80, 82, 84, 86, 100, 101, 104, 105, 106, 110, 115, 116 and 117. The samples observed in zone 9 have a percentage of 44.44%, which come from the stations 15, 16, 17, 18, 19, 22, 23, 24, 26, 32, 36, 39, 42, 43, 44, 45, 48, 49, 50, 51, 52, 54, 55, 56, 57, 58, 59, 60, 61, 62, 66, 74, 75, 81, 83, 85, 87, 88, 90, 91, 93, 95, 96, 98, 99, 102, 103, 108, 109, 111, 113 and 114.

In post-monsoon season, zone 5 has 10.25% with stations 1, 2, 11, 43, 90, 92, 94, 95, 96, 97, 98 and 99, zone 7 has 32.47% with 8, 9, 17, 20, 22, 23, 25, 32, 35, 37, 38, 48, 52, 53, 56, 65, 66, 70, 71, 74, 75, 76, 77, 78, 85, 87, 100, 105, 106, 107, 108, 110, 111, 112, 113, 115, 116 and 117 stations, and zone 9 has 57.26%, which include stations 3, 4, 5, 6, 7, 10, 12, 13, 14, 15, 16, 18, 19, 21, 24, 26, 27, 28, 29, 30, 31, 33, 34, 36, 39, 40, 41, 42, 44, 45, 46, 47, 49, 50, 51, 54, 55, 57, 58, 59, 60, 61, 62, 63, 64, 67, 68, 69, 72, 73, 79, 80, 81, 82, 83, 84, 86, 88, 89, 91, 93, 101, 102, 103, 104, 109 and 114.

The above results indicate that these zones are due to the formation of carbonate hardness, non-carbonate alkali and

Table 1: Statistical summary of chemical analysis data in pre and post-monsoon seasons.

Para meter*	Minimum		Maximum		Mean		Standard deviation	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
pH	7.1	7.1	8.5	8.7	7.7	7.6	0.37	0.34
E.C.	178	562	4828	4280	1237.7	1513.6	770.7	723.0
TDS	110	294	3093	3428	855.1	1034.7	542.2	532.1
Ca^{2+}	08	20	272	226	59.9	68.6	35.5	39.5
Mg^{2+}	04	14	126	154	37.5	43.4	23.	23.6
Na^{+}	06	24	680	560	139.6	177.1	112	100.2
K^{+}	01	01	175	110	18.1	17.2	27.5	22.3
HCO_3^{-}	40	80	722	702	216.4	275	121	104.7
Cl^{-}	09	42	1018	872	167.3	215.6	177	163.6
SO_4^{2-}	01	02	284	415	51.6	74	38.6	81.1
F^{-}	0.1	0.1	1.6	2.12	0.81	0.8	0.4	0.3
PO_4^{2-}	0.001	0.001	1.2	1.66	0.18	0.3	0.3	0.3

***All parameters are expressed in mg/L, except pH and E.C.; TDS = Total Dissolved Solids, E.C. = Electrical Conductivity (µSiemens/cm)

Table 2: Hydrogeochemical ratios of groundwater samples along Thandava River basin.

Hydrogeochemical ratio	Mean	
	Pre Monsoon	Post Monsoon
$Mg^{2+} : Ca^{2+}$	0.67	0.75
$Ca^{2+} : Mg^{2+}$: Total cations	0.01	0.07
$Na^{+} : K^{+}$: Total cations	0.11	0.12
$Cl^{-} : Na^{+}$	1.26	1.33
$HCO_3^{-} : Cl^{-}$	2.15	1.81
$Na^{+} : Cl^{-}$	1.07	1.04
$CA_1 = Cl^{-} (Na^{+} + K^{+}) : Cl^{-}$	157.63	306.40
$CA_2 = Cl^{-} (Na^{+} + K^{+}) : (SO_4^{2-} + HCO_3^{-})$	167.341	210.000

mixed types of water, and were earlier observed by Subba Rao et al. (1996) in Visakhapatnam area and by Abjit & Alan (2008). In the present case, it is evident that the carbonate hardness results from the dominance of alkaline earths (Ca^{2+} and Mg^{2+}) and that of the weak acids (HCO_3^{-}) indicating the influence of soil chemistry on the groundwater chemistry. This water type (zone 5) represents the freshwater environment. The movements of the drainage (sub-dendritic) in the rainy season form the elevated to the plains along the stretch of the southern part highly donate this kind of activity in the sub surface topography. The non-carbonate alkali is attributed to the abundance of alkalies (Na^{+}, K^{+}) and strong acids (Cl and SO_4^{2-}) which are the effect of marine environment and/or clay horizons and topographic lows.

The waters occurring in the zone 7 belong to brackish/saline type. The mixed type (zone 9) represents the cations and anions that are not excessive of 50% in their total concentration due to combination of various types of water chemistry. Deviations from the general to an extent were observed in the geochemical evolution of the groundwaters classification basing the above criteria. They include the stations where the TDS value is greater than 1000 mg/L but fall in the mixed type in the pre-monsoon season are 49, 51, 52, 58, 59, 61, 91, 95, 111 and 113, and that of the freshwater are stations 25 and 112. In case of the post-monsoon season, the deviations include stations 5, 6, 10, 13, 14, 19, 21, 31, 33, 36, 44, 47, 49, 50, 58, 62, 68, 72, 73, 82, 84 and 89, which should be marine according to the criteria but were falling in the mixed type of water in the diagrams. In post monsoon season there were no deviations of station having the TDS value more than 1000 mg/L and falling in the freshwater environment of the classification.

The probable reason for these samples' deviation from the normal trend would be their undersaturation environment towards the new environment and sooner or later they would shift to maintain the new environment leaving the characteristics of the old environmental conditions. Another reason that would explain this deviation would be the recent changes in those areas like extension or compression between the fractures in the rocks to allow a different type of water into the formers environment and thus exhibiting variation. In cases of marine characteristics observation in the freshwater zones might be resulting from the forced intrusion of seawater due to overexploitation of groundwaters, where the upward pressure would force the surrounding waters to pave their way out by widening the linear fractures in the rocks. This is generally not observed in the natural circumstances, where the groundwaters remain static. The geochemical evolution of the groundwater in the pre and post-monsoon seasons are shown in Figs. 2a and 2b.

Stations showing the marine environment observed in most cases of the post-monsoon season, even in the absence of their TDS values less than 1000 mg/L or in cases of existence of the environment which is suitable for fresh or mixed type of water, might be the effects of the upland characteristics carried through different facies of different places after the rainfall, where these are observed. This dominance did not observe far away from the coast line nor the middle of freshwater environment would be temporary still the flow is settled and thereby the origin of the local geology would be evolved with time log. During the flow of water from the elevated to the downstream, results of the restless chemical equilibriums (Das & Kaur 2007) among various solute and solvents showcase these types of invariable environments and that to especially surrounding the flowing water bodies.

Flow pattern of the groundwater can be correlated with the hydro-geochemical facies as stated by Ophori & Toth (1989). According to them, low TDS, $Mg^{2+}:Ca^{2+}$ ratio and SO_4^{2-} and high HCO_3^{-} occur in the recharge areas. Whereas

Table 3: Geophysical characteristics of water sampling stations along Thandava River basin

Station	Type	D-1	D-2	W.L.D	Geology
Srungavaram	DW	11.50	02.62	05.12	Granite Gnesiss
Sarabhavaram	DW	05.62	02.40	04.01	Red Soils
Gannavaram	DW	07.33	01.80	04.70	W.Gneiss/ Black Soils
Bhimavarapukota	DW	07.70	02.02	03.80	Sand
Kakarapalli	BW	06.90	02.11	03.50	Alluvium
Allipudi	DW	06.50	02.05	03.20	Alluvium
Kotananduru	BW	06.15	01.82	04.02	Sand
Lakshmidevipeta	BW	18.02	100.00	05.30	Black Clay
Lakshmidevipeta	DW	08.20	02.12	04.55	Silty Clay
ChinnayyaPalem	DW	05.25	08.01	02.60	Silty Clay
Kotananduru	DW	04.50	08.35	02.01	Silty Clay (Khondalite Base)
K.Mallavaram	BW	21.05	102.00	03.02	Clay/Coarse Sand
K.Mallavaram	DW	06.02	01.62	02.20	Clay/Coarse Sand
Kotananduru	BW	18.50	105.00	-	Silty Red Soil
Kothapata	BW	22.55	102.00	04.56	Silty Red Soil
Boddavaram	DW	05.30	12.90	03.70	Red Soils
K.Agraharam	BW	25.02	104.00	06.05	Medium Sands
Venkatanagaram	DW	06.00	01.72	03.50	Red Soils
Venkatapuram	DW	09.60	01.62	03.55	Red Soils
Kottapalem	DW	08.30	01.65	03.45	Red Soils
Surapurajupeta	DW	09.35	02.50	05.80	Red Soils
Bangarayya Peta	D&B	12.65	03.50	06.30	W.Khondalites
Billananduru	DW	06.20	04.00	04.20	Red Soils
Jagannadhapuram	DW	07.60	02.50	02.40	Red Soils
Indupalli	DW	09.30	02.20	04.30	Red Soils
T.Jagannadhapuram	DW	08.10	02.00	11.00	Red Soils
Dondawaka	DW	05.10	05.60	04.45	Red Soils
C.Agraharam	BW	12.00	102.00	-	Red Soils/ Silty Sands
Atikivanipalem	BW	18.90	101.00	06.00	Silty Clay
D.Polavaram	BW	24.55	101.00	06.02	Silty Clay
Subbadrampeta	DW	09.12	02.30	06.10	Silty Clay
S.M.Peta	BW	13.40	105.00	03.60	Silty Clay / Medium soils
N.Suravaram	DW	09.80	02.10	04.70	Red & Silty Soils
Kollimeru	BW	21.00	104.00	04.60	Silty sands, Coarse sands
Kollimeru-2	BW	46.00	102.00	04.60	Silty Clay/W. Khondalite
Kollimerla	BW	21.50	100.00	06.00	Cobbles/ Pebbles Silty Sands
D.Polavaram-2	BW	27.00	01.00	07.20	Sity Clay/ Fine Clay
Atikivanipalem-2	DW	11.70	102.00	06.40	Silty Clay
Nandivampu	BW	18.50	100.00	06.00	Red Soil/ Silty Soil
Marrivada	BW	30.00	100.00	06.00	Red Clay/ Kankar
Marrivada-2	D&B	8.7/6	08.00	07.40	Red Soil/ Fractured Khondalite
Kummarilova	DW	05.30	03.80	02.70	Red Soils
Kumamrilova-2	D&B	8.5/15	08.40	06.50	Silty Soils/ Cobbles & Pebbles
Rekhavanipalem	D&B	8.6/20	08.30	06.40	Silty Soils/ Cobbles & Pebbles
Rekhavanipalem-2	BW	18.00	101.00	05.00	Silty Soils
PayakaraoPeta	DW	18.50	100.00	09.20	Red Soils/ W.Khondalites
PayakaraoPeta-2	BW	24.00	102.00	07.00	Silty Soil/Clay
Namavaram	DW	08.10	02.30	03.70	Black Clay
Namavaram-2	BW	34.50	102.00	-	Black Clay/ Khondalites
Guntapalli	DW	06.50	03.50	04.30	Clayey Silt
Mangavaram	Bw	19.50	100.00	08.00	Black Clay
PeddirajuPeta	DW	08.80	06.80	07.50	Silty Soils
Mangaram-3	DW	08.20	03.00	06.20	Alluvium
Mangavaram-4	BW	18.00	100.00	06.00	Black Clay
PayakaraoPeta-2	BW	45.00	100.00	06.00	Silty Soils
Aratlakota	BW	24.50	100.00	06.20	Clay
Aratlakota-2	DW	07.20	02.30	04.90	Alluvium
Satyavaram	DW	06.90	01.80	04.15	Alluvium
Mahasahebpeta	BW	24.00	100.00	03.10	Kankar/ Coarse Sand
Mahasahebpeta-2	DW	07.45	02.65	04.60	Black Clay
Srirampuram	BW	30.00	100.00	-	Sand Stone
Srirampuram-2	DW	06.00	01.90	04.00	Clay
Kesavaram	D&B	6.3/36	5.8/100	03.90	Clay/ W.Khondalite
Srirampuram-3	D&B	4.4/30.1	4/100	03.00	Clay/ W.Khondalite
Kotturu	BW	16.00	11.00	06.00	Clay with medium sand
Kotturu-2	BW	12.00	100.00	06.50	Clay/Fine Sand
Rambadrapuram	DW	07.60	02.30	03.90	Clay
Suravaram	DW	06.75	03.60	03.50	Clay
Suravaram-2	BW	18.00	100.00	08.00	Red Clay
Tuni	BW	15.00	100.00	06.00	Red Clay
Narsapuram	DW	07.20	06.30	07.00	Cobble & Pebbles
Narsapuram-2	DW	08.10	-	06.20	Red Soils

**BW = Bore Well; DW = Dug Well; D&B = Dug cum Bore
D-1 = Depth of the Well; D-2 = Dimension; W.L.D. = Water Level Depth

the opposite conditions, such as high TDS, Mg^{2+}:Ca^{2+} ratio and SO_4^{2-} and low HCO_3^-, are associated with the discharge areas. They further stated that the groundwaters of Ca^{2+}-Mg^{2+}-HCO_3^- and Na^+-HCO_3^- types are dominant in the recharge areas, while Ca^{2+}-Mg^{2+}-SO_4^{2-}-HCO_3^- and Na^+-HCO_3^- types occur in the discharge areas.

According to the correlation of hydro-geochemical facies with the flow pattern of groundwater system, which were observed in the pre-monsoon season, the low TDS (<1000mg/L), low Mg^{2+}:Ca^{2+} ratio (0.67) and SO_4^{2-} (<100 mg/L), and high HCO_3^-:Cl^- ratio, (2.15) and of the same when observed in the post monsoon season are as follows, 0.75 and 1.81 along with Na^+-HCO_3^- type hydrogeochemical facies

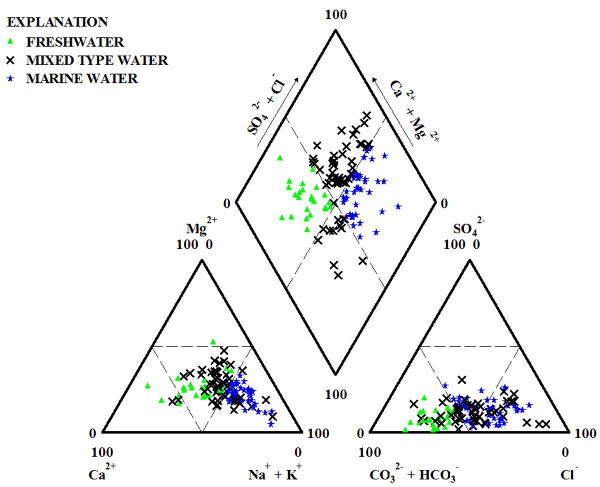

Fig. 2a: Geochemical evolution of groundwater in pre-monsoon season.

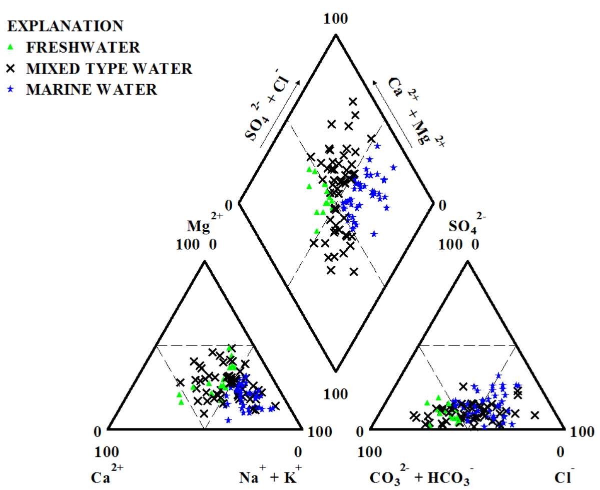

Fig. 2b: Geochemical evolution of groundwater in post-monsoon season.

observed in the parameters suggest that these areas lie in the predominated recharge zones (Table 2). But, in cases of high Mg^{2+}:Ca^{2+} ratio (17, 18, 22, 43, 45, 47, 49, 57, 68, 73, 75, 83, 84, 90, 107, 111 and 112 stations, where it is >1; and for the same in the post-monsoon are stations 4, 14, 15, 22, 25, 28, 29, 37, 46, 59, 67, 70, 77, 79, 80, 81, 82, 84, 86, 87, 88, 94, 104 and 112), indicate the association of these areas with discharge source. These variations in the local geology are being dominant in places of very high agricultural activities as stated by Alexander (1995) and crust weathering (Chebotarev 1955). In the present study, it can be concluded that, this is caused by either the low concentrations of Ca^{2+} due to ion exchange between Ca^{2+} and Na^+ or by the preferential removal of Ca^{2+} by precipitation as carbonates (kankar and/or calcrete). These waters seldom deviate from these local characteristics and thus are potable and reliable for agriculture with normal fertilizer additions.

Geological and geophysical assessment: The soil/aquifer samples collected at some of the points were thoroughly analysed for the differentiation and origin basis in and around the river basin. Table 3 is the summarized results of the analysis 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 behaviour of sub soil waters also plays an important role in the final outcome. Under natural conditions, there is a soil-water crop relationship peculiar to each area.

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% (362.00 sq. miles) of red sandy, 29.2% (165.22 sq. miles) of coastal sands and alluvial, and 7% (39.7 sq. miles) of red loamy. Red sandy soils cover the largest area (interior) in the basin. The regions occupied by acid granite, genesis, quartzite and felpathic, with only subordinate rock types rich in iron and magnesium bearing minerals, give particularly to red soil, but at places yellow to grey or even black coloured soils. Some red coloured 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 colour not always necessarily so, and the colour is not due to a high percentage of the iron content. Texturally, red soils comprise coarse sandy loams, medium fine sandy loams, fine sandy loams and loams. The deep red soils exhibit a sandy loamy texture at the surface and 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 fee from lime concentration and carbonates, etc. Generally, 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 being friable, well drained and easily manageable, they 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 colour. These are generally suitable for light tube wells with a discharge of about 30,000 litres per hour, and these groundwaters are in general good. Coastal sands and alluvial soils occur in the coastal belt of 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 textural characteristics, 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 cases there have been reports of saline depths at various depths along the coast.

CONCLUSIONS

The geochemical and geophysical assessment for the groundwater along Thandava river basin revealed the local geomorphology. The geological structure of the Thandava basin mainly consists of three types of rocks, i.e., the coastal belt is Pleistocene, the central zone and northern part of the basin is formed by Archean type rock, and khondalites. The remaining portion is unclassified crystalline which also belongs to Archean group. Red and mixed soils, which predominantly exist in this basin because of their permeability and low water holding capacity, react favourably to the application of irrigation water and do not give trouble. They are friable, well drained and easily managed. As such their behaviour is normal and good crop yields, especially paddy can be obtained from them with application of irrigation and modernization of the canals. Sugarcane and paddy can be raised in Kharif and bajra, ragi, ginger and other commercial crops can be grown in other season. Groundwaters include the geochemical zones due to carbonate hardness, non-carbonate alkali and mixed types of water. The carbonate hardness results from the dominance of alkaline earths (Ca^{2+} and Mg^{2+}) and that of the weak acids (HCO_3^-) indicating the influence of soil chemistry on the groundwater chemistry as observed in the geological assessment and represents the freshwater environment. The mixed and marine traces from non-carbonate alkali due to abundance of alkalies (Na^+, K^+) and strong acids (Cl and SO_4^{2-}) are curtsey of clay horizons and topographic lows as observed in the coastal belts.

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