Aquifer Systems and their Characteristics in West Godavari District, Andhra Pradesh, India

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Abstract : *West Godavari district with a geographical area of 7,795 sq.kms is one of the nine coastal districts of Andhra Pradesh. Alluvium, Sandstones (Gondwana-Tertiary formations) and granites/gneisses (Archaean crystallines) are the principal aquifer systems in the district. Deep exploration revealed the occurrence of areally extensive productive multiple aquifer systems down to a depth of 647 m in gondwana and tertiary formations. The thickness of cumulative thickness of granular zones is of the order of 24-124 m in gondwana formations and 18-98 m in tertiary formations. The number of major aquifer zones encountered ranges from one to six. The discharges of wells generally vary from 5-35 litres per second. The transmissivity is in the order of 50-3540 m^2/day while the storage coefficient is between 8.5 x 10^{-5} and 1.3 x 10^{-2}. Deccan trap with maximum of three flows form a ideal confining layer to the underlying gondwana formations resulting in free flow conditions. There has been considerable groundwater development in sandstone aquifers, resulting in considerable decline in piezometric surface over a period of time.*

Key words: *Aquifers, groundwater, granular zones, aquifer parameters, water levels*.

1..Introduction:

Groundwater is the backbone of India's agriculture and drinking water security (Govt. of India, 2012). Ground water, which is the source for more than 85 percent of India's rural domestic water requirements, 50 percent of its urban water requirements and more than 50 percent of its irrigation requirements is depleting fast in many areas of the country due to its large-scale withdrawal for various sectors (CGWB, 2013). For sustainable management of groundwater resource, understanding of aquifer systems with their disposition, potential and quality aspects is essential. No concerted effort has been made on aquifer mapping and characterisation in the country on microlevel for efficient groundwater management on micro-watershed/administrative level. Of late Ministry of Water Resources, Government of India proposed aquifer mapping on 1:50,000 scale with an objective of delineation of aquifer geometry, linked to groundwater management with participatory mode at village level. Central Ground Water Board (CGWB) has brought out atlas of aquifer systems of India on regional scale (1:2 million scale), in which country has been divided into 14 principle aquifers, which are further divided into 42 major aquifers (CGWB, 2012). As part of its regular programmes, CGWB generated huge sub-surface data through exploratory drilling down to 647 m depth in West Godavari district, Andhra Pradesh. The data generated is utilized for preparation of cross section and to understand aquifer geometry and aquifer characteristics. The objective of this paper is to bringout aquifer geometry and to understand their aquifer characteristics in the district, which helps planners in formulation of management plans.

2. Study area:

The West Godavari district with a geographical area of 7,795 sq. km (north latitudes 16^0 51' to 17^0 30' and east longitudes 80^0 50' to $81^0$55') is one of the nine coastal districts of Andhra Pradesh (**Fig.1**). Agriculture is the mainstay of population in the district. It is mainly drained by Godavari, Yerrakalava, Tammileru and Ramileru rivers. Physiographically, the district is divided into alluvial plain (mostly delta) covering 30 % of the area and upland areas constituting 70% including forest area. The alluvial plain is mainly served by surface irrigation with good network of canals, whereas in the upland areas comprising sedimentaries and crystallines, the irrigation is mainly by ground water. The net area irrigated through canals form 59.5 % of the area irrigated while 35 % is irrigated through ground water. The principal crop grown is paddy. The normal annual rainfall recorded is 1078 mm. The important landforms include structural hills, pediplain, pediment inselberg complex, coastal landforms and valley fills.

3. Geology:

The district is underlain by geological formations ranging from the oldest Archaeans to Recent alluvium (**Fig.2**). The Archaeans occupy an area of 15 %, in northern most part of the district and forms basement for the Gondwanas (Lower Triassic to Middle Jurassic period), in the remaining area, constituting Chintalapudi, Gollapalli, Raghavapuram and Tirupathi formations comprising sandstones, clays and shales. Two isolated patches of Deccan Traps (Basalts) of Upper Cretaceous to Lower Eocene age occur in west central part overlying the Gondwanas. They are inturn overlain by

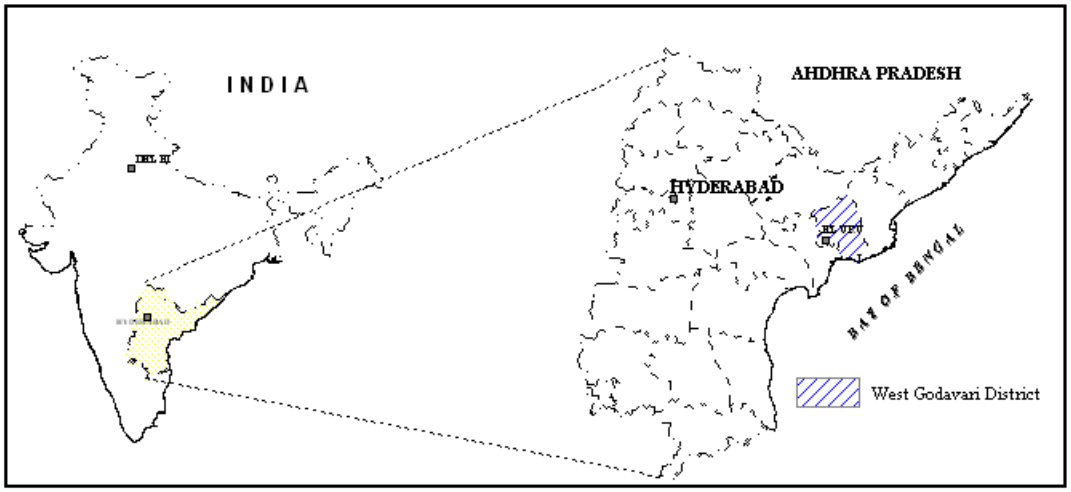


Fig. 1 Location of Study Area, West Godavari District, Andhra Pradesh

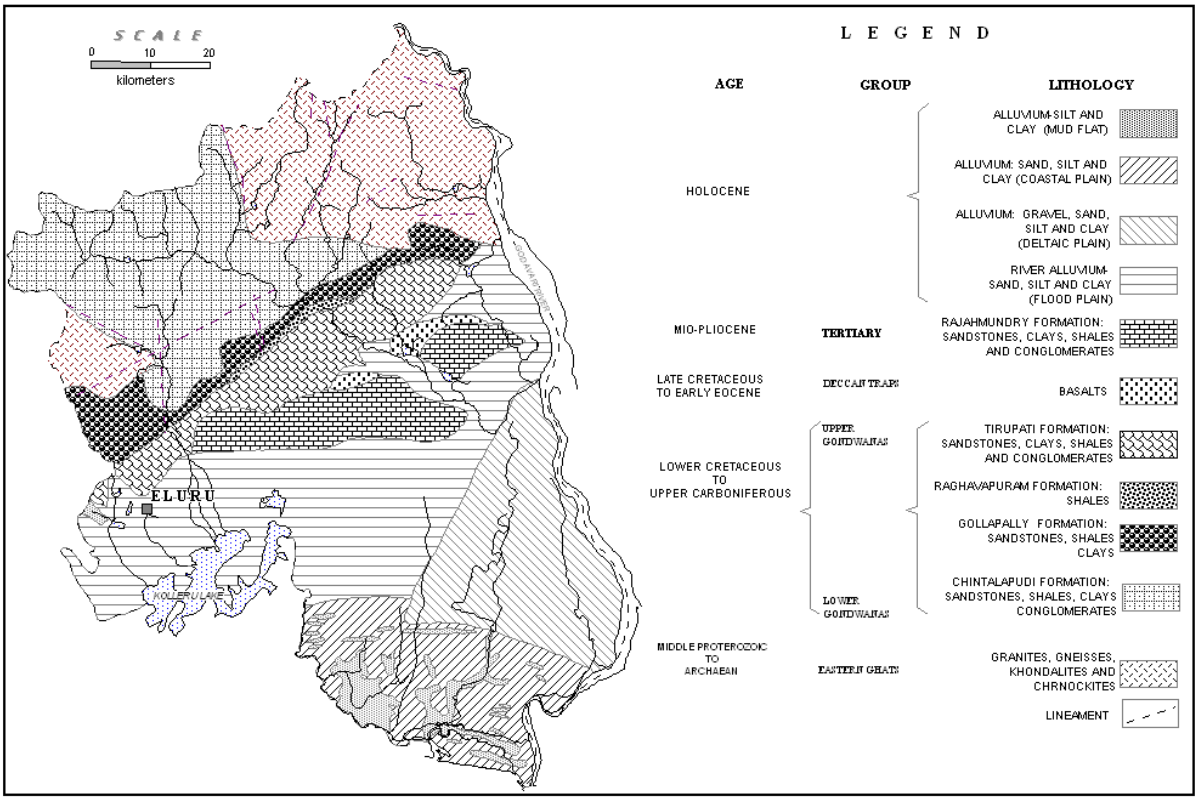


Fig. 2 Geology of West Godavari District, Andhra Pradesh

Rajahmundry formation (sandstones and clays) of Tertiary (Mio-Pliocene) age. Gondwanas and Tertiary formations occupy major part of the upland area. Deltaic Alluvium of Recent origin covering about 30% of area is the youngest formation occupying alluvial plain. The geological succession is given in **Table-1.**

4. Aquifer Systems and their disposition:

Hydrogeologically, the geological formations in the study area can be classified into three distinct groups: Alluvium (deltaic and fluvial), Sandstones (Gondwana-Tertiary formations), and crystallines (granites/gneisses, basalts). Alluvium composed of sand, silt, clay is formed under deltaic (fluviatile-marine) and fluviatile environments. Gondwana-Tertiary formations consist of sandstone, conglomerate, shale etc., in which sandstones (of different ages) form aquifers. In crystallines, granite (granite, charnockite), gneisses (khondalite) are the major formations while basalt outcropped area is limited. Considering this, the geological formations in the district have been divided into three principal aquifers i.e., gneiss, sandstone, alluvium (**Fig.3**).

Table 1: Geological Succession in West Godavari District, Andhra Pradesh

Age	System	Formation	Lithology
Recent to Sub-Recent		Alluvium	Gravel, sand, silt, clay
Unconformity			
Mio-Pliocene		Rajahmundry	Conglomerate, sandstone, clays
Upper Cretaceous to Lower Eocene		Deccan Traps	Basalt, inter trappean and intra-trappean beds
Lower Cretaceous to Upper Carboniferous	Upper Gondwana system	Tirupathi Raghavapuram Gollapalli	Gritty and ferruginous sandstone, clays Sandstone, shale, Conglomerate Sandstone, shale
	Lower Gondwana	Chintalapudi	Sandstone, shale, clays
Unconformity			
Archaean			Khondalites, charnockites, granites and gneisses

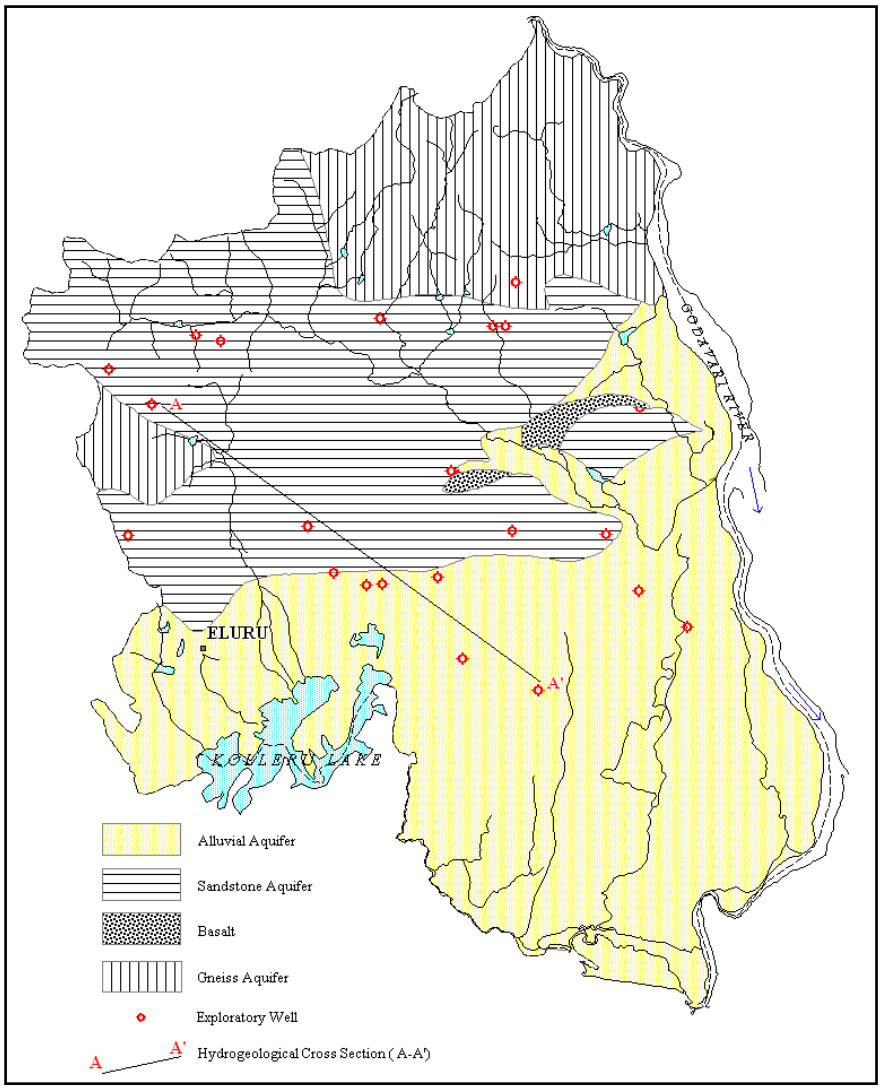


Fig. 3 Principal Aquifers, West Godavari District, Andhra Pradesh

4.1. Gneiss Aquifer System:

Weathered (shallow) and fractured (deep) zones constitute aquifer zones. The occurrence and movement of groundwater is controlled by the degree of inter connection of secondary pores or voids developed through fracturing and weathering. The weathering thickness varies from 5.0 to 20 m bgl. Groundwater occurs under unconfined conditions in shallow weathered zone while it occurs under semi-confined conditions in fractures at various depths. In shallow aquifers the groundwater is developed by large diameter dug wells with depth ranging from 5 to 20 m and yield of 20 to 50m^3/day. In deep fractured aquifer, groundwater is tapped through bore wells at favourable locations (site specific) with depths varying from 20 to 50 m bgl. In general these rocks are not suitable for extensive ground water development except at hydrogeologically favourable locations.

4.2. Sandstone Aquifer System:

The deep exploration carried out by Central Ground Water Board revealed the occurrence of areally extensive multiple aquifer systems down to explored depth of 647 m (Rao.P.N., 2009). Chintalapudi, Gollapalli and Tirupati sandstones of Gondwana Super Group and Rajahmundry sandstones of Tertiary age form productive aquifers. The Tertiary Rajahmundry formation has a minimum of 9 m thickness and a maximum of 442 m while the Gondwana has a maximum thickness of 600 m. The thickness of coarse granular zones tapped in wells ranges from 24 to 107 m in Chintalapudi, 12-71 in Gollapalli, 20-124 in Tirupati, and 18-98 m in Rajahmundry formations, down to explored depths. The aquifer zones available vary from one to six. The percentage of granular zone thickness ranges from 14 to 93 down to 300 m while the same varies from 25 to 77 beyond 300-600 m depth.

An attempt was made to bring out the sub-surface aquifer disposition of aquifer zones by sub-surface cross section (**Fig.4**), along Pragadavaram - Kesavaram in NW-SE direction cutting across all sandstone formations (A-A^1 shown in Fig.3). In all four faults have been deciphered. Two aquifers are delineated at Vempadu – the top one lies in Gollapalli formation and the bottom lies in Chintalapudi formation. Similarly at Tirumalampalem, three aquifers viz., two in Tirupati and one in Chintalapudi formation are identified. At Pulla, six aquifer zones are deciphered viz., one aquifer in the alluvium, three aquifers in Rajahmundries and two aquifers in Tirupatis. At Kesavaram three aquifers i.e., one in alluvium and the other two in Rajahmundry formation are identified. It can be seen that the shale of Chintalapudi formation which is exposed at Pragadavarm and Mudicherla is encountered below Gollapalli formation at Vempadu and below Tirupati sandstones at Tirumalapalem. Similarly, the Gollapalli sandstones which are exposed at Vempadu do not occur at Tirumalapalem due to faulting.

4.3. Disposition of Deccan Trap:

Deccan traps occur as two isolated patches in the west central part of the district. The exploratory drilling has brought the presence of traps at different depths with varying thicknesses (**Table- 2**). The Deccan traps do not form aquifers and however act as confining layer to the underlying Gondawana aquifers and represents a

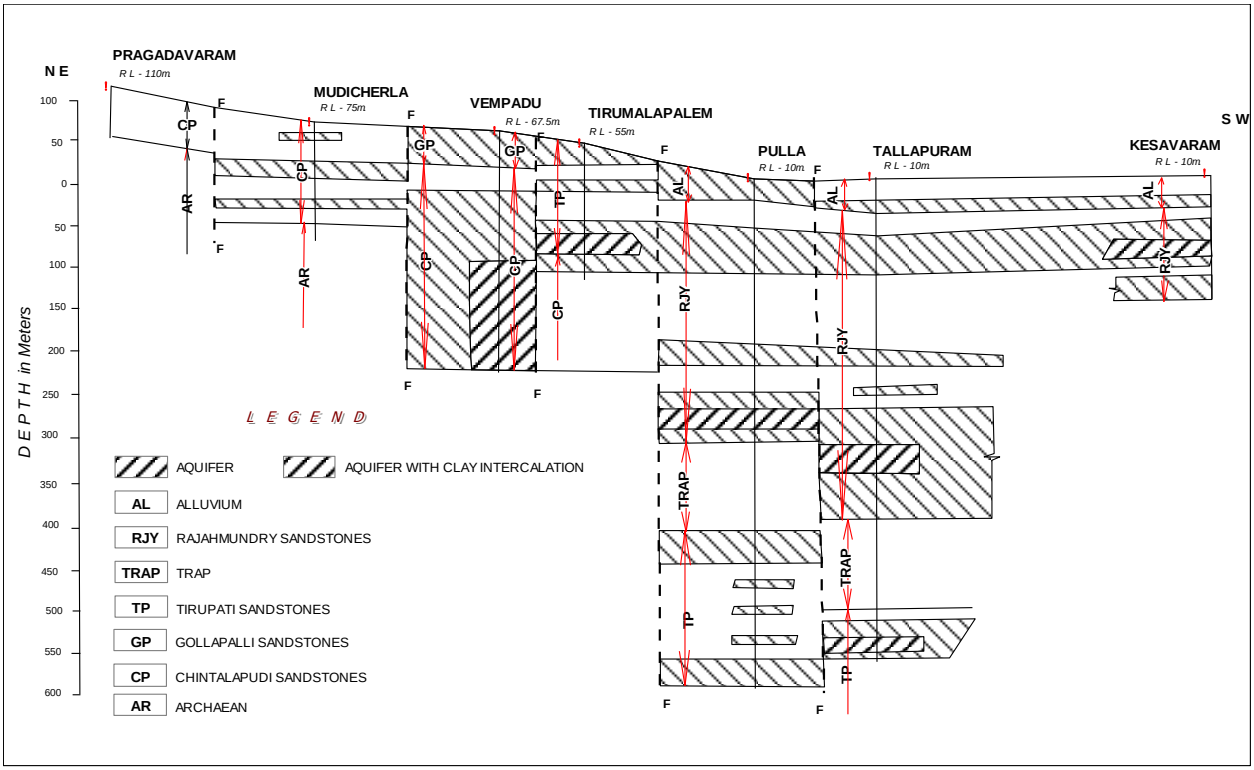


Fig. 4 Geological Cross Section in West Godavari district, Andhra Pradesh

conspicuous marker horizon. The depth to top of trap ranges in between 1.3 m and 421 m. The number of flows varies from one to three and the total thickness of trap is of the order of 3.5 to 82 m.

4.4. Alluvial Aquifer System:

Ground water resource is not tapped as the area is under canal command and as such development is insignificant. Ground water is developed through dug wells for domestic purpose. However, along Godavari river groundwater is exploited by shallow filter point wells down to depths of 30 m with discharges varying upto 15 lps in fluviatile borne alluvium. In deltaic alluvium, which is deposited under marine-fluviatile environments, fresh water is limited to shallow zone only. Deeper aquifers are saline, as seen from data collected from two exploratory wells drilled down to depth of 400 m, which were abandoned due to high salinity. The salinity is of inherent nature, owing its genesis to depositional environment of formation (Rao, 2009).

5. Aquifer Characteristics:

Ground water occurs under unconfined, semi to confined conditions in different formations of the area. In the gneiss aquifer system the yield of the open wells range from 20 – 50 m^3/day and the discharge of bore wells varies from 17.28 to 648 m^3/day for drawdowns of 1.35 to 4.78 m (**Table-3**). In sandstone aquifers the aquifer characteristics vary widely depending upon the thickness of granular zones and compaction. The Chintalapudi sandstone formations are relatively hard on surface and forms good aquifers with granular zone thickness varying from 24 – 107 m and the yield of wells ranges between 7-28 lps and the transmissivity values are in the order of 50 to 1338 m^2/day. In Gollapalli sandstone, the thickness of granular zones varies from 12 to 71 m and the depth of the wells range between 75 and 120 m with discharges of 8-16 lps. In Tirupati sandstone formation, the depth of the wells range between 99 and 250 m with yields varying from 4-18 lps and the thickness of granular zone is in the order of 20-93 m. In Gondwana sandstones, the yield of wells ranges from 3,700 to 60,000 lpm for drawdowns of 19 to 25 m. The average permeability is of the order of 10 m/day. The transmissivity of aquifers ranges from 25 to 3540 m^2/day. The storage coefficient is between $8.5x10^{-5}$ and $1.3x10^{-2.}$ The depth of the wells in Rajahmundry sandstones range between 32 and 611 m and the discharge varied from 15-35 lps with thickness of granular zone in the order of 18 to 175m (Table-2). Ground Water development is negligible in alluvium, particularly in delta area. However, in fluviatile borne alluvium (along Godavari river) groundwater is developed through filterpoint/shallow tubewells ranging in depth down to 30 m with yield varying up to 15 lps.

Table 2: Disposition of Deccan Trap in sub-surface at select locations in West Godavari District

S. No.	Location	Top of Trap (m bgl)	Bottom of Trap (m bgl.)	Number of flows
1.	Pangidigudem (16°51'14": 81°19'33")	150.0	183.0	1
2.	Bhimadolu (16°48'38": 81°15'46")	132.0; 151.0	140.0; 177.0	2
3.	Pulla (16°48': 81°22')	348.0; 353.0; 374.0	353.0; 366.0; 400.0	3
4.	Kaikaram (16°48': 81°22')	295.0; 331.0	317.0: 382.0	2
5.	Pullalapadu (16°56': 81°25'57")	3.0; 33.0	24.0; 45.0	2
6.	Jagannadhapuram (16°53': 81°24'10")	6.0	21.0	1
7.	Tallapuram (16°47'30": 81°25'25")	393.0; 454.0; 496.0	421.0; 469.0; 506.6	3

Table 3: Aquifer Characteristics in West Godavari District, Andhra Pradesh

S. No	Aquifer System		General depth range of wells (m)	Aquifer thickness/ granular zones (m)	Discharge range (lps)	Trans-missivity (m^2/day)	Type of aquifer zone
1	Gneiss - Shallow Deep		5-20 20-50	20 1-2	20-50 (m3/day) 1-5	- -	Weathered, Fractured
2	Gondwana	Chintalapudi Sandstone	60-120	24-107	7-28	50-1338	Granular zones
		Gollapalli sandstone	75-120	12-71	8-16	247-1055	-do-
		Tirupati sandstone	99-250	20-124	4-18 (occasionally upto 45)	76-846	-do-
	Tertiary	Rajahmundry sandstone	32-611	18-98	13-35 (occasionally upto 128)	395-3540 (cumulative values for Tirupati/Raja-mundry sandstones)	-do-
3		Alluvium	20	>5	Upto 15	-	-do-

There is a decline in the growth rate of dug wells (about 20 %) and increase in the growth rate of tube wells (300 %) during the last three decades in the district. The increased number of tube wells has resulted in a declining water table in major parts of Punjab state, India (Chawla, Khepar, Sondhi, Yadav, 2012). Since the alluvial area is under canal command, most of the groundwater development has taken place in potential sandstone aquifers in the area. The net area irrigated has increased from 50,978 (1975) to 2,05,787 ha (2006) in the district indicating an increase of four fold during three decades (Rao.P.N, 2009). The increased groundwater withdrawal on account of increased irrigation resulted in increased groundwater draft which is manifested in declining water levels in sandstone aquifers (**Fig.5**). The water levels truly reflect all the modifications that occur in aquifer system either in relation to rainfall, seepage, or natural discharge and extraction (Reddy,A.G.S., 2012). The total decline in the piezometric levels during the two decades is upto 2.08 m/annum in sandstone aquifers (Rao.P.N, 2009). In the late seventies, there used to be two autoflow zones in the district around Bhimadolu-Kaikaram in west central part and around Jeelugumilli-Darbavarm in northern part in sandstone aquifers. With the progressive groundwater development, free flow ceased to exist by mid nineties.

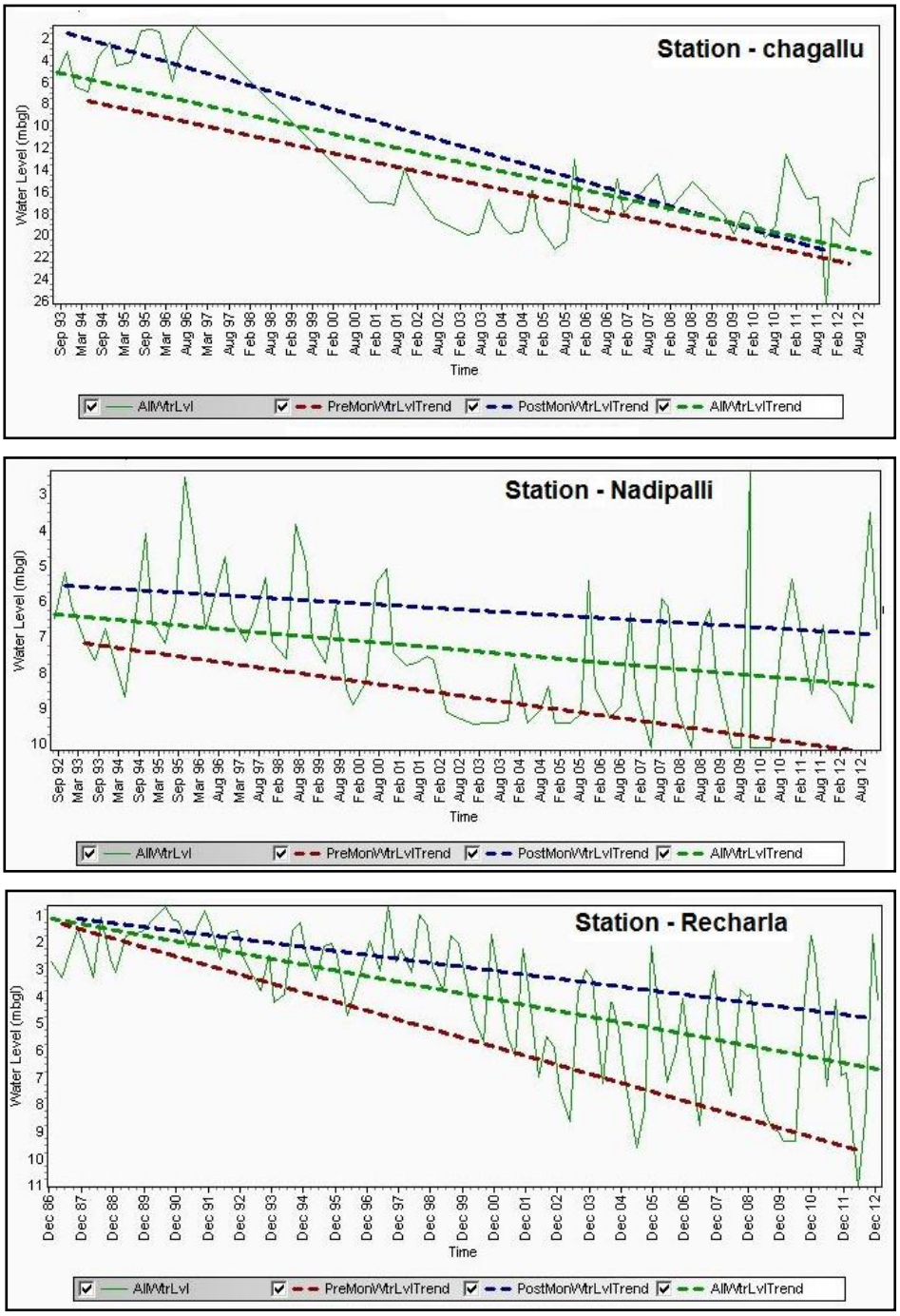


Fig. 5 Hydrographs of Select Monitoring Stations in West Godavari District, Andhra Pradesh

6. Conclusions:

1. In West Godavari district, areally extensive productive multiple aquifer zones exist down to a depth of 600 m in Gondwana-Tertiary sandstones. The thickness of granular zones tapped in wells ranges from 24 to 107 m in Chintalapudi sandstones, 12 to 71 m in Gollapalli sandstones, 20-124 m in Tirupati sandstones in Gondwana formations and from 18-98 m in Tertiary formations. The total number of principal aquifers varies from one to six, with a maximum of three in Tertiary and five in Gondwana formations.
2. In sandstone aquifers the aquifer characteristics vary widely depending upon the thickness of granular zones and compaction. The discharge of wells varies upto 35 lps. The transmissivity ranges from 25 to 3540 m^2/day. Considerable development is observed which has resulted in cessation of free flow and decline in piezometric heads over a period of time.
3. The Deccan Traps form ideal confining layer to the underlying Gondwanas resulting in free flowing conditions and is conspicuous marker horizon. However, they do not form aquifers.
4. In gneiss aquifer system the yield of the open wells ranges from 20 – 50 m^3/day and the discharge of bore wells varies from 17.28 to 648 m^3/day.
5. In alluvium groundwater development is negligible due to salinity and fresh water aquifers are limited to shallow depths only.

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