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Delineating the hydrostratigraphic units, hydrogeological boundaries and disposition of the multilayered aquifer system of Gundar river basin, Southern India through groundwater exploration techniques

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ABSTRACT

Information on aquifer geometry, primarily of the 3-dimensional and 2-dimensional aquifer disposition helps in better understanding of multilayered aquifer system. The study area, Gundar river basin of Tamil Nadu, India has been taken up for defining the fractured hard rock and sedimentary terrain and also for delineating the hydrostratigraphic units, hydrogeological boundaries and disposition of multilayered aquifer system. Three hydrostratigraphic units i.e., Alluvium (Quarternary), Cuddalore Sandstone (Tertiary) and Cretaceous Limestone are identified in the sedimentary terrain and one hydrostratigraphic unit i.e., fractured granitic gneiss / charnockite / khondalite (Archean) in hard rock areas. VES data of 48 locations in the basin have been interpreted to verify the existence of structurally weak zones and to decipher the depth of weathered rocks. The average values of apparent resistivities and the correspondingly high thicknesses of subsurface lithounits shown in most of the cases are indicators of structurally weak zones, which are important from the point of view of ground water development/recharge. NW-SE trending lineaments are potential in nature, Sustainable groundwater yields at depths ranging between 100–150 m. Shallow fractures, dense lineaments, deep water levels, high yields are indicative of recharge zone. This method will help identify possible groundwater zones which will help with targeted measures addressing groundwater sustainability.

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1. INTRODUCTION

Aquifer disposition defines the 3-dimensional and 2-dimensional representation of subsurface water bearing formations which are delineated by their hydrogeological properties and thereby helps in establishing the hydrostratigraphy of the region. Hydrostratigraphy is the identification of mappable units on the basis of their hydraulic properties that have a considerable lateral extent and form a geologic framework for hydrogeologic system. Structure of subsurface porous materials in reference to the flow of groundwater, often relating to stratigraphy. A hydrostratigraphic unit is defined as a part of a body of rock that forms distinct hydrologic unit with respect to the flow of ground water (Maxey, 1964).

Hydrostratigraphic unit is a body of rock distinguished and characterized by its porosity and permeability. Hydrogeologic boundaries are the natural subsurface physical barriers to the ground water flow i.e., aquifers are bounded in both horizontal and vertical directions. An attempt has been made to understand the lateral and vertical disposition of the multilayered aquifer system of Gundar river basin that falls in the state of Tamil Nadu, India and covers Madurai, Virudhunagar, Ramanathapuram and

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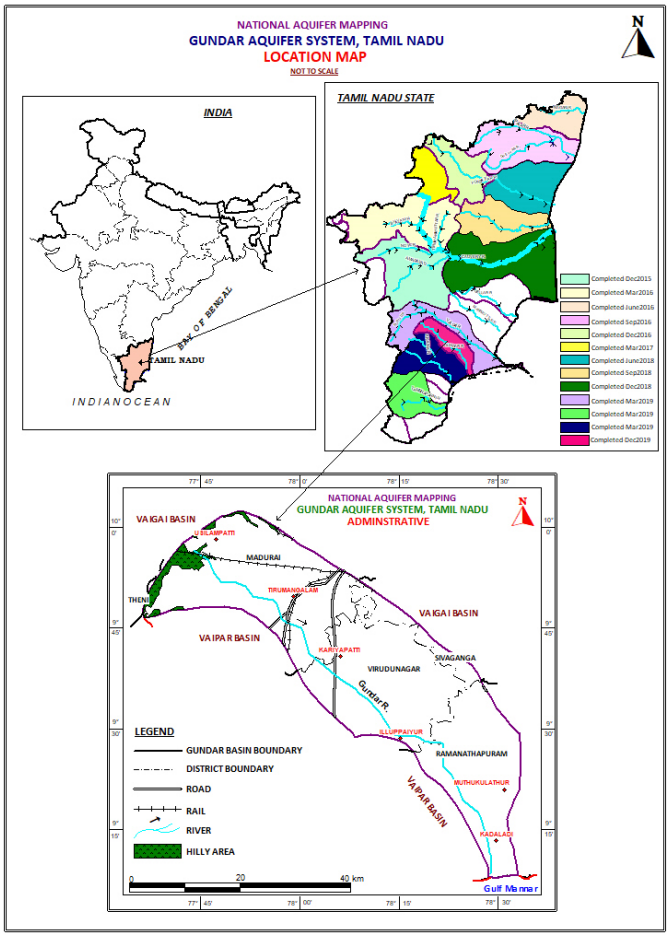

Fig. 1. Location map of Gundar River Basin.

Sivagangai districts. (Fig. 1) The study area lies in between north latitudes 9° 57' 43.2" N to 9° 6' 46.8" N and east longitudes 77° 36' 3.6" E to 78° 39' 46.8" E that falls in survey of India toposheet number 58G/9, 58G/10, 58G/13, 58G/14, 58K/1, 58K/2, 58K/3, 58K/5, 58K/6, 58K/7, 58K/8, 58K/11, 58K/12. The Gundar aquifer system covering an area of 3008 sq. km comprises of 96 sq. km of hilly area, with mappable area of 2912 sq. km. (Fig. 1). Average annual rainfall in the study area is 928 mm (Shaikh et al., 2023). The average length of the basin is around 150 km and average width of the basin around 25.2 km with maximum altitude of 1293 m (Fig. 2). The major tributaries of Gundar river are Therkkar river, Goundanadhi, Giridhamal river, Kanal odai and Paralaiaru. Geomorphologically, the area has been delineated into hills and plateau, pediment zone, flood plains and coastal plains. The hills and plateau are found in the western and north- western parts of the area comprising the Charnockite group of rocks and Migmatites, The pediments in the central part overlie the Migmatites and Charnockitic domain. The rocks

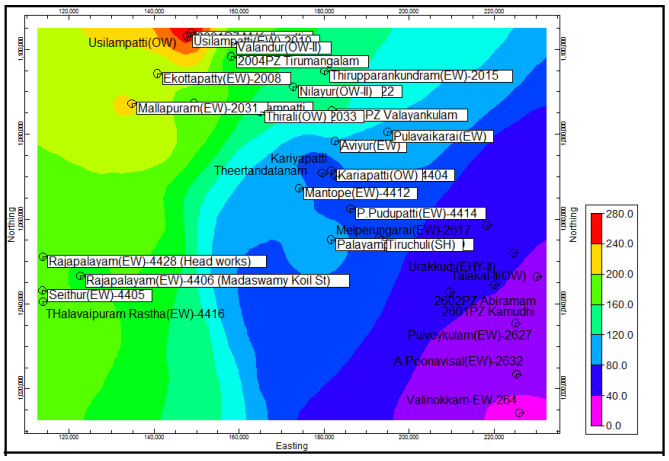

Fig. 2. Elevation map of Exploratory wells.

of Upper Gondwana and recent fluvial sediments form the plains. The coastal areas are flanked by beach ridge complex-sand dunes, swales and swamp. The sand flat is another feature of the coast comprising of clays and silts, often inundated by seawater and encrusted with salt. Agricultural land occupies nearly, 65 % of the Gundar aquifer system area and spread throughout the study area. Forests, water bodies, waste land and built up/urban area occupy 20 %, 8 %, 7% and 4 % of the area respectively.

2. MATERIALS AND METHOD

Integrated multi-disciplinary approach involving geological, geophysical, hydrological and hydrogeological and hydrogeochemical components were taken up in 1:50000 scale to meet the objectives of study (Kumar, 2014; Gnanasundar et al., 2013). Geological map of the basin has been generated based on the GSI maps, geophysical data has been generated through vertical electrical soundings and geoelectrical layers with different resistivities have been interpreted in corroboration with the litho stratigraphy of the observation wells and exploratory wells down to depths of 200 m bgl and 300 m bgl for hard rocks & soft rocks respectively (CGWB Report, 2015). Hydrological and Hydrometerological data have been collected from state PWD and IMD departments. Drainage, soil and geomorphology of the basin were prepared based on the IRS –IC data, obtained from Institute of Remote Sensing, Anna University, Chennai. Data of 156 Nos. of exploratory wells were drilled in the Gundar aquifer system (40 Nos. CGWB and 116 Nos. State department wells) prior to National Aquifer Mapping

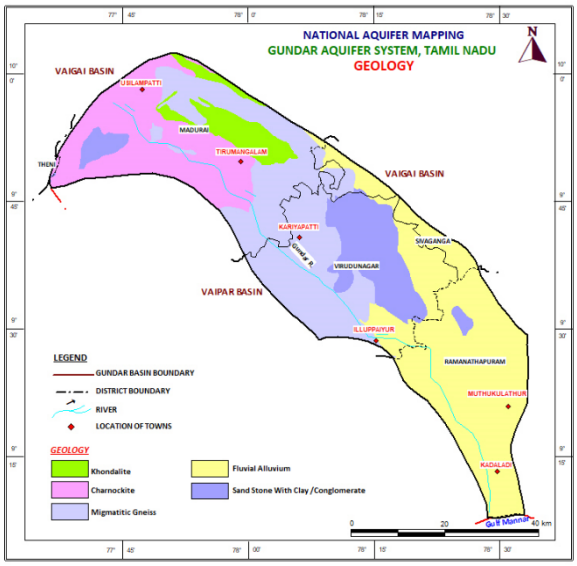

Fig. 3. Geology map.

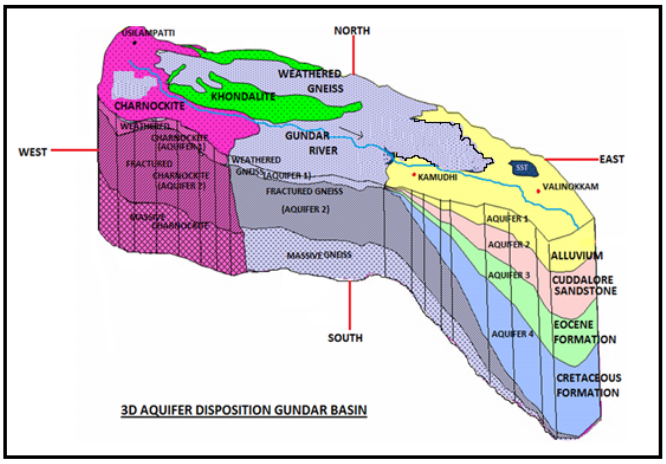

Fig. 4. 3D Aquifer Disposition of Gundar River Basin.

project was compiled and analysed. The 3D and 2D representation of the aquifers are acquired by ROCKWORKS 17 software and the maps are generated through ArcGIS 10.2 software. The hydrogeochemical analysis of the samples determining the general parameters are carried out in CGWB, SECR Chennai.

3. RESULTS AND DISCUSSIONS

3.1. Geology

Geologically, the Gundar aquifer system comprises of Recent sediments of marine, estuarine and fluvial alluvium, Lower Cretaceous, underlained by Precambrian rocks of Granitic gneiss, Hornblende biotite gniess, khondalites and charnockites (Fig. 3). The charnockites occur in the western part, and migmatite gniess occurs in the central part of the area. Alluvium underlain by sandstone and claystone are found in the southeastern part of area. The Precambrian rocks belonging to Archaean age comprising khondalite group, charnockite group, the Migmatite Complex, Hornblende biotite gneiss and granitic gneisses are found in western, northwestern and central part of the study area. Charnockite forms the basement for the Cretaceous and Quaternary sediments. Charnockite has a patchy distribution in the western and central part, and the rocks are scarcely weathered and poorly jointed, generally massive and unfoliated. Granitoid gneiss forms the linear band within Charnockite and the contact between them is highly sheared. The migmatite complex made up of Hornblende biotite gneiss, pink Augen gneiss and pink Migmatite, occurring in the central part are micaceous with bands of granite, pegmatite and quartz veins. Dolerite dykes form the youngest basic intrusive traversing both charnockite as well as the migmatite complex. Upper Gondwana and Lower Cretaceous formation of Mio-Pliocene age occur in the central and southeastern part. Shale, sandstone and conglomerates are the main rocks of Sivaganga formation. Quaternary sediments are found in the southeastern part of Gundar aquifer system all along the coast and river courses. Coastal alluviums are underlain by Cuddalore formation of Mio-Pliocene age. The Quaternary sediments are of two types, deposited under fluvial environment (river deposits) and marine environment. The fluvial sediments include clays and sands, mud, silt and medium to coarse grained sand (beach deposits). The thickness of the alluvial deposits is about 50 m. The marine deposits extend all along the coast of Ramanthapuram district. The 3D aquifer disposition is shown in Fig. 4.

3.2. Aquifer Disposition & Hydrostratigraphic units

Hard rock region comprising of Charnockite rocks and gneissic rocks is found in the western and central portion of the Gundar aquifer system. Hard rock regions cover an area of 2246 sq,km. The gneissic formation covering an area of 1346 sq.km and encompasses 18 firkas. The charnockite formation covers an area of 900 sq.km and is found in 6 firkas. The gneissic formation and charnockite formation form two aquifer units namely the weathered and fracture/jointed aquifer unit.

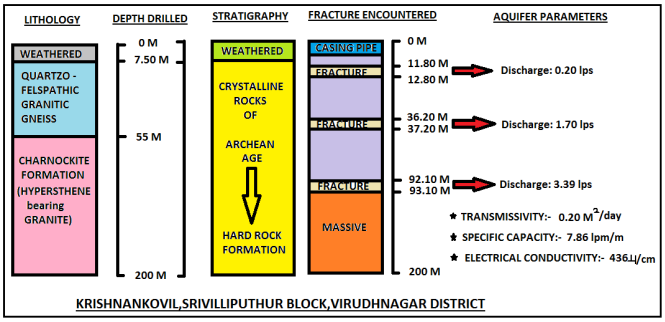

Fig. 5. Lithostratigraphic Correlation of an Exploratory well (Hardrock terrain).

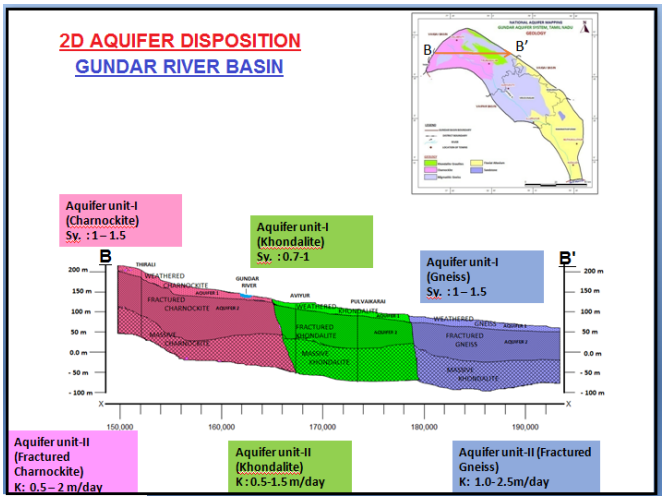

Fig. 6. 2D Aquifer Disposition along B-B' (Gundar River Basin).

Aquifer Unit I – Weathered
Region A: Charnockite rock area.

The weathered aquifer unit occurs from the ground level and has a minimum thickness of 4.1 m and maximum thickness of 31 m with average thickness of 14.6 m. Yield of this weathered aquifer unit ranges from 0.72 to 9 m^3/hr with discharge of < 3.6 m^3/hr. The aquifer parameter such as transmissivity in this aquifer unit ranges from 0.1 to 158 m^2/day. The Specific yield of this aquifer unit ranges from 1 to 1.5% with highly potable groundwater quality.

Region B: Gneissic rock area

In the area covered by gneissic rock the weathered aquifer unit occurs from the ground level and has a minimum thickness of 4.0 m and maximum thickness of 36 m with average thickness of 17.5 m. Yield of this weathered aquifer unit ranges from Nil to 15 m^3/hr with an average discharge of 1 to < 3.6 m^3/hr. During monsoon period the wells tapping this aquifer unit sustains for 2 to 4 hrs/day of pumping, while during non-monsoon period (May to July) wells sustain for less than 1 to 2 hour/day of pumping. Groundwater occurs in unconfined condition. The aquifer parameter such as transmissivity in this aquifer unit ranges from 0.2 to 253 m^2/day. The Specific yield of this aquifer unit ranges from 1 to 1.5% with highly potable groundwater quality.

Aquifer Unit II (Fractured/Jointed)
Region A: Charnockite rock area

This aquifer unit comprises of fractured and jointed charnockite formed due to tectonic activity. Thickness of this aquifer unit is from 46 to 189 m bgl (In general 3 to 4 set of fractures exists and even nil at some places). Based on the analysis of the 156 exploratory well data and 72 VES data it is observed that there is a possibility of occurrence of 3 to 4 Fractures/joints up to 195 m bgl in the charnockitic region. The yield of this aquifer unit II ranges from 0.3 to 9.5 m^3/hr. During monsoon period the wells tapping this aquifer unit sustains for 2 to 6 hrs /day of pumping, while during non-monsoon period (May to July) sustains for 1 to 2 hour/day of pumping. Transmissivity of this aquifer unit ranges from 0.1 to 4.5 m^2/day.

Region B: Gneissic rock area

This aquifer unit comprises of fractured and jointed Gneiss formed due to tectonic activity. Thickness of this aquifer unit is from 13 to 143 m bgl. In general 3 to 4 set of fractures exists and even nil at some places). Based on the analysis of the 156 exploratory well data and 72 VES data it is observed that there is a possibility of occurrence of 3 to 4 Fractures/joints exists up to 197 m bgl in the gneissic region. The yield of this aquifer unit II ranges from 0.05 to 25 m^3/hr. During monsoon period the wells tapping this aquifer unit sustains for 1 to 6 hrs /day of pumping, while during non-monsoon period (May to July) sustains for 1 to 3 hour/day of pumping. Transmissivity of this aquifer unit ranges from 3 to 296 m^2/day. Figs. 5 and 6 display the lithostratigraphy of a single well and a cross-section of the of the hard rock terrain along NW-SE direction of the basin respectively.

Hydrogeology of Sedimentary area of the aquifer system (C)

Sedimentary rock region comprising of alluvium and Tertiary formations occupy the eastern part of the

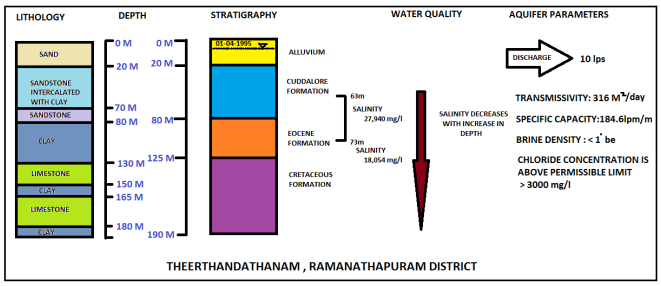

Fig. 7. Lithostratigraphic Correlation of an Exploratory well (Sedimentary terrain).

aquifer system. It covers an area of 762 Sq.Km. sedimentary area (Alluvium, Tertiary formation & Cretaceous formation) encompasses 9 firkas. Alluvium and the unconfined layers of Cuddalore formations form phreatic aquifer- Aquifer unit-I (C1), Tertiary formation is the confined aquifer unit (Cuddalore sandstone and Eocene sandstone formation) defining aquifer unit II and Cretaceous formation is the confined aquifer unit defining aquifer unit III (Fig. 7).

Aquifer Unit – I (C1 - Alluvium and Cuddalore Sandstone)

The top most aquifer is the Aquifer Unit –I and it is a phreatic aquifer or Water table aquifer. This aquifer unit composed of recent river alluvium, Coastal alluvium, Cuddalore sandstone and laterite formations. The thickness of the Aquifer Unit-I varies from 6 to 40 m in the area covered by river alluvium, about 30 to 50 m thick in the area covered by coastal alluvium and it is about 10 to 20 m in areas where the Cuddalore sandstone are exposed to the surface. The thickness of the aquifer unit I is less in the western portion and gradually increases towards east near the coast. The groundwater abstraction from the aquifer is mostly by dugwells and shallow tubewells. The diameter of the dugwells ranges from 1 to 4 m and the depth ranges from 3 to 25 m below ground level (mbgl). The dugwells are energized mostly by electric pumps and the groundwater extracted is mainly used for irrigation and domestic purposes. The depth to the water level of the phreatic aquifer ranges between 1 and 18 mbgl and yield varies in different formation. Yield of the aquifer unit in the river alluvium varies from 2.4 to 65 m^3/hr. whereas in coastal alluvium area the yield varies from 39-132 m^3/hr and the yield varies from 3.5 to 7 m^3/hr in the phreatic unit of Cuddalore sandstone formation. The transmissivity of alluvial formation ranges between 210 and 1500 m^2/day and the specific yield ranges between 12 and

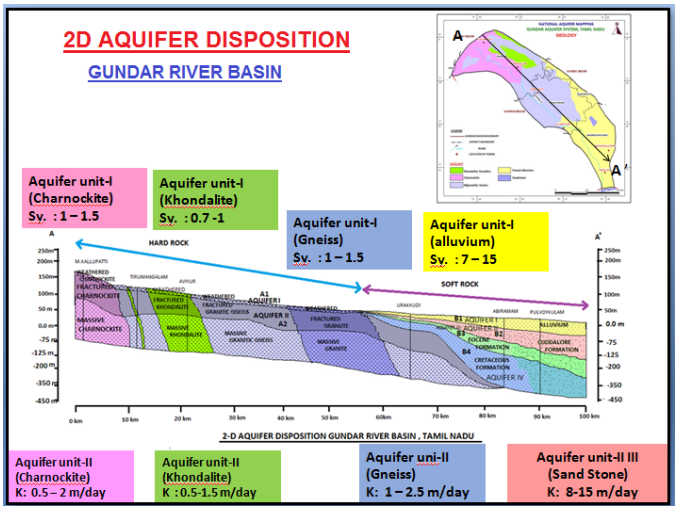

Fig. 8. 2D Aquifer Disposition along A-A' (Gundar River Basin).

18 % whereas the transmissivity of Cuddalore sandstone formation ranges between 350 - 2500 m^2/day and its specific yield ranges between 8 to 13%.

Aquifer Unit II (C2): Tertiary sandstone

Tertiary sandstone of the Gundar aquifer system consists of Cuddalore formation and Eocene formation.

Cuddalore Sandstone

Cuddalore Sandstone comprises of argillaceous sandstone, pebble bearing sandstone, ferruginous sandstone, grits and clay beds and are whitish, pinkish, reddish in colour which are friable in nature. The sands and sandstones of Cuddalore formations of Mio-Pliocene age comprise of fine to very coarse grained and are sub-angular to sub-round in shape, occasionally with rounded pebbles of quartz with diameters even upto 3 mm. The Cuddalore sandstones occur beneath the alluvium formation and in place where alluvium formations are absent; they are exposed on the surface. The sandstone formation which lies below the unconfined unit of Cuddalore formation forms the aquifer unit II (C2) which is confined in nature.

The clay layers separating the unconfined and confined unit of the Cuddalore sandstone are discontinuous at many places. The depth of occurrence of aquifer unit II is between 20 and 60 m bgl with thickness varying from 68 to >300 m. The thickness is less in the western portion and gradually increases towards east. Clay occurs as intercalations within the sandstones at some locations. The groundwater abstractions from the aquifer are by shallow tube-

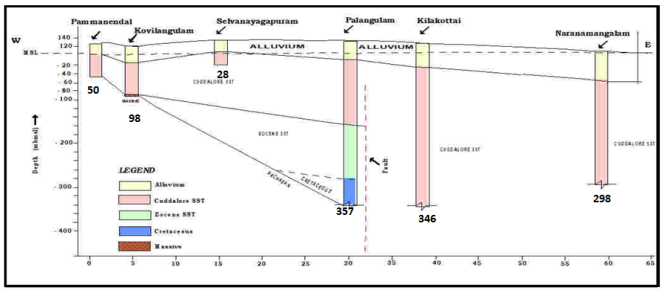

Fig. 9. Lithological Striplogs along west to east.

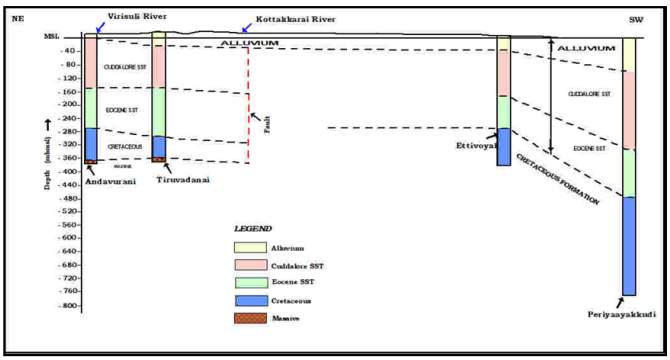

Fig. 10. Lithological Striplogs along northeast-southwest.

wells, depth ranges from 40 to 80 mbgl and are energized by electric submersible pumps which are mainly used for irrigation and industrial purposes having EC <2500 microseimens/cm. The piezometric level of the confined aquifer ranges between 15 and - 10 m with respect to mean sea level (msl) having yield between 10.8 to 66.6 m^3/day. The major source of recharge to the aquifer is rainfall and leakage from unconfined aquifer. The transmissivity ranges between 5and 3615 m^2/day and storativity between 1.2 x 10 $^{-3}$ and 4.1 x 10 $^{-4}$ respectively.

Eocene Sandstone

The Eocene formations composed of sandstones are made up of fine to coarse grained sand and pale grey in colour with occasional clay intercalations. Similar to the Cuddalore sandstones, Eocene sandstones are also friable in nature. They are shallow in the central part and deeper in the eastern part towards the sea. The occurrence of these formations is restricted to the eastern part of the Gundar aquifer system and found at a depth of 50 to 120 m below mean sea level and is restricted to the firkas like Melakodumalur, Mudhukulathur, Aapanur, Kadaladi and Sayalkudi. In the eastern part the Eocene formations are found in greater depth. The Eocene sandstone formation forms aquifer which is confined in nature. The thickness is varying from 40 to 85 m. The groundwater in this aquifer unit is abstracted sparely for irrigation activity. Since last decade, tubewells have been constructed by farmers to tap groundwater from this aquifer for irrigation activity. This aquifer unit is highly potential and its yield varies from 65 to 85 m^3/hr. The transmissivity of the aquifer unit range between 300 and 2750 m^2/day and the storativity ranges between 1.6 x 10 $^{-4}$ and 2.9 x 10^{-5}.

Aquifer Unit III (C3 Cretaceous sandstone)

Cretaceous sandstone which consists of litho units viz the top units of marker fossiliferous sandstone, which is flesh red in colour and compact in nature and the bottom consists of pinkish and greyish sandstone intercalated with clay and shale. These form the Aquifer unit III in the sedimentary area of the Gundar aquifer system and it occurs only at subsurface. Aquifer Unit III lies below the Aquifer unit-II and separated by confining clay layer which is discontinuous in many places. The Aquifer Unit-III occurs at the depth of 88 to 150 m bmsl. The thickness is less in the western portion i.e 40 m and gradually increases towards east extending more than 200 m. The groundwater abstraction from the aquifer through tubewells constructed to the depth of 220 to 350 mbgl. The Aquifer Unit-IV is highly potential and yields 55 to 85 m^3/hr. The transmissivity of aquifer varies from 56.17 to 594.00 m^2/day (Andavurani) with field permeability ranging from 2.810 to 27.00 m/day. Storage co efficient values as computed are indicative of confined condition of the aquifer and ranges from 5.54x10^{-4} to 2.72x10^{-5}. Further the pump test conducted in this area has brought to light the existence of barrier boundary conditions. For instance the pumping test conducted in the exploratory wells at Tiruvadanai, Pandakudi, and Mandathukottai in adjoining Sivagangai district. The drawdown is rather high indicative of their proximity to the barrier boundary, thereby of the limit of the extent of the confined aquifer. Figs. 8, 9 and 10 display the cross-section of the sedimentary terrain and the lithological strips along W-E direction , north east- southwest directions of the basin respectively.

Lineament Analysis

Structural features in hard rocks, such as faults, dykes, contacts of zones of deep weathering are often recognized on the surface from remote sensing data as lineaments, ie linear differences in soil tone, vegetation, topographic relief linear components of drainage

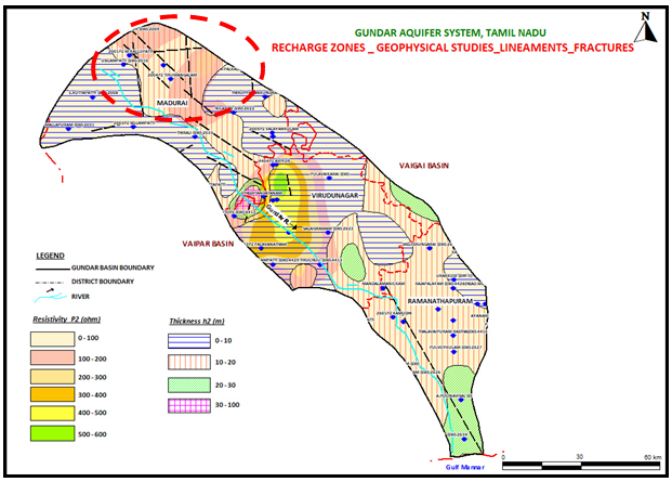

Fig. 11. Lineament map of Gundar Basin.

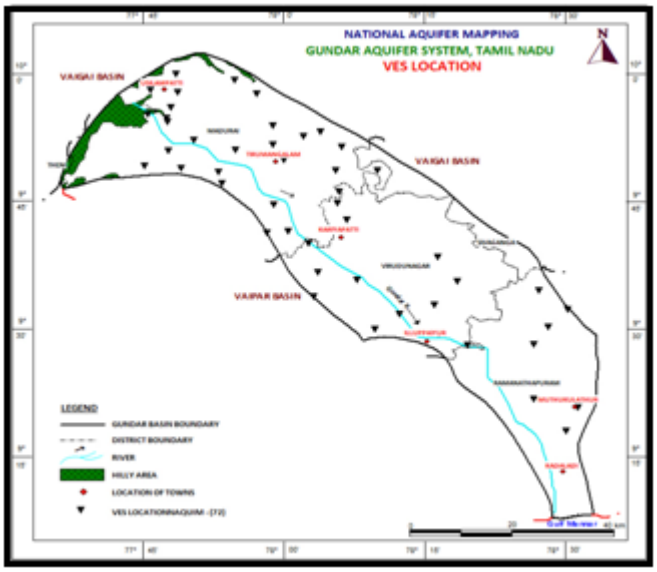

Fig. 12. VES Locations in Gundar basin.

systems or a combination of these. Lineament studies have their greatest application for locating vertical and near vertical zones of fracturing in consolidated rocks with low primary porosity (Ahmad, 1984a,b). A number of lineaments have been identified from the satellite imagery, which have been digitized (Fig. 11) .VES data of 48 locations in the basin have been interpreted to verify the existence of structurally weak zones and to decipher the depth of weathered rocks (Fig. 12). The average values of apparent resistivities and the correspondingly high thicknesses of subsurface lithounits shown in most of the cases are indicators of structurally weak zones, which are important from the point of view of ground water development/ recharge.

4. CONCLUSIONS

Fracture analysis of the borewells drilled in the study area reveals that the almost entire area is covered under hard rock terrain represented by Region A-Charnockite & Khondalite group of rocks and Region B- Gneiss group of rock. In both the region the rocks are massive in nature. In the Region-A most of the fractures occur within 40-60 m bgl and the frequency of occurrence of fractures are promising in these depth zones. In some area the fracture system exists upto a depth of 197 m bgl, but the frequency of occurrence of fractures in this depth range is low. In Region B-Gneiss rock terrain most of the fractures occur within a depth range of 60-80 m bgl. In Granitic Gneiss region most of the fractures are confined to 100 – 150 m bgl. Comparatively charnockites are more massive than granitic gneiss and it occupies about 30% of the study area. These areas are water stressed and the people are struggling to meet their domestic demands. Salient interpretations made through the analysis of data reflect the occurrence of 4 high yielding wells located along the NW-SE trending lineaments (Fig. 11). These high yielding wells are located along areas having high fracture intensity. High Lineament density in this area indicate structural disturbance. Low resistivity values ranging from 200 to 300-ohm m at 100 m depth corroborate this. Potential shallow fractures within a depth of 50 mtrs yield above 10 lps. Over exploited firkas along this zone indicate high groundwater development. Deep water levels, low resistivity values are indicators of structurally weak zones NW-SE trending lineaments are potential in nature. However sustainable groundwater yields are encountered in areas where fractures occur at depths ranging between 100–150 m. Shallow fractures, dense lineaments, deep water levels, high yields are indicators to recharge zone. The potential groundwater zones identified through this method will aid in focused interventions addressing groundwater sustainability.

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