केंद्रीय भूमि जल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण

विभाग, जल शक्ति मंत्रालय

भारत सरकार

Central Ground Water Board

Department of Water Resources, River Development and Ganga Rejuvenation,

Ministry of Jal Shakti

Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

TAMBRAPARNI AQUIFER SYSTEM, Tamil Nadu

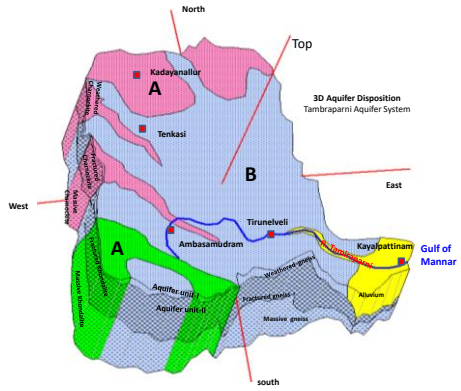
दक्षिण पूर्वी तटीय क्षेत्र, चेन्नई

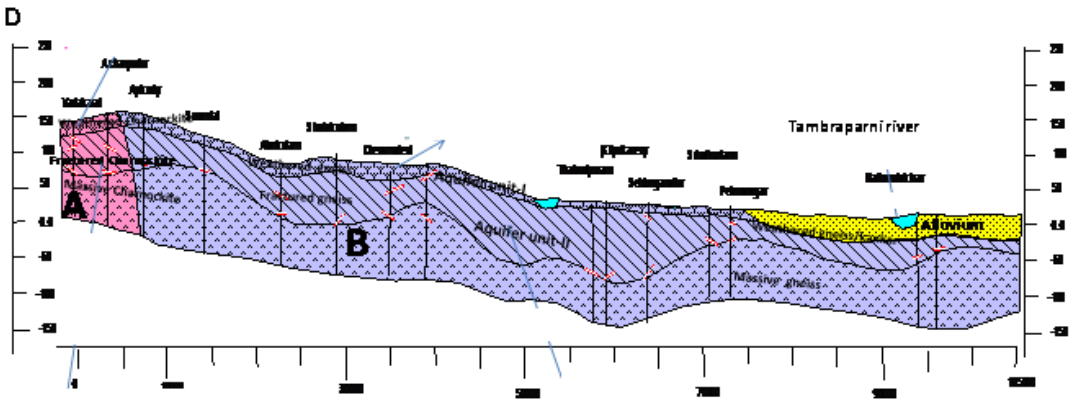
South Eastern Coastal Region, Chennai

सरकारीउपयोगकेलिए

तांबरपर्णीएक्वीफर सिस्टम, तमिल नाडुपर जलभृत और मानचित्रणजलभृत प्रबंधन योजना

REPORT ON
AQUIFER MAPPING AND AQUIFER MANAGEMENTPLAN FOR THE TAMBRAPARNI AQUIFER SYSTEM,TAMIL NADU





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दक्षिण पूर्वी तटीय क्षेत्र
चेन्नई

GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES
RIVER DEVELOPMENT AND GANGA REJUVENATION
CENTRAL GROUND WATER BOARD
SOUTH EASTERN COASTAL REGION
CHENNAI

Foreword

Groundwater is the major source of freshwater that caters the demand of ever growing domestic, agricultural and industrial sectors of the country. This renewable resource has been indiscriminately exploited in some parts of the country by several users as it is easily available and reliable. Intensive and unregulated groundwater pumping in many areas has caused rapid and widespread groundwater decline. In India out of 6607 groundwater assessment units (Blocks/ mandals/taluks/firkas etc.), 1071 units are over-exploited and 914 units are critical. These units have withdrawal of groundwater is more than the recharge (over exploited) and more 90% of recharge (Critical).

Central Ground Water Board (CGWB) has taken up largest Aquifer mapping endeavour in the world, targeting total mappable area of country 23.25 lakh sq.km with a vertical extent of 300m in soft rocks areas and 200m in hard rock areas. The extent of aquifers, their potential, resource availability, chemical quality and its sustainable management options will be addressed by National Aquifer Mapping (NAQUIM). The NAQUIM programme will also facilitate participatory management of groundwater to provide long-term sustenance for the benefit of farmers. Currently, focus is on groundwater stressed areas of nine states comprising 5.25 lakh sq.km viz. Tamil Nadu, Haryana, Punjab, Rajasthan, Gujarat, Andhra Pradesh, Telangana, Karnataka and Bundelkhand region.

South Eastern Coastal Region (SECR), CGWB, Chennai under NAQUIM has been envisaged with the Mapping of an area of 70,102 sq.km during 2012-17 (XII Five Year Plan) in Tamil Nadu and UT of Puducherry. This report deals with the Aquifer mapping studies carried out in water stressed Tambraparni aquifer system covering an area of 5506 sq.km with 4481 sq.km as mappable area. The basin comprises of water stressed Tirunelveli and Thoothukudi districts with 51firkas. Fifteenfirkas are Over exploited and Critical firkas which are mainly dependent on groundwater (85%) for its drinking water needs. The major issues in the basin include declining groundwater levels, massive formation with poor yielding aquifer and groundwater quality issues in pocket. Aquifer units have been deciphered firkas-wise and regions of high yielding zone and low yielding zone have been demarcated for the different aquifers in the Tambraparni aquifer system. In area is mainly compried of hard rocks of Charnokite&Khondalite group of rocks and Gniessic group of rocks which forming two aquifer units namely Aquifer unit-I (weathered rock) and Aquifer Unit –II (fractured/Jointed zone). In order to arrest the declining groundwater levels and increase the sustainability of wells, firka wise groundwater management plans in supply and demand side have been formulated.

I hope this report will be useful for the district administrators, water managers, stakeholders including farmers in knowing the aquifer and managing the resources effectively in the Tambraparni aquifer system.

(Dr. A.Asokan)

Regional Director

EXECUTIVE SUMMARY

Detailed hydrogeological studies were conducted in the Tambraparni Aquifer system areas wherein huge existing data pertinent to geology, geophysics, hydrology, hydrochemistry were collected, synthesized and analysed to bring out this report. This report mainly comprises the lateral and vertical extent of the aquifers with their geometry, aquifer properties of the study area which are considered to be measuring scales for groundwater availability and potentiality. Aided through these parameters a sustainable management plan has been suggested through which the groundwater needs can be fulfilled in a rational way.

The study area experiences tropical climate with 985 mm annual normal rainfall covering 5506.33 km^2 area in Tirunelveli and Thoothukudi. About 57% of the geographical area is under agricultural activity of which 76% is groundwater irrigation. The main crops irrigated are paddy, sugarcane, groundnut, maize, cotton, ragi and other minor crops are turmeric, vegetables and flowers.

Two main aquifers units exist in the hard rock region of the Tambraparni aquifer system constituted by 1. Weathered zone at the top followed by 2. Discrete anisotropic fractured/fissured zone at the bottom in the western and central parts of the study area. The predominant water levels are in the range of 2-10 m bgl during pre-monsoon season (May 2018) and 2-10 mbgl during post-monsoon season of 2019. The annual extractable groundwater availability is 846.28 MCM and the gross groundwater extraction for all uses is 408.45 MCM and the stage of groundwater development is of 48.26% (2017).

The major issues in the region are over exploitation condition and decline in groundwater level and low sustainability, massive formation with non-availability of fracture which leads to water scarcity problem etc.

In hard rock regions aquifer systems can be conceptualized as weathered zone down to the depth of 30m with average thickness of 12 to 20 m and fractured zone between 10m and 195 mbgl. The weathered zone is disintegrated from the bed rock (upper part–saprolite zone) and partially/semi -weathered in the lower part (soft rock zone) with transmissivity varying between 1 & 110 m^2/day and specific yield of 0.5 - 1.5%. The fractured zone is fractured gneiss or CharnockiteorKhondalitewhich occur in limited extent, associated sometimes with quartz vein. The average transmissivity of this zone varies between 1&135 m^2/day and storativity varies from 0.002 to 0.01. The fast growing urban agglomerations shares the portion of groundwater which is being used for irrigation purpose with either resultant shortage in resources for irrigation needs or creates excessive draft in groundwater potential areas while catering to both the demands. The study formulates management strategies for supply side as well as demand side. The supply side measures include construction of artificial recharge structures of 52 Check dams, 229 nala bands, 334 recharge shafts in addition to the 1300 farm ponds and 132 tanks earmarked for rejuvenation with recharge shafts in all the 13 OE& 2 Critical firkas of the basin.

The estimated recharge to groundwater system through these structures will be in the order of 33 MCM. Demand side management is also recommended by change in irrigation practices from the conventional flooding to Ridge & furrow method for paddy and to drip irrigation for sugarcane and banana crops. This intervention would save 8.74 MCM of water annually. By ensuring both supply and demand side interventions the stage of groundwater development would be lowered from 130 to 96 %.

The existing regulatory measures may be modified suitably for optimal utilization of groundwater as well as for sustainable development of rural agricultural based economy. To achieve this goal opinion pool has to be obtained from more user groups and valid suggestions gathered may be incorporated in the regulatory acts.

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AQUIFER MAPPING AND MANAGEMENT PLAN FOR THE TAMBRAPARNI AQUIFER SYSTEM, TAMIL NADU

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1.0. INTRODUCTION

National Project on Aquifer Mapping (NAQUIM) initiated by Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India with a vision to identify and map the aquifers at the micro level with their characteristics, to quantify the available groundwater resources, topropose plans appropriate to the scale of demand and institutional arrangements for participatory management in order to formulate a viable strategy for the sustainable development and management of the precious resource which is subjected to depletion and contamination due to indiscriminate development in the recent past.

Groundwater is being increasingly recognized as a dependable source of supply to meet the demands of domestic, irrigation and industrial sectors of the country. The development activities over the years have adversely affected the groundwater regime in many parts of the country. Hence, there is a need for scientific planning in development of groundwater under different hydrogeological situations and to evolve effective management practices with involvement of community for better groundwater governance.

Aquifer Mapping has been taken up in Tambraparni Aquifer systemto formulate strategies for sustainable management plan for the aquifer system in accordance with the nature of the aquifer, the stress on the groundwater resource and prevailing groundwater quality which will help in drinking water security and improved irrigation facility. It will also facilitate better management of the vulnerable areas.

1.1. Objectives:

The objectives of the aquifer mapping project in Tambraparniaquifersystemcan broadly be stated as

- To define the aquifer geometry, type of aquifers and their lateral and vertical extent
- To define 2D and 3-D dispositions of the aquifer units.
- To determine the groundwater regime scenario
- To determine the hydrogeochemical characteristics of the aquifer units
- To estimate the availability of groundwater resources in the aquifer system
- To develop asustainable groundwater management plan for the aquifer system.

1.2. Scope of the Study:

The important aspect of the aquifer mapping programme is the synthesis of the large volume of data already generated during specific studies carried out by CGWB and various Government organizations with a new data set generated that broadly describe the aquifer system. The available generated data are assembled, analysed, examined, synthesized and interpreted from available sources. These sources are predominantly non-computerized data, which is to be converted into computer based GIS data sets.

Data gaps have been identified after proper synthesis and analysis of the available data collected from different state organisations like TWAD Board, PWD, Agricultural Engineering Department, etc. In order to bridge the data gap, data generation programme has been formulated in an organised way in the study area. Exploration work has been carriedout in different segments of the regions and aquifer parameters have been estimated. Groundwater monitoring regime has been strengthened by establishing additional monitoring wells. 2D and 3D sections have been prepared twice, one prior to the

generation of data based on the data collected, assembled and synthesized through different sources and two, after generation of data at identified gaps. The aquifer geometry prepared with the denser set of data points have finer details of the subsurface disposition and are realistic.

1.3.Issues of the study area

The main issues pertaining to the Tambraparni aquifer system are as follows (Figure 1)

a. Over exploitation and Declining GW resources in Hard rock areas
b. Poor aquifers – massive & compact formations
c. High EC in isolated pockets

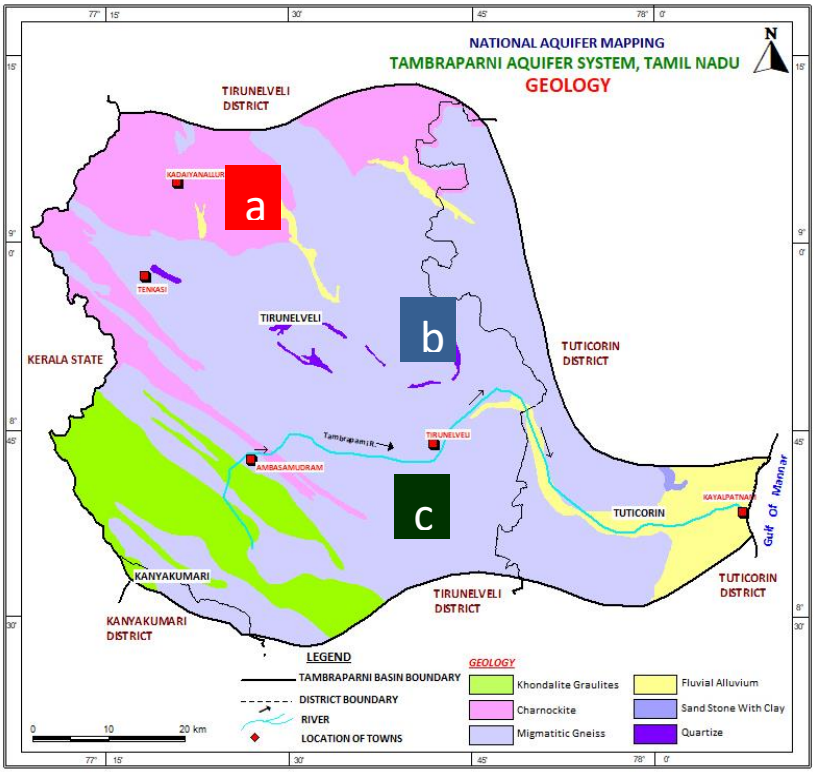


Figure.1. Issues pertaining to the Tambraparni Aquifer system

1.4. Approach & Methodology:

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. Geological map of the study area has been generated based on the GSI maps, geophysical data have been generated through vertical electrical soundings and geoelectrical layers with different resistivity have been interpreted in corroboration with the litho stratigraphy of the observation wells and exploratory wells down to depths of 200 m bgl for hard rock. Hydrological and Hydrometeorologicaldata have been collected from the state PWD and IMD departments. Drainage, Soil and Geomorphology of the sub-basin were prepared based on the IRS –IC data, obtained from Institute of Remote Sensing, Anna University, Chennai.

Based on the data gap analysis, data generation process has been scheduled through establishing observation wells, pinpointing exploratory sites for drilling through in-house and outsourcing, collecting groundwater samples for geochemical analysis in order to study groundwater regime, geometry of the aquifer and aquifer parameters, and quality of the groundwater respectively. Groundwater recharge and draft have been computed through different methods and resources of the aquifer system estimated through groundwater balance method.

Based on the above studies management strategies have been developed both on the supply side through artificial recharge and water conservationenhancing the groundwater resources and on demand side through change in irrigation pattern for sustainable management of the groundwater resource.

1.5. Study area:

The Tambraparniaquifer system covering an area of 5506 sq.km comprises of 1025 sq.km of hilly area and 4481 sq.km of mappable area between latitudes 08°27'37”N - 09°12'42”N and longitudes 77°08'57”E - 78°09'32”E. It is bounded by the Vaipparaquifer system in the North, Kodaiyar Aquifer system in the South,Kallar aquifer system in the Northeast, Nambiyar aquifer system in Southeast, Kerala state in the West and the Bay of Bengal sea on the east. The aquifer system hoststwo districtsvizTirunelveli district (swath of3432.2 km²) and Thoothukudi district (swath of 1049.8 km²). This aquifer system covers 51firkas out of which 15 are over exploited/critical firkas**(Table1).**The major part of the basin area comes under Tirunelvelidistrict. Tambraparni Rivers carries floodwater and drains Tirunelveli and Thoothukudi districts and its environs. The river irrigate its banks and carry only the flood discharge during the northeast monsoon period for a few days. The administrative map of the Tambraparni aquifer system is presented as **Figure 2**.

Table.1 Districts and Firkas of the TambraparniAquifer system

Sl. No	District	Area (Sq. Km.)	No. of firkas	OE and critical firkas	Safe and semi critical firkas
1	Tirunelveli	3431.21	41	15	26
2	Thoothukkudi	1049.82	10	0	10
Total		4481.03	51	15	36

1.6. Data availability

During the aquifer mapping period, existingdataof CGWB i.e. exploration, depth to water level, water quality, geophysical logging and groundwater resource data have been collected and compiled. In addition to this, borewell data, water quality & water level data have been collected from Tamil Nadu Water Supply and Drainage Board. Cropping pattern and soil data have been collected from Agricultural Department. Groundwater level and groundwater exploration data have been collected from Public Works Department. Thematic layers such as geology (GSI), soils, landuse&landcover,geomorphology, etc., from various State Government agencies has been collected, compiled and used in this study.

1.7. Data adequacy

Exploratory well data is available for 114 wells drilled by CGWB (44 Nos.) and State Departments (70 Nos. upto the depth of 45 meters). Water level (78 Nos.) and water quality monitoring data (85 Nos.) data are available for a long period i.e., more than ten years. Eighty five vertical electrical sounding (VES) data are available. Cropping pattern and soil data have been collected from Agricultural and Statistics Department. After plotting the available historical data on 1:50,000 scale maps, data gaps were identified and data generation process was taken up in those gap areas to generate the Aquifer map on the desired resolution of 1:50,000 toposheets.

1.8. Data Gap Analysis & Data Generation

Dug wells 62 Nos. have been established to monitor the first phreatic aquifer and 16 bore wells drilled down to a depth of 200 m bgl to know the aquifer characters of semi-confined aquifer system. It is also proposed to carryout quality monitoring through 85 Nos. of established dug wells for first phreatic aquifer and through 12 Nos. of irrigation/domestic bore wells for the second semi-confined aquifer in order to assess the groundwater quality for drinking and irrigation purposes.

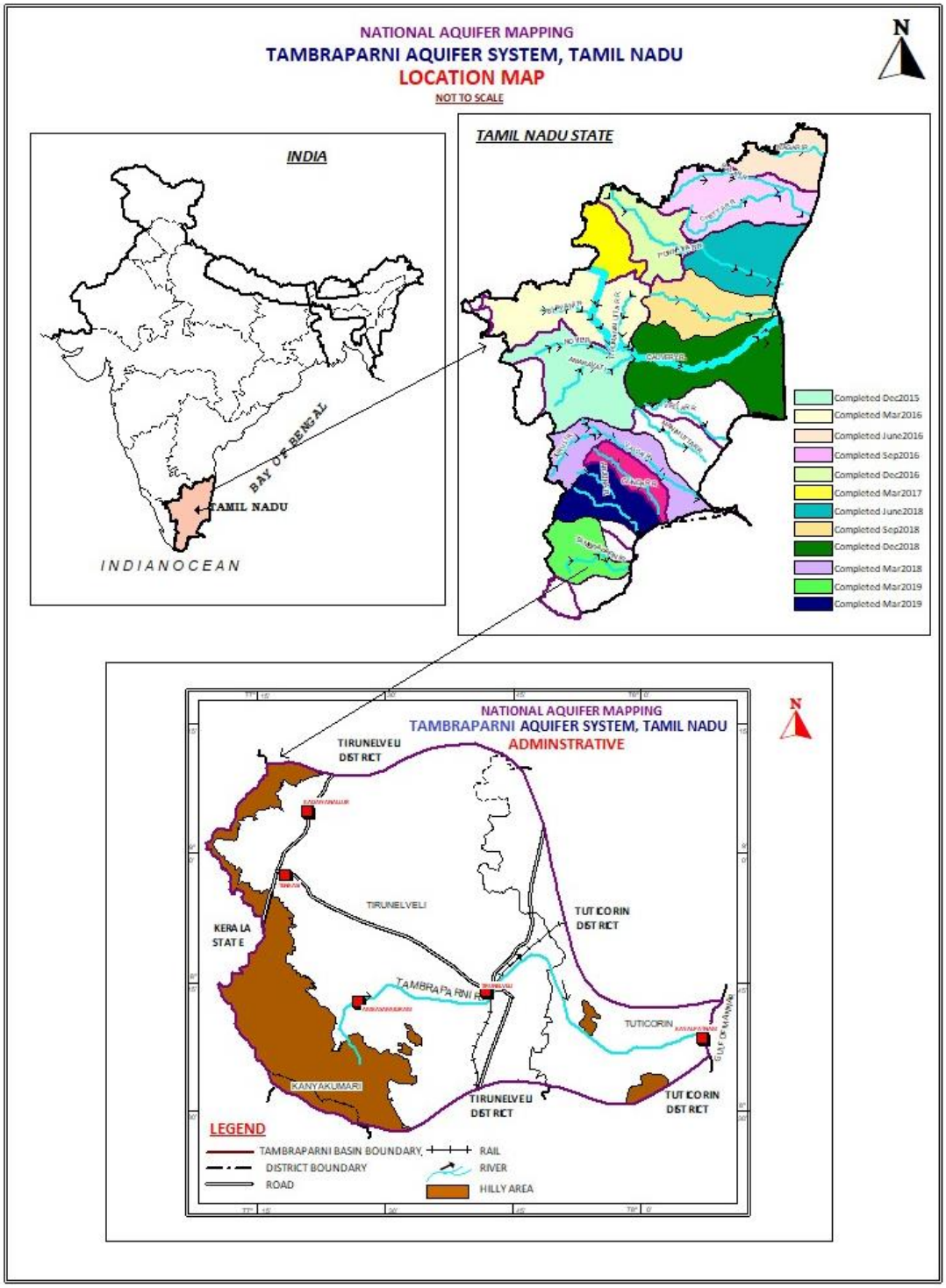


Figure 2. Administrative setup of the Tambraparni aquifer system

1.9. Climate and Rainfall

The basin area experiences semi arid to dry humid climate, being hot and dry for the greater part of the year. The period from April and May recording maximum temperature and the temperature goes up to 43 º C during May month. Average monthly maximum temperature Maximum is 32.66 ^{0}C and Average monthly minimum temperature 25.82 ^{0}C.

Maximum evaporation takes place during the month of August. Average pan evaporation in 166 mm/month. Humidity of the region ranges from 63.61 to 89.57 % with an average relative humidity in 70.35 %. Average wind velocity in 2.17 km/hour. Occasional thundershowers during April and May bring welcome relief.The afternoon sea breezes also bring some relief in the coastal parts. With the onset of the southwest monsoon by the end of May or beginning of June, there is some drop in temperature.

There are 16Raingauge stations located in the study area. They are Kadayanallur, Thenkasi, Senkottai, Ayukudi, Sankarankoil, Karpunadi, Gatana reservoir station, Kadayam&Sivagiri. The average annual rainfall of the regions ranges between 670 and 880 mm with 35 to 48 rainy days. The normal rainfall of the district is 814 mm (IMD normals-1970-2000). The coefficient of variation ranging from 26 to 35 percent. Rains are received during both southwest (June to September) and northeast (October to December) monsoon seasons. There is a considerable spatial variability in the distribution of rainfall, which shows a gradual decrease towards east. Rainfall is the major source of recharge for the area. Northwest monsoon always exceeds the southwest monsoon. The blocks located in the western side of the study area always experiences more rainfall than theircounterpart on the eastern side.

Blocks located on the western side also receive bonus showers/sprays of rainfall that occur in the western ghats. The probability of occurrence of normal annual rainfall over the district has been studied. It is observed that the chances of receiving normal annual rainfall vary from 45 to 51%. These are the maximum (51%) around Sivagiri in the northern part. The coefficient of variation of annual rainfall from the normal rainfall ranges from 26% at Nanguneri to 35% at Kadayam. It is minimum (25-30%) in the western parts around Senkottai and central part and it gradually increases and reaches a maximum in the western part around Kadayam (33%).

1.10. Physiography and Drainage

The term physiography deals with the actual existing in-situ conditions of the land, depending upon the structures, formational changes and available natural agencies such as hydrogiene and epigiene agents. Physiographically, the Tambraparni aquifer system region comprises of interdependent river basin of Tambraparni**(Figure.3).**Tambraparni and its tributaries originate for the eastern slope of Western Ghats. There are around 12 tributaries join the river. The main tributaries are *Karaiyar, Servalar, Manimuthar, Gandanadhi, RamanaNadhi, Pachiayar* and *Chittar*. *Karaiyar* and servalar originate from Mundanthurai reserve forest, *Manimuthar*orginates from Manjolai Hills, *Gandananadhi* and *RamanaNadhi*orginate from Agathiyamalai Biosphere reserve forest, *Pachiyar*orginate from Kalakkadu Reserve forest and *Chittar* from Courtallam hills. Most of the tributaries flow from west to east and joins with Tambaraparniriver and confluence with the Bay of Bengal in the East.

The maximum and minimum elevations of the Tambraparni aquifer system are from 1869 m amsl in the West to sea level in the East. The nominal topography is generally sloping towards the Southeast and East. The general trend of dipping ranges from West to East. The Hydraulic gradient and the flow lines of ground and surface water are towards east, the sea.

There area number of systems and non-system rain fed tanks in the study area. These water bodies were very specifically used for catering to the drinking water needs of the area and few are occasionally used for irrigationpurposes.

1.11. Geomorphology:

The geomorphology of an area is the external appearance of landforms that gives a reliable picture of the underground strata and its physio-chemical condition. The different formations and the layer confirms and cogent to its geomorphology. Three major geomorphic units can be demarcated viz. hills & Plateaus, Piedmont zone and plains with few units of urban areas and coastal landforms. The eastern part adjoining to beach and shores covers coastal geomorphic units. The inland topographical units are being described as the piedmont geomorphology.

Nearly 74 % of the region is covered by Piedmont zone is represented in **Figure.4**. These are terrestrial erosional surface inclined at a low angle and lacking significant relief. The piedmont regions are characterized by the occurrence of boulders, cobbles, pebbles, gravels, sand, silt and clay of varying lithology. Formed by coalescence of several alluvial fans by streams covering large area at the foothills, with gentle slopes, in humid to sub humid in regions (upper humid to sub humid regions).

The Hills&Platueauscover an area of about 19.18%. These structure hills cover the western part of the Aquifer system with the maxium elevation of 1869 m above mean sea level.

About 6.5 % of the region is covered by plains. These plains are the inland topography where the terrain sediment such as laterite, limestone and other calcareous sedimentary have been leached and washed away by erosion. When these plains are weighed against its potential for groundwater they fare poor owing to its low Groundwater storage capacity. The surface of these formations are showing a honeycomb structures and the water level are medium to high from the top surface. These were located in the eastern part of the aquifer system.

Plain area is occupied by river alluvium. In these areas the thickness of the alluvial sand varies from 1 to 29 m. **Figure 5** illustrates the level I classification of geomorphological features of the Tambraparniaquifer system.

The coastal landforms include the beaches, beach ridges and beach terraces. The beaches are landforms covered by sand and sandy materials having high porosity and unconsolidated loose formation with voids and spaces. Beach Ridges are elevated sandy tops adjoining the beaches and are good horizons for groundwater presence. The step like projection bordering the sandy terrain and the shoreline are called as beach terraces. These terraces are undulated and according to the forces of the tide and their deposition. These terraces were having a very low groundwater gradient that too towards the sea as they are slopping towards them.

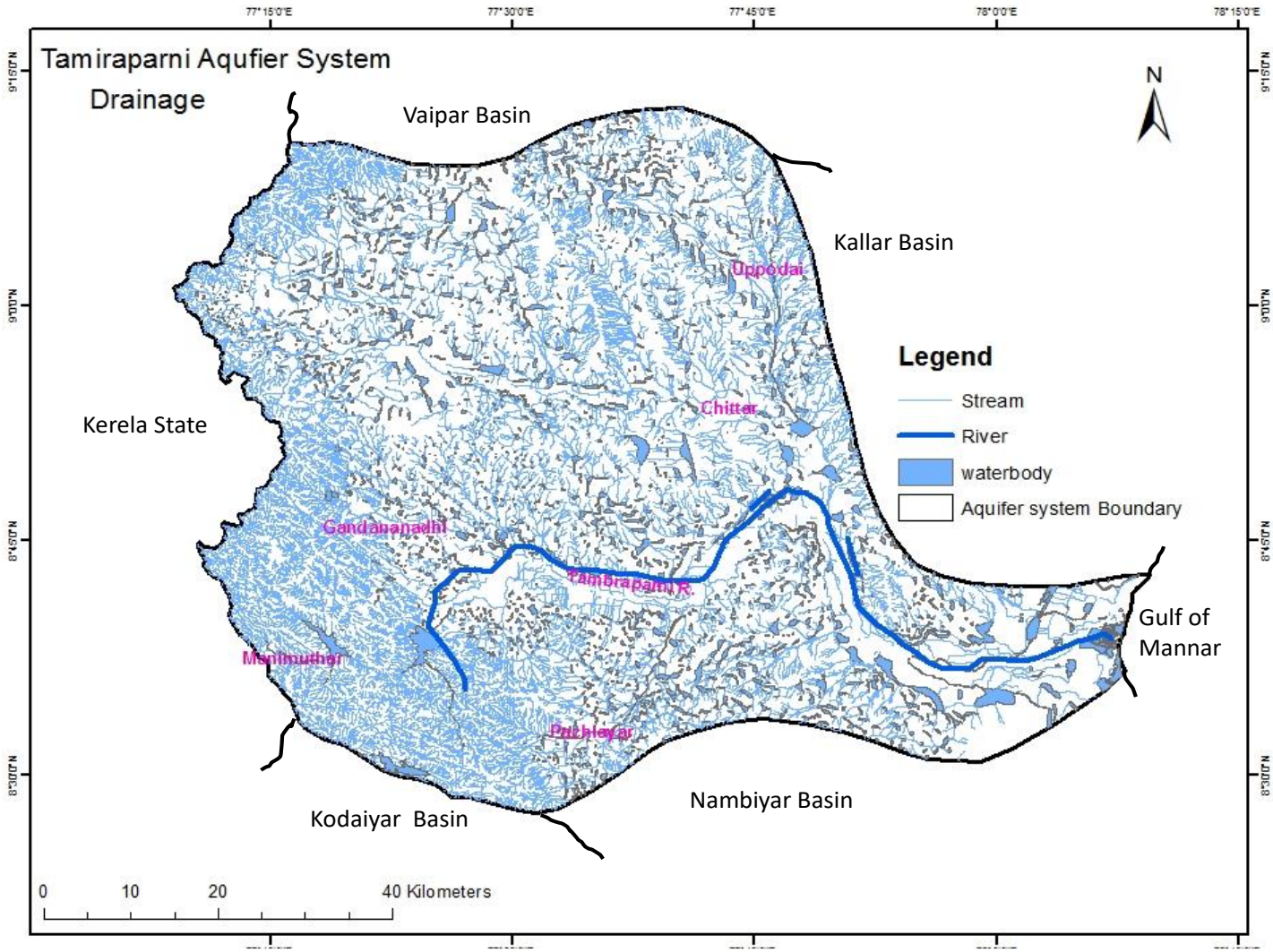


Figure3. Drainage of the Tambraparni aquifer system

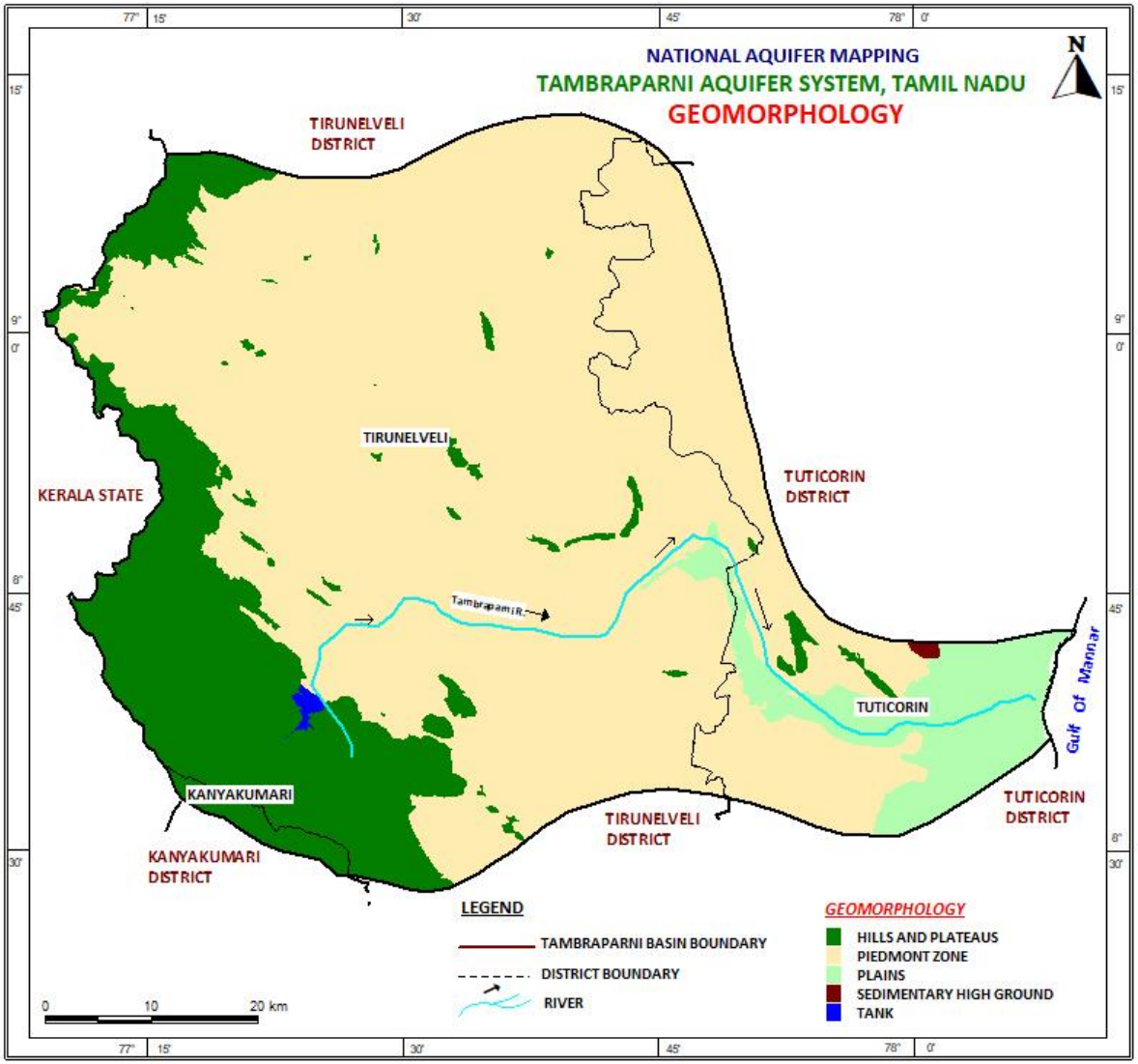


Figure 4. Geomorphology of Tambraparni Aquifer System

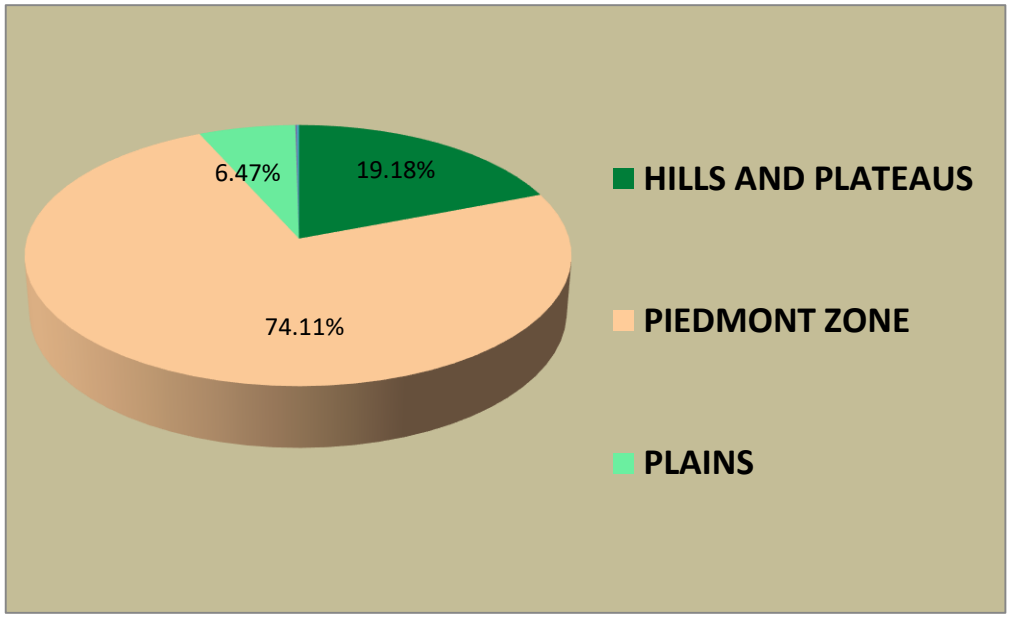


Figure 5. Level I classification of geomorphology of the Tambraparniaquifer system.

1.12. Landuse and Land cover:

Agricultural land occupies nearly 3138.42 sq.km i.e., 57% of the Tambraparni aquifer system and spread throughout the study area. Deciduous forest occupies nearly 1101.2 sq.km (i.e., 20%) of thearea taking the green area to 20% **(Figure 6&7).** Water bodies, Waste land and built up/urban area occupies 7%, 12% and 4 % respectively.

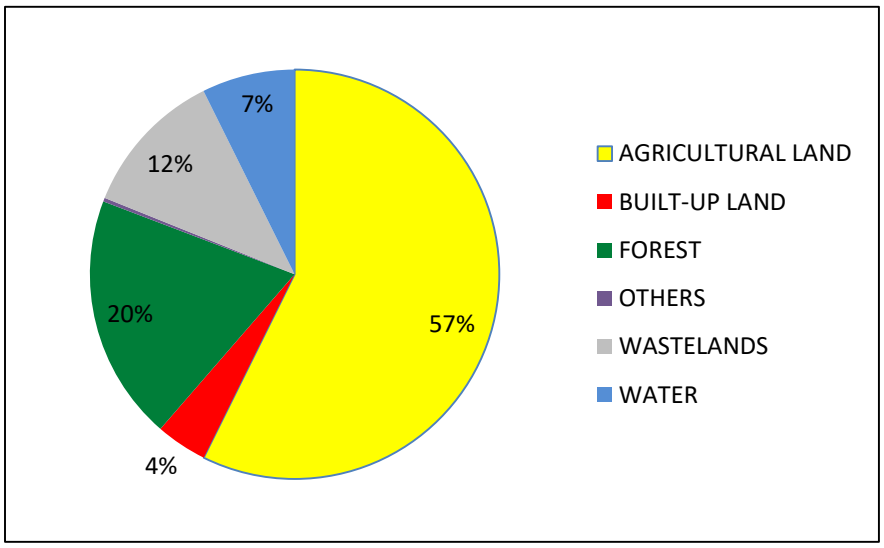


Figure 6 . Level 1 Landuse/Land analysis diagram of the Tambraparni aquifer system

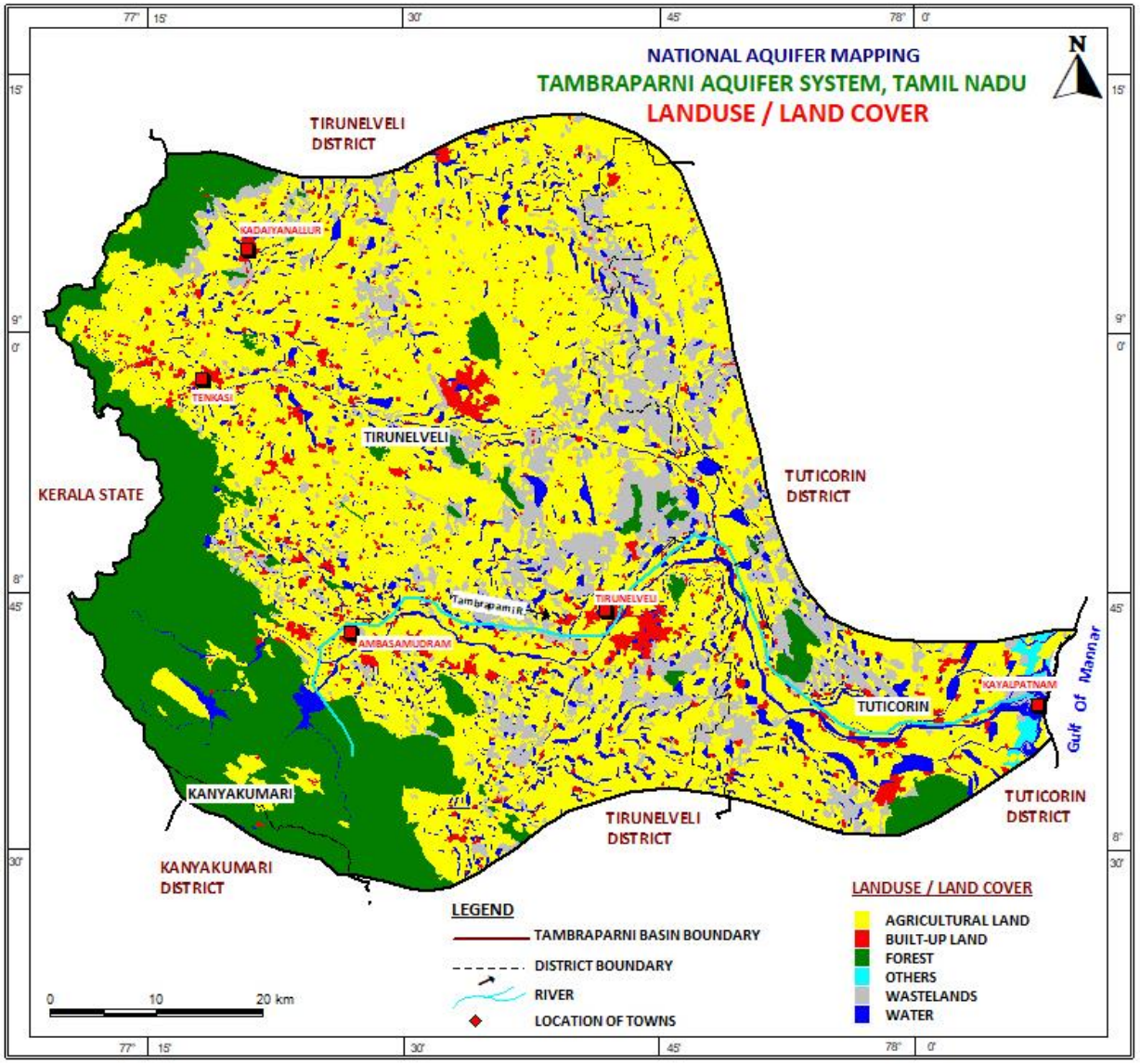


Figure 7. Level-3 Landuse/Land cover of the Tambraparni aquifer system

1.13. Soils:

Soils play a major role in hydrologic control of the infiltrating water. Soils are generally classified by taking their color, texture, fertilities and chemical combinations includes salts, minerals and the solution effect over them. The major soil types in the study area are inceptisols,alfisols, vertisols,entisolsand forest soils **(Figure.8).**

Entisols are alluvial soils comprising sand and sandy materials occurring along the beaches, at the confluence of rivers and by the side of the rivers & channels. Because of their permeability, these soils while being good storehouses of groundwater are not fit for paddy cultivation. Inceptisols are the major soil group found in the study area and consists of the red sandy to brownish clayey soil fragments derived from parent rock and is spread all along the northern and central parts of the area. The Inceptisols are suitable for agricultural and hold moderate groundwater reserves. Vertisols are clayey soil with high specific water retention capacity but poor in supporting agriculture. The rate of infiltration is very low in this type and ranges from 1 to 3 cm / hr for fine red sandy clay, clayey sand, sandy clay, sand fine to medium, sand medium to coarse and very coarse and gravel and for weathered rock, fractured and jointed rock it varies from 0.2 to 0.5 cm / hr. which normally occur in the study area.

1.14.Slope:

The slope of any terrain plays a vital role in allowing the infiltration of water into the subsurface system. In regions of gentle slope the runoff will be slow and will have more time for percolation of rainwater, whereas steep slope facilities high runoff allowing less residence time for rainwater to percolate. The maximum and minimum elevations of the Tambraparni aquifer system are from 1869 m amsl in the West to sea level in the East. The nominal topography is generally sloping towards the Southeast and East. The general trend of dipping follows an East- West direction. The Hydraulic gradient and the flow lines of ground and surface water are towards east, the sea.

1.15. Agriculture:

Agriculture is the main stay of the rural population in the entire study area. The total irrigated area of the Tambraparni aquifer system area is 1155 sq.km with main water intensive crops irrigated are Paddy, sugarcane and bananacovering about 988 sq.km**.** The less water intensive crops irrigated are maize, Cholam, groundnut and chilly. The other crops include cotton, ragi, turmeric, flowers, vegetables etc.

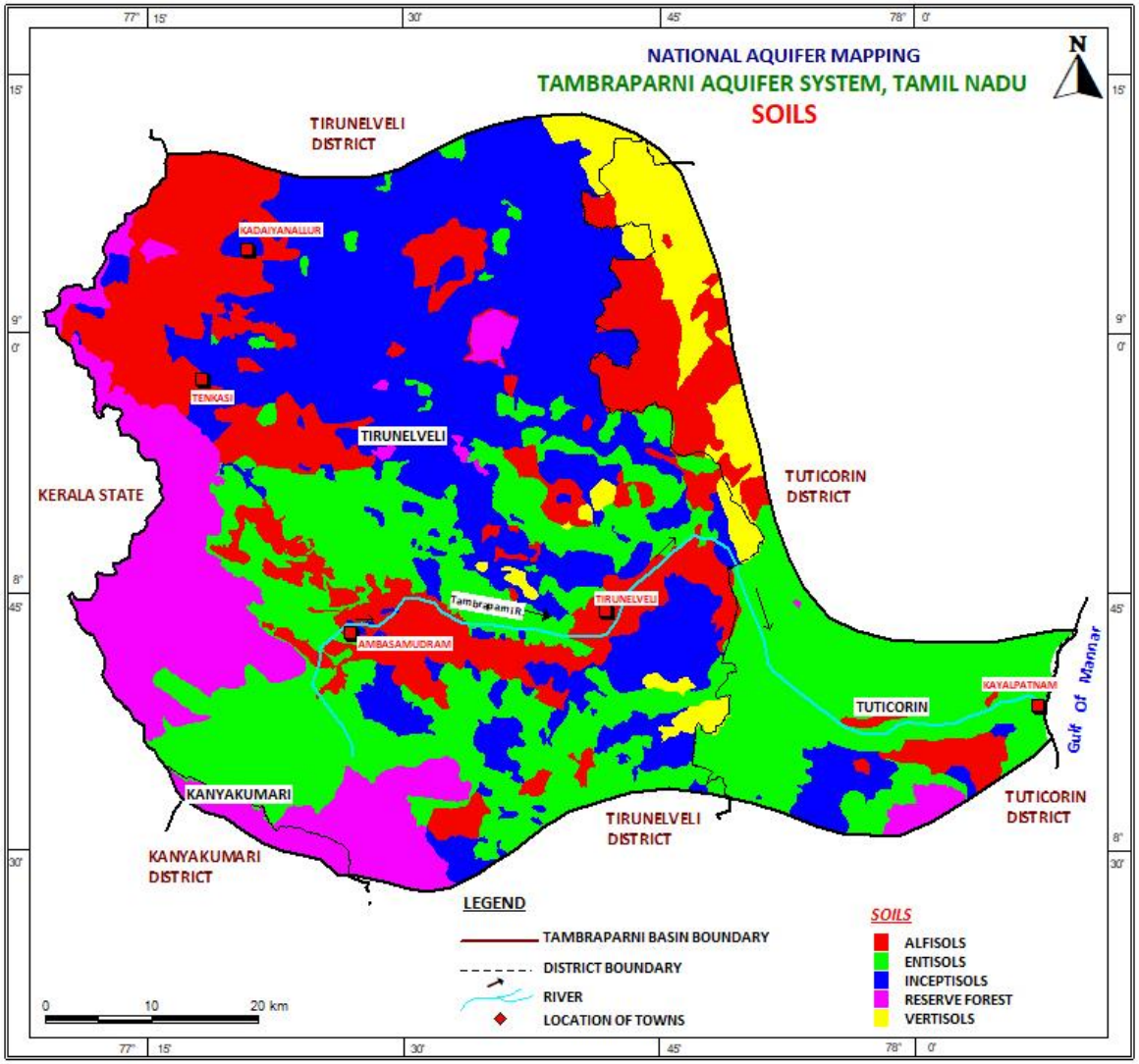


Figure8. Soils of Tambraparni aquifer system

1.16Geology:

Geologically, the Tambraparni aquifer system comprises ofcrystalline rocks of Archaean age consisting of Khondalite, Charnockites, gneisses, basic and acidintrusives groups. Khondalite, Charnockites and Gneiss form the major rock types and constitute the residual hills aroundnorth western, western and central and eastern parts of the study area. A layer of fluvial/coastal alluvium occupies the eastern part of the study area **(Figure 9).** Geologic succession of the Tambraparni aquifer System is presented in **Table2.**

Table 2. Geological succession of the Tambraparni Aquifer System

Period	Age	Lithology
Quaternary	**Holocene to Recent**	Soils, River alluvium, Kankar, laterite.
Archaean	**Acid intrusives**	Pegmatites, Quartz veins, pink
		Granites grey granites, leucogranites
	Basic intrusives	Basic dykes - dolerites
	Migmatite complex	Garnetiferous-quartzo-feldspathic gneisses, hornblende biotite gneiss.
	Charnockite group	Charnockites, pyroxene granulites,
	Khondalite group	Crystalline limestone, CalcGranulites, garnetiferousbiotite-
		Sillimanite graphite-gneiss, granulites, quartzites

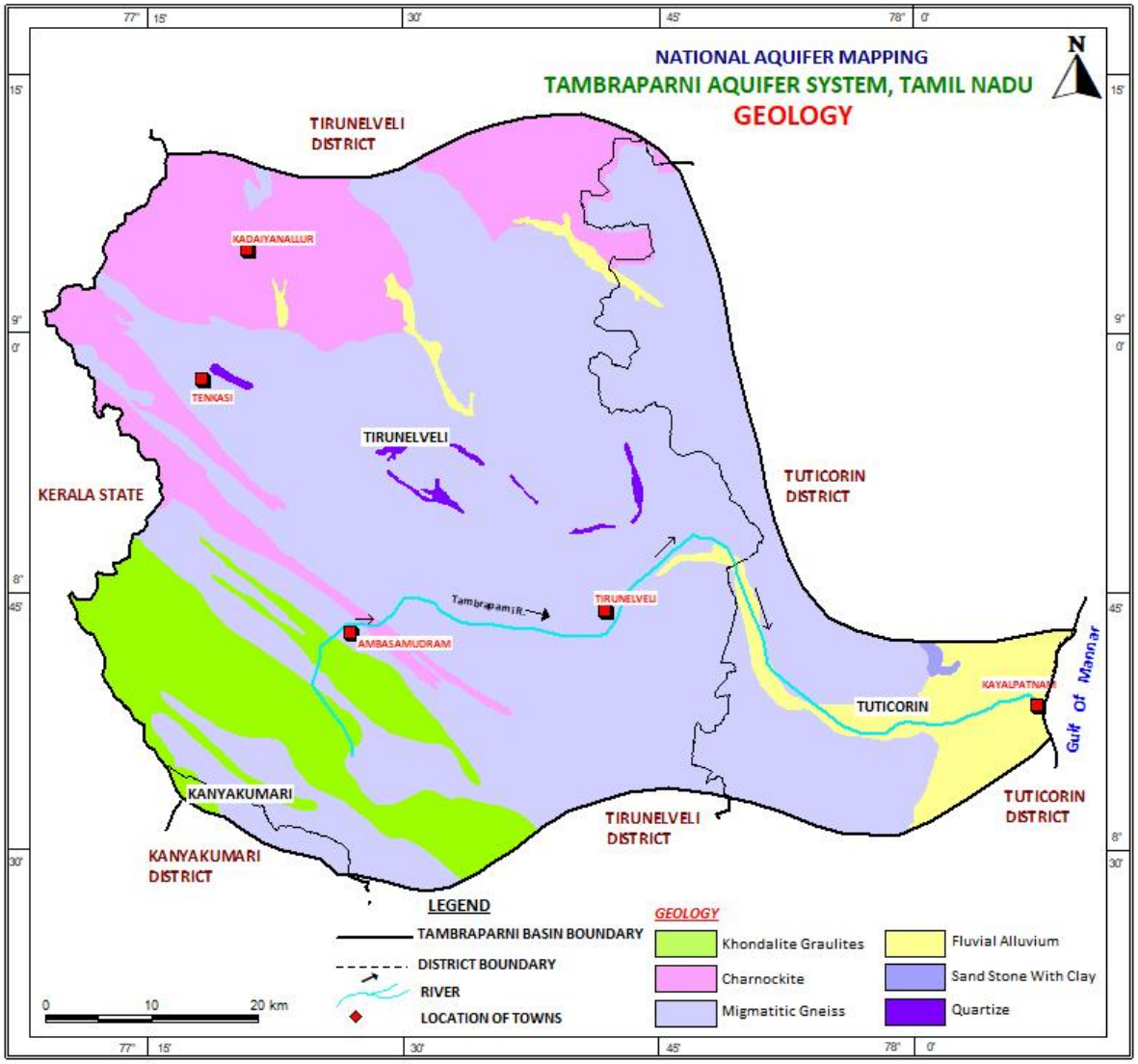


Figure 9. Geological map of the TambraparniAquifer system

1.16.1. Precambrian Rocks

Crystalline rocks of the area is mainly represented by Khondalite, Charnockites and gneisses groups. Acid intrusive and basic dykes are observed in several locations of the study area.

1.16.1.1 Khondalite group:

Khondalite group of rocks include garnetiferousbiotite gneiss and granulites with or without graphite and sillimanite, calc-granulite, quartz and Crystalline limestones. Garnetiferousbiotite gneiss and granulite with graphite or sillimanite or both occurring together are seen in the southwestern part of the Tambraparni aquifer system. Isolated occurrence of garnetiferous graphite gneiss and granulite with or without sillimanite occurs at places. Also bands of garnetiferous graphite gneiss occur within the Charnockites are noticed in the area. These rocks are generally medium to coarse grained, bluish white to light brown in colour and contain quartz, feldspar, garnet and sillimanite with varying amounts of graphite. The rocks are well foliated and at places, massive and granulitic and contains small clusters of sillimanite.

Calc- granulite occurs sporadically in garnetiferoussillimanite graphite gneiss. A few narrow bands of calc-granulite are seen in association with charnockite and garnetiferousbiotite gneiss. The bands vary in length from 5 to 15 m with widths varying from 1 to 5m.

The calc-granulites are generally greenish grey in colour, fine to medium grained and contain chiefly pyroxene and feldspar. The calc-granulite occurring near Sanganeri and Kudankulam is medium grained, greyish and contains graphite flakes.

Crystalline limestones occur along with calc-granulites and garnetiferousgranulites near Sanganeri. It is white and exclusively composed of calcite at places. It occurs as small bands. The limestone bands near Thalaiyuttu consists of coarse-grained calcite rich rocks of varied colours. A number of narrow bands of quartzite are seen in different parts of the district. They are commonly associated with charnockite and occasionally with gametiferousbiotite-gneiss and pinkish granitoid.

1.16.1.2 Charnockite Group:

The Charnockite group comprises pyroxene granulites and charnockites. Narrow bands and lenses of pyroxene granulites occur inter-banded with the charnockites, khondalites and garnetiferousquartzo-feldspathic granulite. The bands and lenses of pyroxene granulite are parallel to the foliation of the rock. Pyroxene granulite band truncate against charnockite at places. These rocks are dark grey in colour, fine to medium grained and contains chiefly pyroxenes and feldspar and in many places contain large flakes of biotite. These rocks exhibits spheroidal weathering at places.

Charnockites are the predominant rock unit in the hill ranges of the district. Isolated low mounds of charnockites are also seen in the plains. Charnockites are generally massive, medium to coarse grained, bluish to greenish in colour and acid to intermediate in composition. Gneissic charnockites occur in many places with considerable amount of biotite. It is composed of bluish quartz, greyish feldspar and pyroxenes. In a few places, it contains reddish and pinkish garnet and also graphite. Pegmatoidalcharnockite occurs as irregular patches within medium to coarse-grained charnockite. Foliations are very distinct on weathered charnockites and concentration of biotite and garnet is seen along foliation planes in Kudankulam area. Charnockite is also associated with garnetiferousquartzofeldspathic granulite and gneiss. Charnockite contains bands of quarzo-felspathic material imparting it a banded and gneissic appearance. The garnetiferouscharnockite retrogrades to garnetiferousbiotite-gneiss at places.

1.16.1.3 Migmatite complex:

The Khondalite and charnockite groups of rocks appear to have undergone varying degree of migmatisation giving rise to a greyish migmatisedcharnockite, garnetiferousbiotite-gneiss and whitish garnetiferous granulite, each having a gradational contact with the other as seen at several places especially in the area NE of Tenkasi. It also occurs as low mounds and low ridges and grades into garnetiferousbiotite gneiss. The rock is medium to coarse grained, more leucocratic than charnockite and contains chiefly quartzand feldspar with varying amounts of biotite and a little ferro-magnesium minerals. Pinkish garnet and blue cordierites also occur at places. Garnetiferousbiotite-gneiss occupies larger part of the plains in the district. It is greyish white in colour, fine to medium grained and contains quartz, feldspar, biotite and pink garnet. This rock is also know as leptynite and is believed to be the migmatised product of Khondalites

1.16.1.4 Basic Intrusives:

Basic intrusives are seen as small dykes. Fine grained basalt and medium grained dolerite dykes occur in south/southeast of Kudankulam observatory. The dykes have widths varying from less than a metre to 25 m and vary in length from 100 to 300 m. Most of these dykes cut across the foliation of the country rock. The dykes are grey in colour, hard and massive and show spheroidal weathering. Basic dykes are seen in a number of wells situated in the khondalitic and charnockitic country in the southern part of the district. They are dark grey to black and fine grained to porphyritic containing phenocrysts of pyroxenes and feldspar. Dolerite dykes are very few in this district. The dyke near Maruduappapuram is dark grey to black in colour, fine grained and composed chiefly of pyroxenes and plagioclase.

1.16.1.5 Acidic Intrusives

A number of prominent conformable bands of granitoids of different types are seen in several places. Pinkish granitoidleucogranite and greyish granitoid are common. Veins of pegmatite intrusion are seen in all the rock types, varying in thickness from a few centimetre to 1.5 m. Few Quartz veins trending N 20° W, NNW-SSE and N-S directions are also seen. Leucogranite of different dimensions are seen in northern part of the district, generally occurring parallel to the regional trend of foliation. Greyish granitoid rocks occur in a few

places in close association with charnockite. Mappable bands of pinkish granitoid rocks are seen in the district associated with charnockite and garnetiferousbiotite gneiss. They occur parallel to the regional foliation and occupy low mounds and ridges in several places in the plain country e.g., north of Senkottai and around Tenkasi. The width of granitoid rocks ranges from 5 to 15 m and lengths vary from 1 m to 3 km. Granitoids occur as linear bodies conformable with the country rock. The grey granitoid rocks have a gradational contact with associated country rock, whereas the white and pinkish types have relatively sharp contacts.

1.16.1.6 Laterites

Isolated cappings of laterite over gneisses, granulites and charnockites are seen in many parts of the district. It is generally reddish to greyish red in colour, Cavernous and Oolitic at places. The thickness of the laterite varies from a few centimetres to about 5 metres. Well exposed patches are noticed along Radhapuram-Edakkadu, VijayaNarayanam-Kumarapuram, Ittamoli, Nanguneri and Uramozhi areas.

1.16.1.7 Kankar

The occurrence of kankar and tuffaceouslimestones are very common in the district. They occur generally on the river courses and tanks. Where, there is a large flow and seepage of water during the rainy seasons. These exposures are seen over a wide area as thick and massive beds of sheet tufa resulting from the deposition of lime leached out from the underlying gneisses and charnockites and the segregation of the calcareous matter brought down by the following water. It is generally whitish, friable but hard and massive at places and shows nodular and pisolittic structures.

2. DATA COLLECTION AND GENERATION

Periodical data pertaining to groundwater levels, quality, pumping tests and slug tests were collected during aquifer mapping studies apart from water sample collection to assess the groundwater quality. In addition Geophysical data has been generated through conducting Geo electrical soundings after evaluation of data gap analysis.

2.1. Hydrogeological data:

The periodical monitoring of groundwater level reflects the groundwater recharge and discharge (natural and manmade) occurring in the aquifer systems. It also reveals the interaction between surface and sub-surface water systems. In Tambraparni Aquifer system area, 78 Nos. of groundwater monitoring wells (which included 29 CGWB monitoring wells&33 State department wells) and 16 piezometers of CGWB are monitored periodically. The locations of monitoring wells are presented as **Figure 10.**

2.2. Hydrochemical data:

The groundwater quality of the TambraparniAquiferSystem was studied by analysing available water quality data i.e CGWB monitoring open wells 33 numbers and State government monitoring wells 33 numbers. Long term record was available only for 52 numbers of open wells. The sample locations in the Tambraparni aquifer system is presented in **Figure 11**.

2.3. Geophysical data:

The geophysical survey was conducted in the study area consisting of Vertical Electrical Soundings (VES) by employing Schlumberger configuration with maximum half current electrode separation of 300m. The objective of the study is to decipher the sub surface conditions such as weathered and fractured layer resistivities, thicknesses and massive formations up to the depth of 200 m bgl. A total number of 85 VES were carried out and geo electric layers inferred through interpretation of the results obtained. The locations of the VES are presented in **Figure 12.**

2.4 Groundwater Exploration data:

Data of 114 Nos. of exploratory wells were drilled in the Tambraparni aquifer system (44 Nos. CGWB and 70 Nos. State department wells) prior to National Aquifer Mapping project was compiled and analysed (**Figure 13**). These wells were plotted on the 1:50,000 scale topographical map and as per the NAQUIM guidelines for the hard rock& soft rocks, data requirements were identified on the plotted topographical map. Based on the data requirements, 19 Nos. of exploratory wells have been recommended for drilling through outsourcing activity as part of the data generation. The data such as lithology, fracture depth, yield, water level, aquifer properties were generated and utilised to depict the prevailing aquifer systems of the basin (Annexure-1).Similarly wells drilled by state department, 70 Nos. wells drilled upto to the depth of 60 m bgl was used for deciphering the first aquifer.

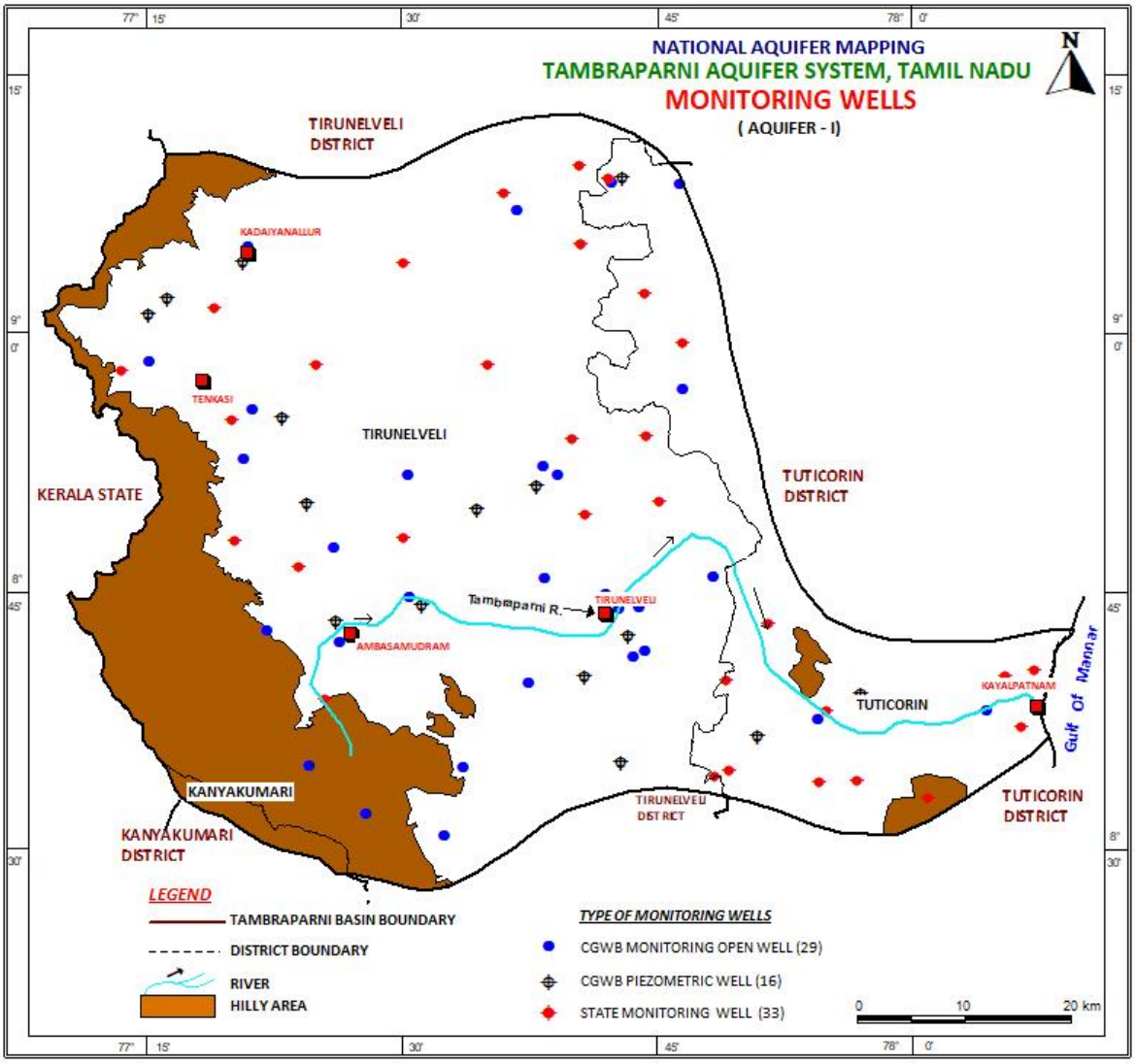


Figure 10. The locations of monitoring wells of the Tambraparni aquifer system.

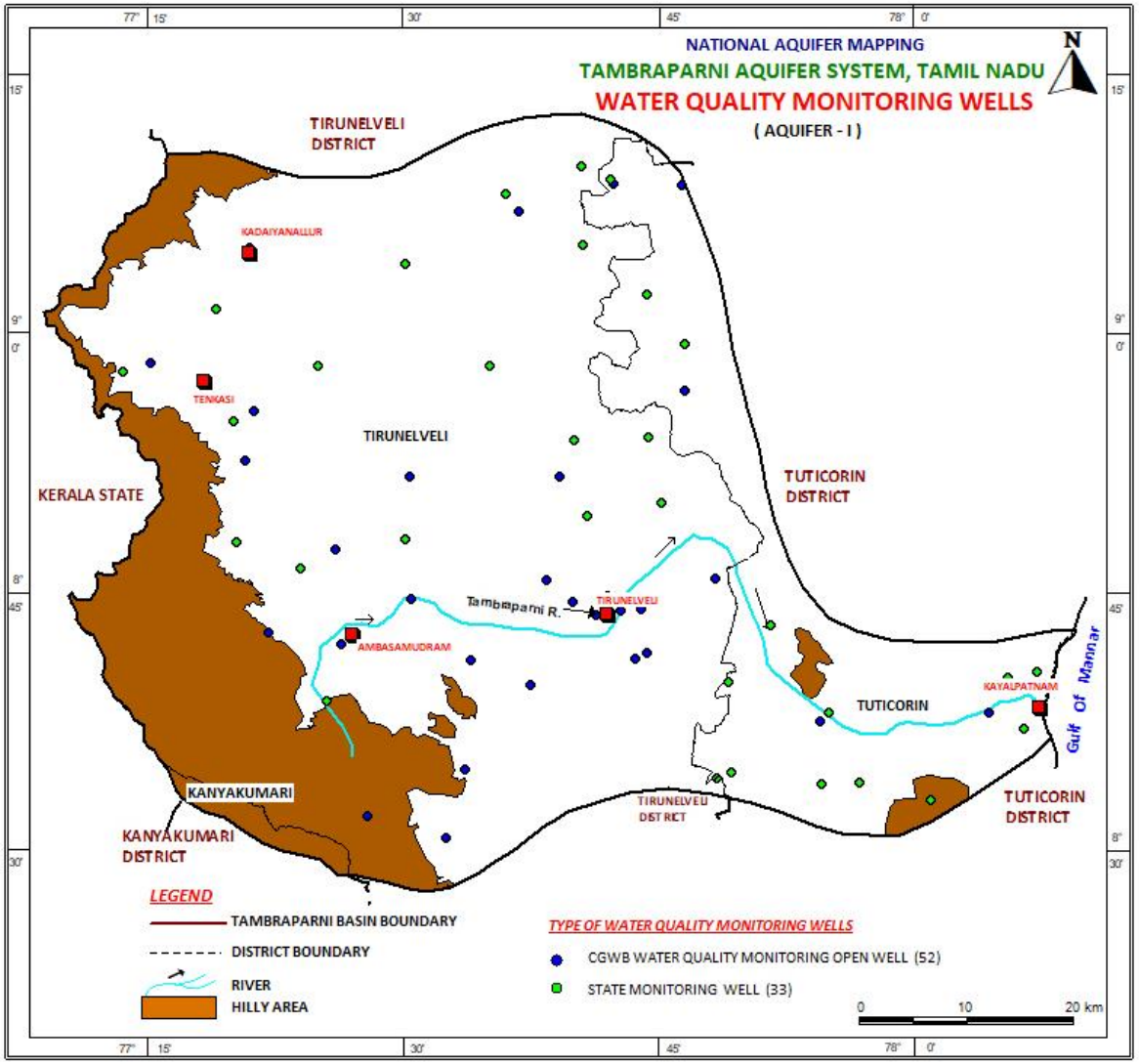


Figure 11. Locations of Groundwater quality Monitoring Wells ofTambraparni Aquifer System

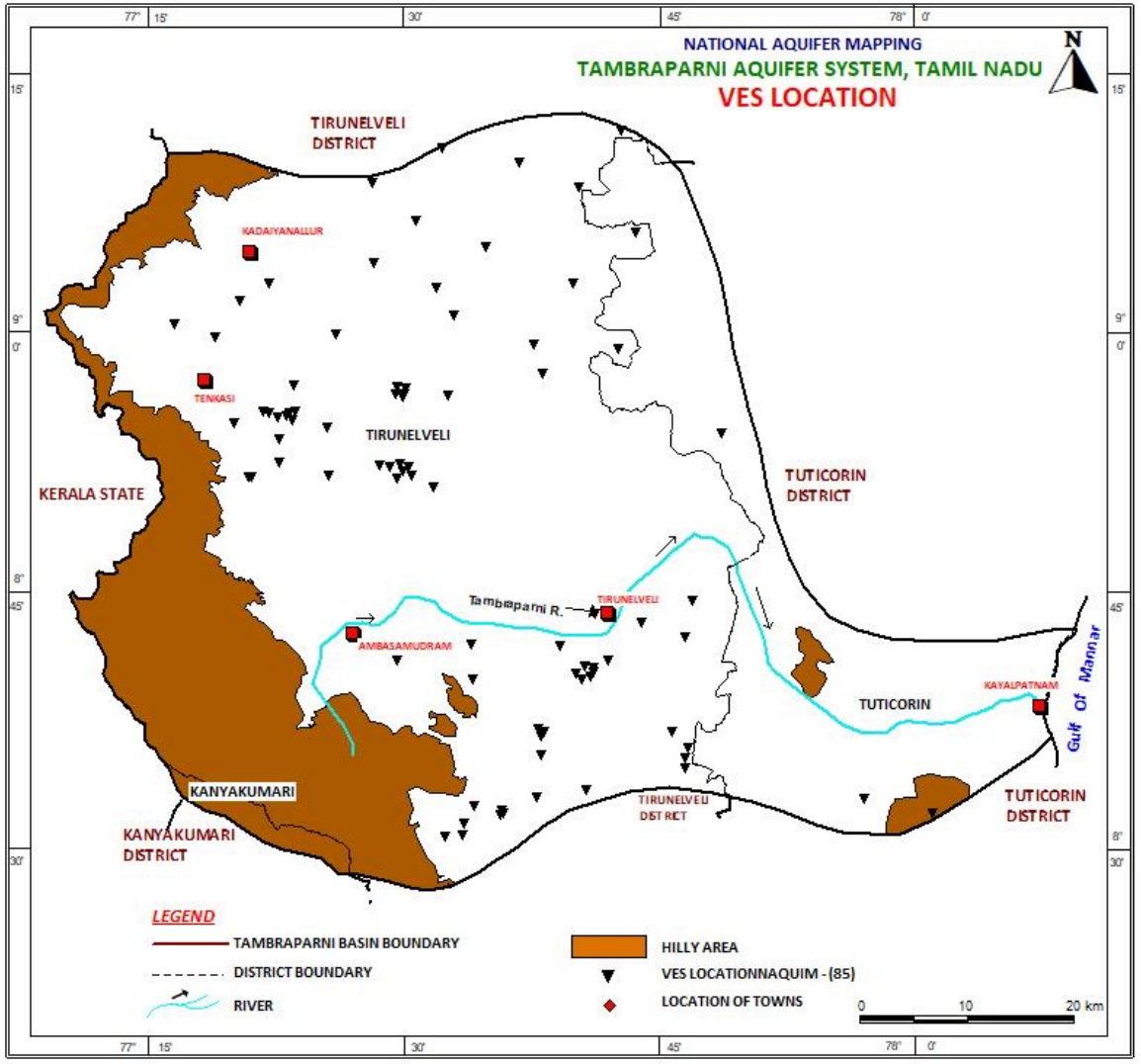


Figure 12. Locations of Vertical Electrical Soundings (VES) of Tambraparni Aquifer System

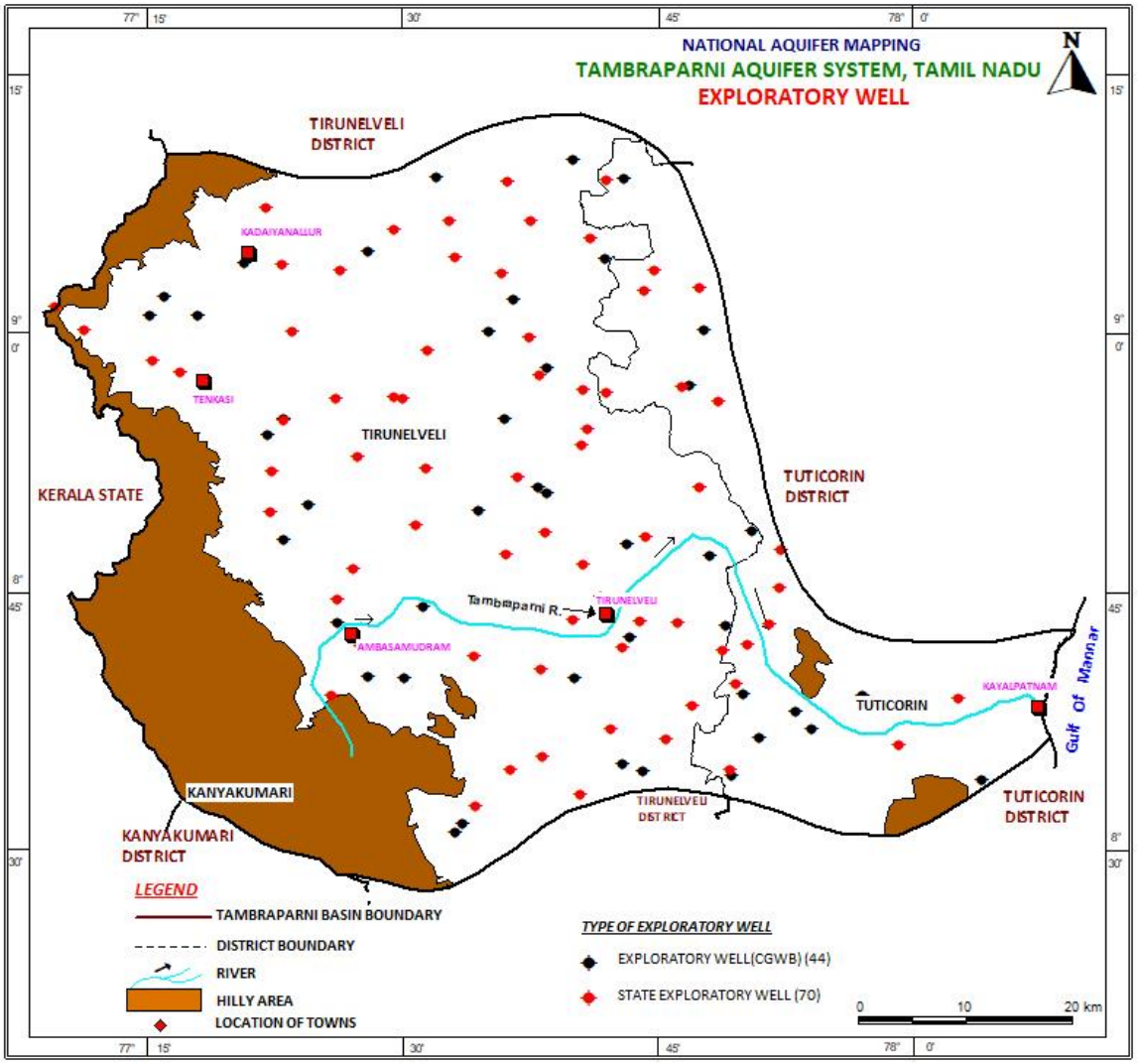


Figure 13. Locations of all Exploratory WellsofTambraparni Aquifer System

3. DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

3.1 Hydrogeological Data Interpretation and aquifer disposition

Tambraparni aquifer system area is divided into A and B regions. A-Region represents area underlined by Charnockite&Khondalite rocks, B region represents area underlined by Gniess rocks. Aquifer units falling in "A" regions are named as A1 & A2, whereas aquifer units falling in "B" regions are named as B1 & B2.

3.1.1.Hydrogeology of Charnockite&Khondalite rock region (A):

Hard rock region comprising of CharnockiteandKhondaliterocks is found in the western and northern portions of the Tambraparni aquifer system. The rocks of region A cover an area of 1513.46sq,km. The charnockite formation covering an area of 919.64 sq.km encompasses 24 firkas**(Table 3).** The Khondalite formation covers an area of 593.82 sq.km and is found in 5 firkas. The Charnockite and Khondalite formation form two aquifer units namely the weathered and fracture/jointed aquifer unit**(Figure 18**).

3.1.1.1. Aquifer Unit I – Weathered (A1) :

The weathered aquifer unit occurs from the ground level and has a minimum thickness of 4.5 m and maximum thickness of 23 m with average thickness of 12-15m. 2D disposition along Northwest to southeast (D-D')and Southwest to Northeast (C-C')clearly shows the vertical and lateral distribution of the CharnockiteandKondalite rock formations. Yield of this weathered aquifer unit ranges from 0.078 to 1.9 m^3/hr with average of <1 m^3/hr. During monsoon period the wells tapping this aquifer unit sustains for 1 to 2hrs/dayof pumping, while during non-monsoon period (May to July) wells sustains for less than 1 hour/day of pumping.Groundwater occurs in unconfined condition.Weathering thickness of Aquifer unit-I, Tambraparni Aquifer System is shown in **Figure 14**.

Table3.Firkas in hard rock region (Region A) of the Tambraparni aquifer system.

Formation	Firkas
Khondalite	Alwarkurichi, Ambasamudram, Cheranmahadevi, Kalakadu, Singampatti.
Charnockitic region : (10firkas-full)	Alwarkurichi, Ambasamudram, Ayikudi, cheranmahadevi, Elathur, Kadayam, Kadayanallur, Kallurani, Kalugumalai, Karuvantha, Kurukkalpatti, Melaseval, Mukkudal, Panpoli, Pappakudi, pazhankottai, Schencottai, Sernthamangalam, Surandai, Tenkasai, Veerasigamani

The aquifer parameter such as transmissivity in this aquifer unit ranges from 1 to 110 m^2/day. The Specific yield of this aquifer unit ranges from 1 to 1.5% with highly potable groundwater quality. The general EC of this aquifer unit ranges from 369 -3290 µS/cm with the average range of 500 to 1100 µS/cm. There are some isolated pockets adjoining the Kalakadu and Tirunelveli area groundwater quality is beyond permissible limit for drinking and irrigation purposes.

3.1.1.2. Aquifer Unit II (Fractured/Jointed):

This aquifer unit comprises of fractured and jointed Charnockite and Khondalite formed due to tectonic activity. Top of this aquifer unit occurs from 5 to 23m bgl&ground level at some places). Based on the analysis of the 114 wells it is observed that there is a possibility of occurrence of 3 to 4 Fractures/joints upto 197 m bgl in the Charnockite and Khondalite region**(Figure 15).**The distribution of the fractures with depth is given in **Table 4**.The yield of this aquifer unit II ranges from 0.3 to 9.5 (majority <4) lps. During monsoon period the wells tapping this aquifer unit sustains for 1 to 3hrs /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 1 to 6 m^2/day**(Table 5).**The general EC of this aquifer unit ranges from 600 to 800µS/cm with the minimum and maximum of 465 to 1060 µS/cm.

Table 4 . Distribution of fractures in the hard rock formation

Gneissic formation		**Charnockite&Khondalite region**	
Depth (m bgl)	**% of fractures**	**Depth (m bgl)**	**% of fractures**
Upto 50	49	Upto 50	52
50 to 100	22	50 to 100	20
100 to 150	12	100 to 150	12
150 to 195	17	150 to 195	16

Table 5. Salient features of the aquifer units in Charnockite&Khondalitehardrock region of Tambraparni aquifer system

Type of Aquifer	**Formation**	**Top of the aquifers (mbgl)**	**Thickness/ occurrence of fractures (m)**	**Range of Yield (lps)**	**Sustainability (hrs)**	**Aquifer parameter (Transmissivity – m2/day)**	**Ground water quality EC values (µs/cm)**	**Suitable for Drinking**
Aquifer unit – A-I	**Weathered Charnockites&Khondalite**	**0.5 - 2**	**4.5 – 23 (Avg. -12 -15 m)**	**0.078 - 1.9 Majority (< 1)**	**Monsoon : 1-2 hrs& Non monsoon: (May, Jun &July) < 1 to 2**	**1-110**	**369-3690 (Avg 500-1100)**	**Yes – except few isolated pockets**
Aquifer Unit – A-II	**Jointed & Fractured Charnockite &Khondalite**	**5– 23 Nil at some places**	**24 -195 (Avg. 40 -60 m) (3 to 4 fractures exist) Mostly confined to 50 m bgl. Nil at few places**	**0.3 – 9.5 (Majority < 4)**	**Monsoon: 1-3 hrs& Non monsoon 1 to 2 hrs**	**1 -6**	**465-1060 (Avg 600-800)**	**Yes - except few isolated Pockets**

3.1.2.Hydrogeology of Gniessicrock area of the aquifer system (B):

Hard rock region comprising of gneissic rock formations occupymost part of the aquifer system.Gneissic rock area coversanarea of 3993Sq.Km. and encompasses 51firkas**(Table 6).**The Gneissic rock formation form two aquifer units namely the Aquifer Unit-I (B1-weathered rock) and Aquifer Unit-II (B2-fracture/jointed aquifer unit).

3.1.1.1. Aquifer Unit I – Weathered (B1) :

The weathered aquifer unit occurs from the ground level and has a minimum thickness of 3.5 m and maximum thickness of 29 m with average thickness of 15-20 m. 2D disposition along Northwest to southeast (D-D') and Southwest to Northeast (C-C')clearly shows the vertical and lateral distribution of the Gniessic rock formations. Yield of this weathered aquifer unit ranges from 0.014 to 3.84 m^3/hr with average of <1 m^3/hr. During monsoon period the wells tapping this aquifer unit sustains for 2 to 3hrs/day of pumping, while during non-monsoon period (May to July) wells sustains for < 1 to 2 hour/day of pumping. Groundwater occurs in unconfined condition. Weathering thickness of Aquifer unit-I, Tambraparni Aquifer System is shown in **Figure 14**.

Table 6.Firkas falling in Gniessic rock region of theTambraparni aquifer system

Formation and number of firkas	Name of the firkas
Gniess rock (51 firkas)	Alankulam, Alwarkurichi, Alwarthirunagari, Ambasamudaram, Arumugamangalam, Authoor, Ayikudi, Cheramahadevi, Deivaseyalpuram, Elathur, Gangaikondan, Kadayam, Kadayanallurm, Kalakadu, Kallurani, Kalugumalai, Karuvantha, Kayathar, Keezhapavoor, Kurukkalpatti, Madhavakurichi, Manur, Melapattam, Melaseval, Mukkudal, MuneerPallam, Naranammalpuram, Narannammalpuram, NetturmPalayamkottai, Panppoli, Pappakudi, Pazhankottai, Perungulam, Poolam, Pudupatti, Schencottai, Seidunganallur, Senthamangalam, Singampatti, Sivanthipatti, Sirivaikundam, Surandai, Tenkasi, Tahaliyuthu, Tirunelveli, Uthumalai, Vallanad, Vannikonenthal, Veerakeralampudur, Veerasigamani,Venkadampatti.

The aquifer parameter such as transmissivity in this aquifer unit ranges from <1 to 110 m^2/day. The Specific yield of this aquifer unit ranges from 1 to 1.5% with highly potable groundwater quality. The general EC of this aquifer unit ranges from 245 -3290 µS/cm with the average range of 1000 to 1600 µS/cm.

3.1.1.2. Aquifer Unit II (Fractured/Jointed) (B2):

This aquifer unit comprises of fractured and jointed Gniessic rock formed due to tectonic activity. Top of this aquifer unit occurs from 4.5 to 30 m bgl& ground level at some places).

Based on the analysis of the 114 wells it is observed that there is a possibility of occurrence of 3 to 4 Fractures/joints exists up to 195 m bgl in the Gniessic rock region **(Figure 15).** The distribution of the fractures with depth is given in **Table 4**. The yield of this aquifer unit II ranges from nil to 14.4 (majority <4) lps. During monsoon period the wells tapping this aquifer unit sustains for 1 to 5hrs /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 1.7 to 135 m^2/day **(Table 5).** The general EC of this aquifer unit ranges from 500 to 800 µS/cm with the minimum and maximum of 465 to 1115 µS/cm.

Table 7. Salient features of the aquifer units in Gniessicrock region of Tambraparni Aquifer System

Type of Aquifer	Formation	Top of the aquifers (mbgl)	Thickness/ occurrence of fractures (m)	Range of Yield (m^3/h)	Sustainability (hrs)	Aquifer parameter (Transmissivity m2/day)	Groundwater quality EC values (µs/cm)	Suitable for Drinking
Aquifer unit –B- I	Weathered gneiss	1 or 2	3.5 - 29 (Avg. 15-20 m)	0.014 - 3.84 Majority (< 1)	Monsoon : 2-3 hrs& Non monsoon: (May,Jun &July) < 1 to 2	0.10 - 110	245-3290 (General range: 1000-1600)	Yes - except few isolated pockets
Aquifer Unit –B- II	Jointed & Fractured Gneiss	4.5 – 30 Nil at some places	9.5 – 175 (Avg. 60-80 m) (3 to 4 fractures exist) Mostly confined to 75 m bgl Nil at few places	Nil – 14.4 Majority (<4)	Monsoon: 1-5 hrs& Non monsoon 1 to 2 hrs	1.7 - 135	465-1115 (General range: 500 – 800)	Yes

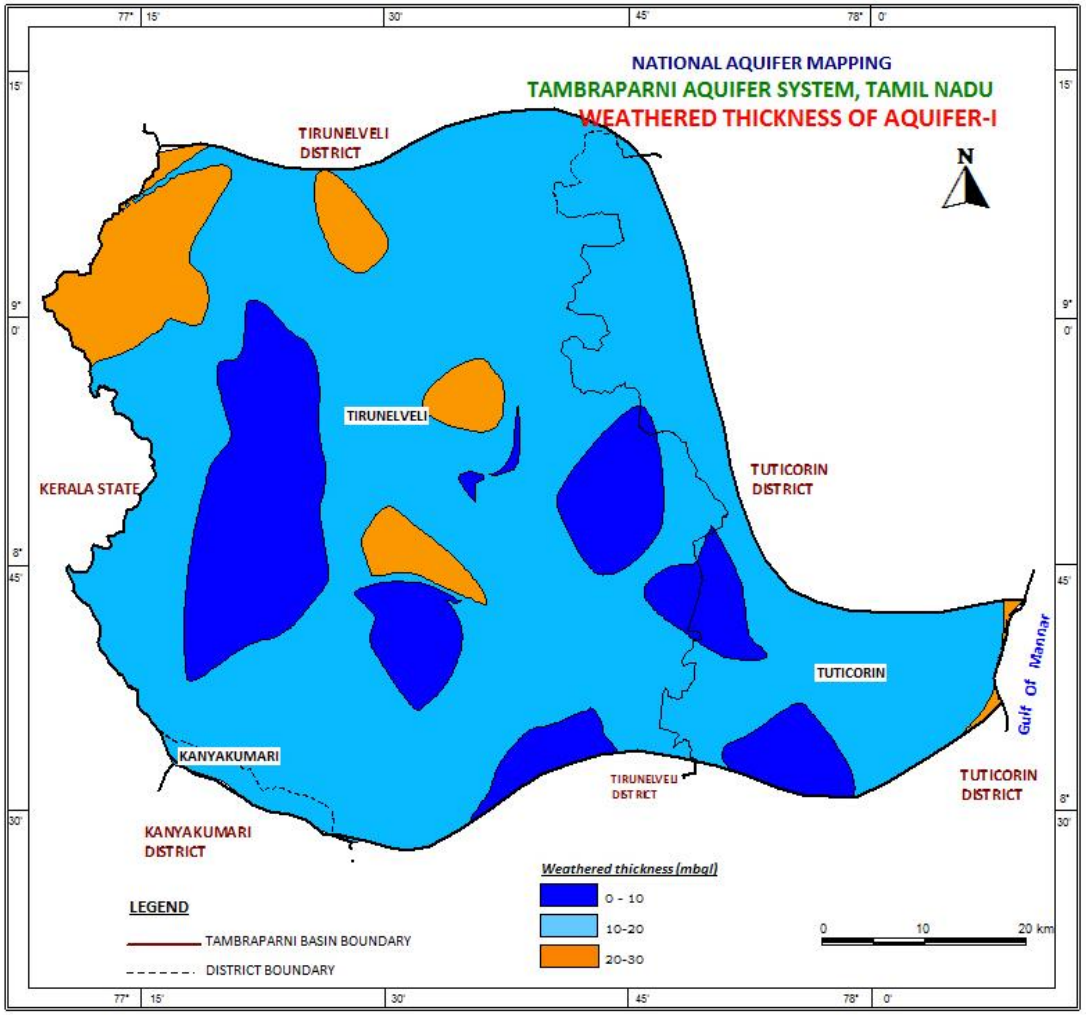


Figure 14. Weathered thickness of Aquifer-I, Tambraparni Aquifer System

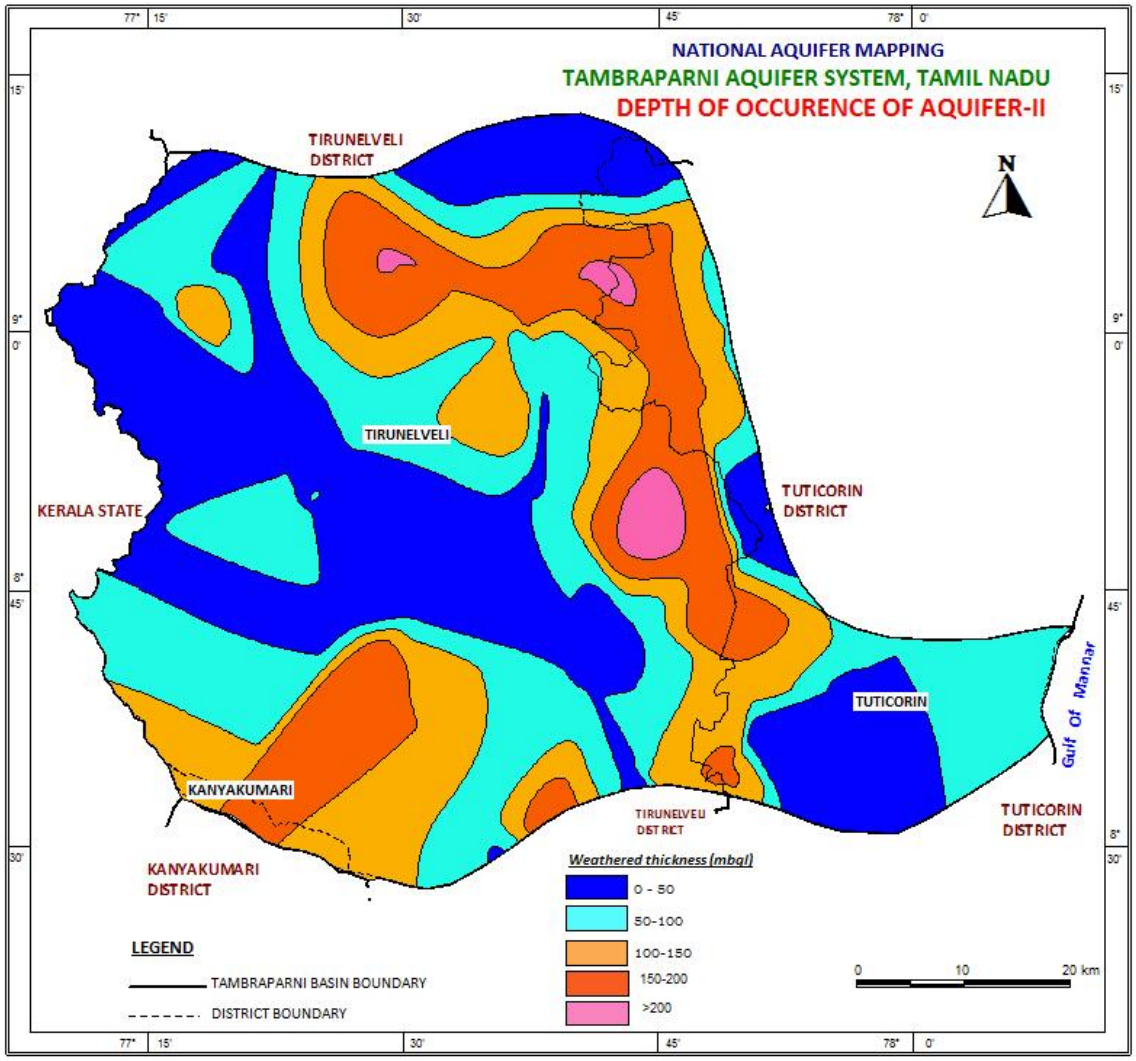


Figure 15.Depth of occurrence of Aquifer-II of Tambraparni Aquifer System

3.2.Groundwater Level

During Aquifer Mapping studies in Tambraparni aquifer system 45Groundwater monitoring wells were monitored regularly in different formations in order to know the behaviour of the groundwater regime. The water levels were monitored from May 2008 to January 2017 (four times in a year). The depth of dug well ranged from 3.00 to 30.00mbgl.

3.2.1. Depth to Water level for aquifer I (May2018)

The water level data pertaining to the period of May 2018(pre monsoon) was used for the preparation of depth to water level map of the basin. The depth to water level during May 2018 varied from 0.69 to 26.65mbgl. Major part of the basin shows water level in the range of 5 to 20mbgl.Isolated pockets had water levels in the range of 2 to 10mbgl. Water levels with>10mbgl are observed in the southern Part of the aquifer system.Hydrogeological map of the aquifer system is given in **Figure. 16** and the Depth to water level map for aquifer I-Premonsoon as **Figure 17.**

3.2.2. Depth to Water level For aquifer I (Jan-2019)

To prepare the depth to water level map for the period of January 2019, based on GWMW data collected from the basin area are used. The depth to water level during Jan 2019 varied from 0.22 to 19.25mbgl.Water level in the range of 2 to 10mbgl found in majority of the area, whereas the deeper water level of > 10 mgbl are found in the southern part of the aquifer system.Depth to water level map for aquifer I-Postmonsoon as **Figure 18.**

3.2.3. Decadal Water Level Scenario of the aquifer system

Decadal water level scenario maps are prepared for pre-monsoon and post-monsoon period. The analysis shows that during the Pre monsoon period (May 2008- May 2017) 59% of the well shows water level between 5 and 10 m bgl, 27% of the wells shows water level 2 to 5 m bgl, 2% of the wells shows shallow water level in the range of 0 to 2 bgl and 11% of the wells shows deeper water level in the range of 10 to >20mbgl. Whereas during the post monsoon period (Jan 2009 – Jan 2018)43 % of the wells shows water level i.e. 2 to 5 m bgl, and 5% of well shows very shallow water level less than 2 m bgl.34 % of the well shows water level in the range of 5 to 10 m bgl. The studies show that the basin is responding to the rainfall and recharging the aquifers. The deeper water level of 10 to 20 m bgl are represented by 16% of the wells. Depth to water level (Aquifer-I) – decadal average- Premonsoon of the Tambraparni Aquifer System presented as **Figure 19**. Depth to water level (Aquifer-I) – decadal average- Postmonsoon of the Tambraparni aquifer system presented as **Figure 20.**

3.3 Pumping Tests

The yields of the wells in the study area are widely varied. Many of dug wells in the area have less than one meter water Column during most part of the year. About 60 to 70 % ofwells located in the eastern and southern parts get dry during summers months. The wells located in favourable hydrogeological settings like shear zones, topographic lows, river alluvium etc., are able to sustain at a rate of 100 lpm for 2 to 3 hrs of pumping. The yield of large diameter wells tapping the weathered mantle of crystalline rocks ranges from <1 to 4 lps for a drawdown of 2 to 3 m and are able to sustain 1 to 3 hours of pumping. The specific capacity of the porous weathered formation ranges from 7 to 35 lpm/m/dd. The transmissivity values of the weathered formation computed from pumping tests ranges from 1 to 110 m^2 /day. At a very few places the weathered mantle extends down to 29 m bgl.

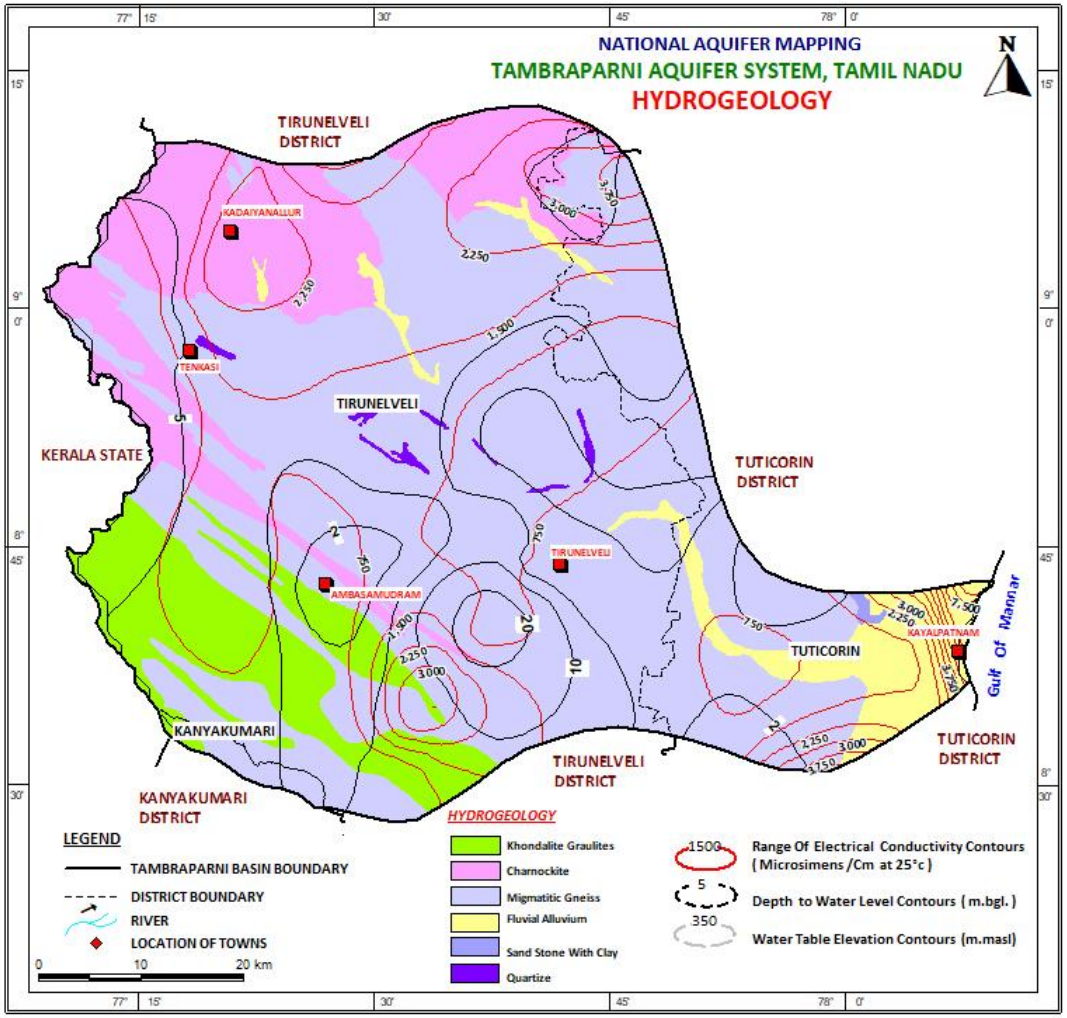


Figure 16. Hydrogeology map of the Tambraparni aquifer system

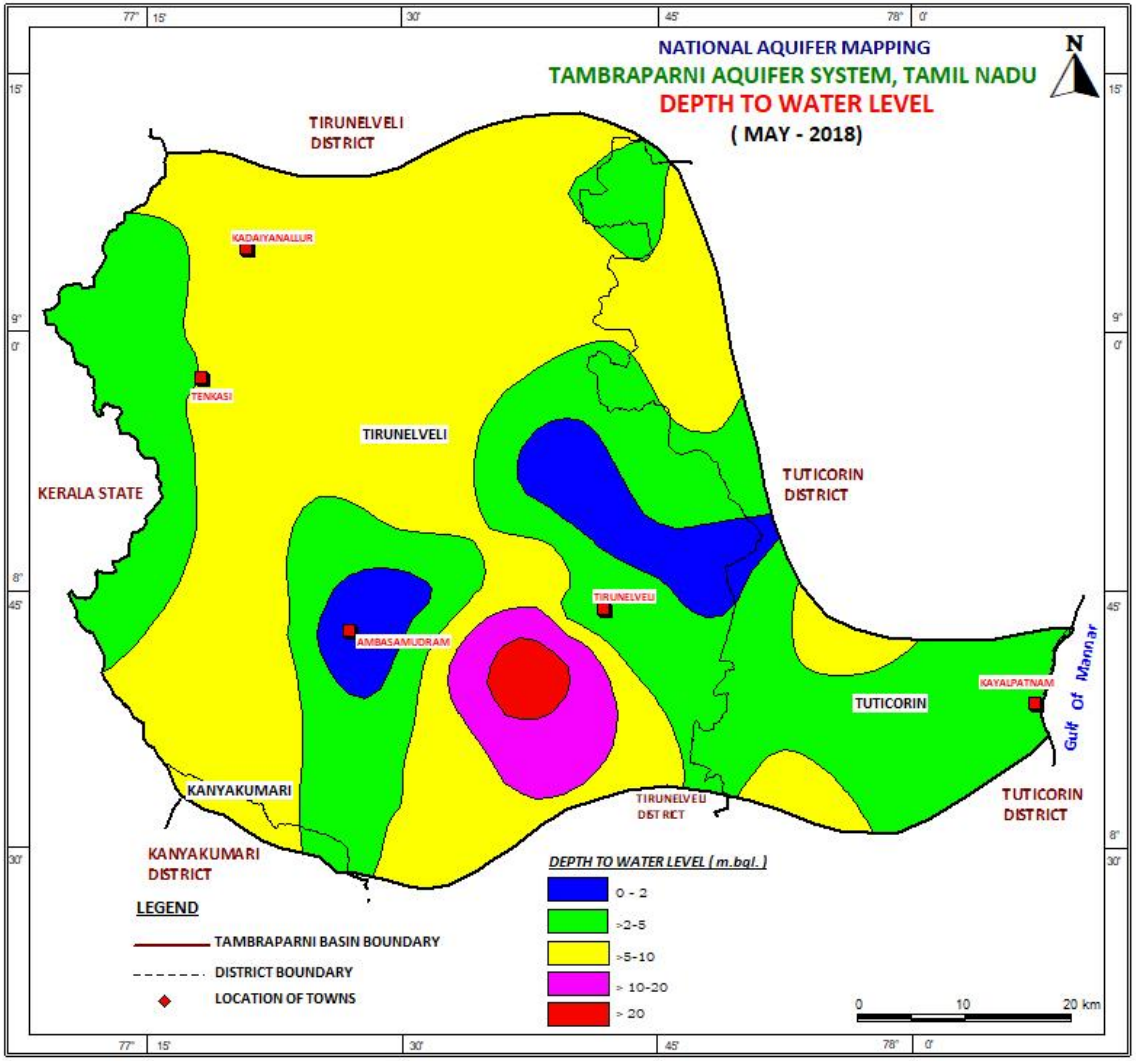


Figure 17. Depth to water level (Aquifer-I) – Premonsoon of the Tambraparni aquifer system

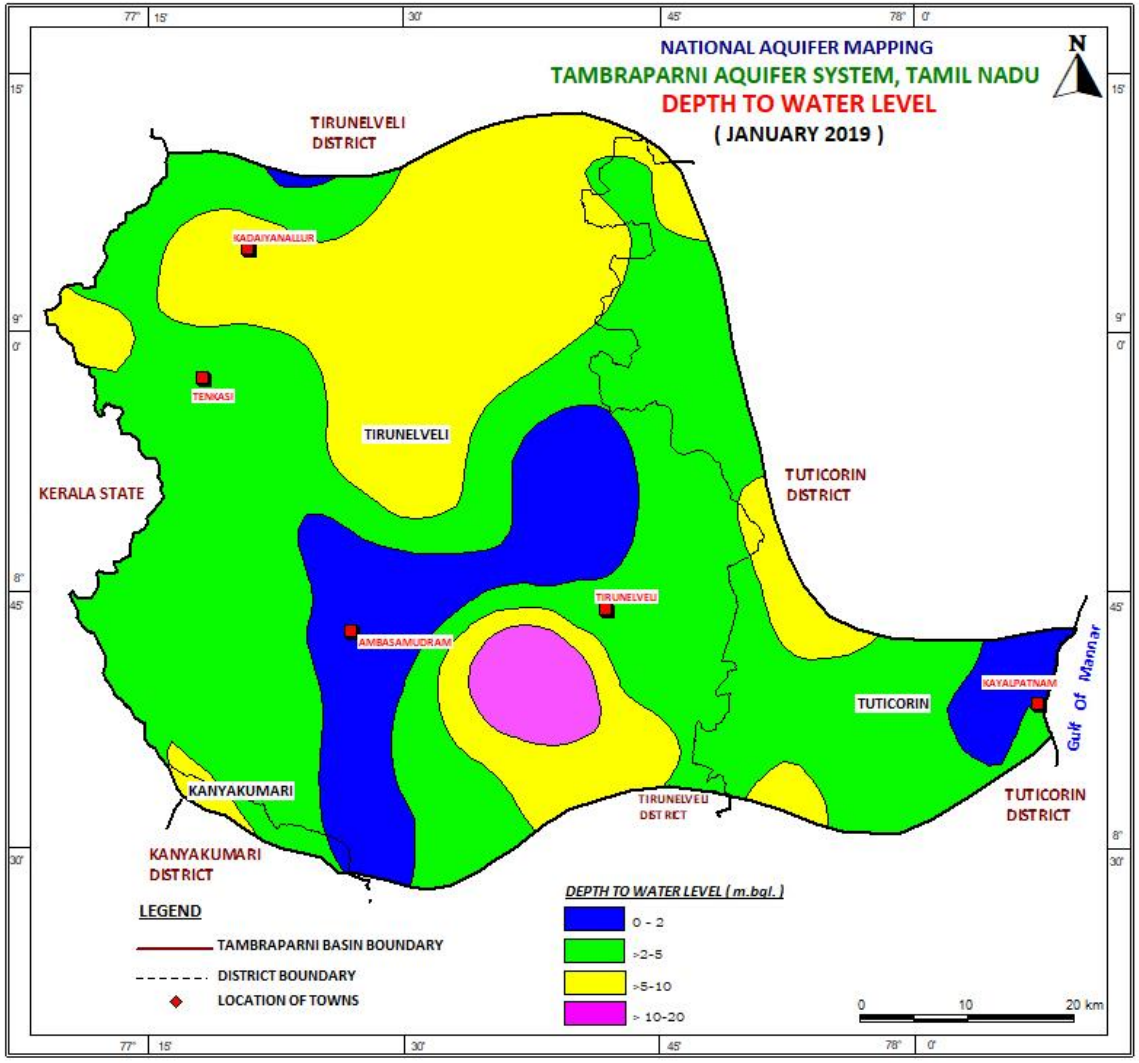


Figure 18. Depth to water level (Aquifer-I) – Postmonsoon of the Tambraparni aquifer system

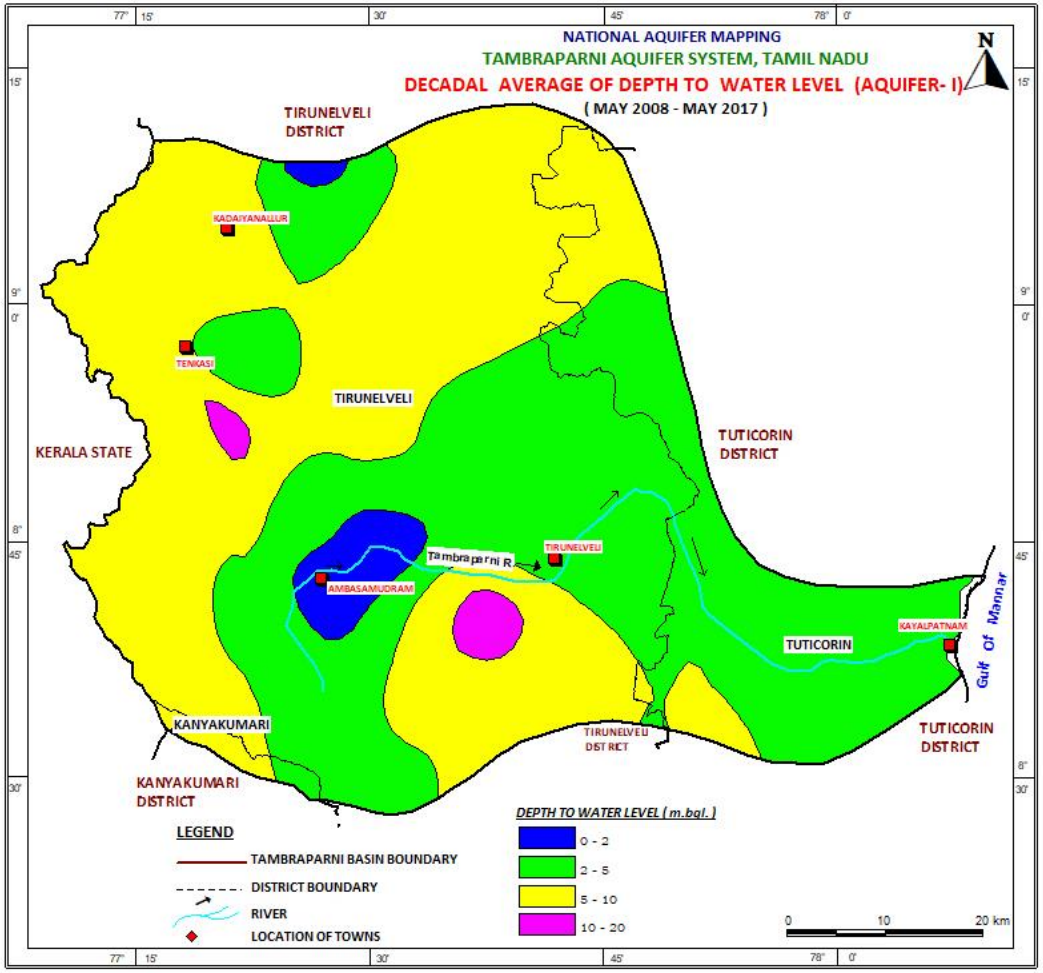


Figure 19. Depth to water level (Aquifer-I) – decadal average- Premonsoon of the Tambraparni aquifer system

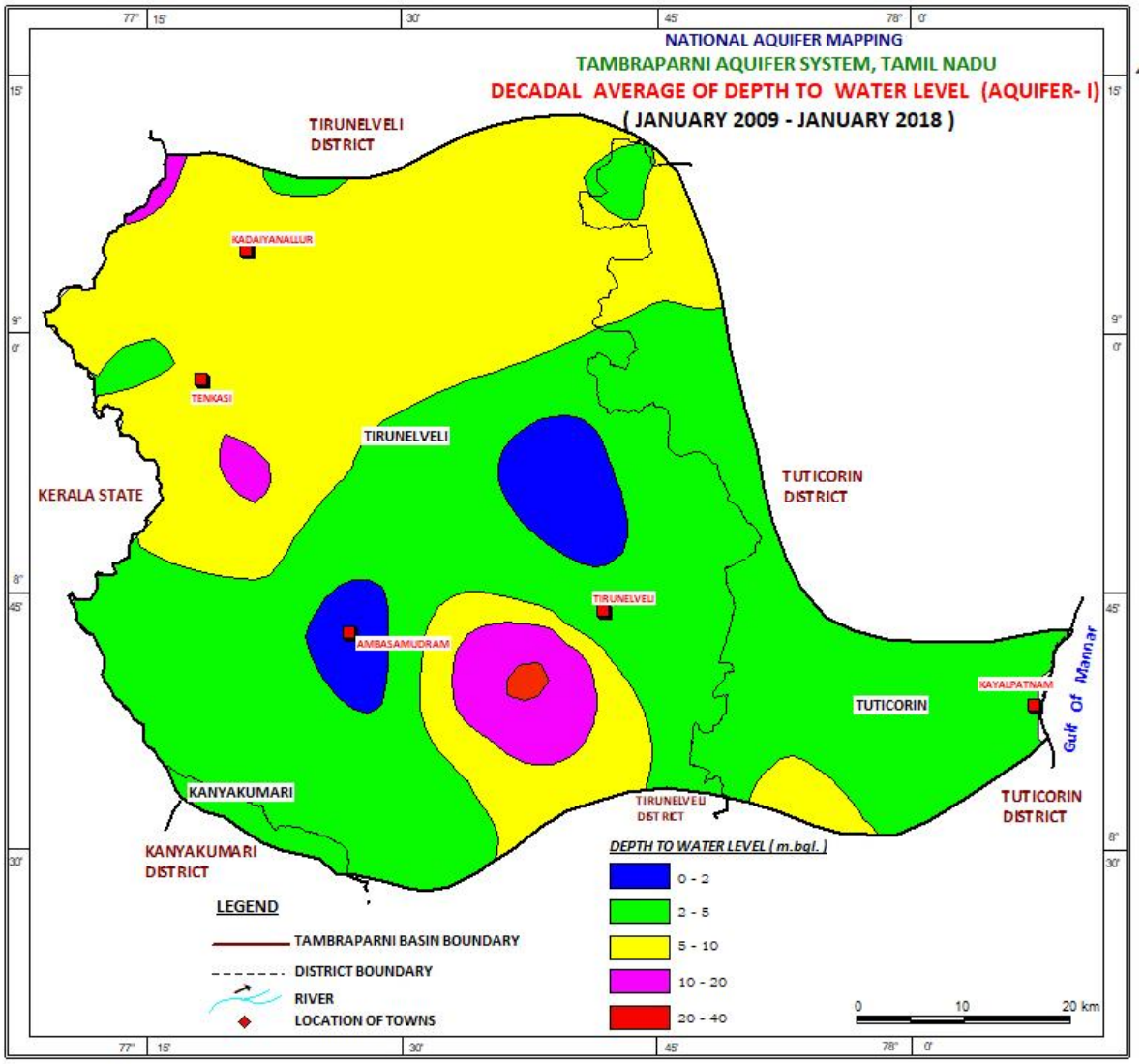


Figure 20. Depth to water level (Aquifer-I) – decadal average- Postmonsoon of the Tambraparni aquifer system

3.4 Groundwater quality

3.4.1. Electrical Conductivity:

Electrical conductivity is the indicator of the total mineral content of water and hence it indicates the total dissolved solids (TDS) present in water. TDS of water determines its usefulness to various purposes. Generally water having TDS <500 mg/L is good for drinking and other domestic uses. However, in the absence of alternative sources TDS up to 2000 mg/L may be used for drinking purposes. The distribution of EC in different aquifers are shown in **Figure 21& Table 8**.In phreatic aquifer the groundwater quality is fresh, about 39% of the samplesshowEC value less than 750 µs/cm at 25ºC. 47% of the groundwatersampleshave moderateECvarying between 751 and 2250µs/cm at 25º C, only 6% of Groundwater showing EC between 2251 and 3000 µs/cm at 25º C indicating that the groundwater is slightly mineralized and about 8% of groundwater wells the EC is more than 3000 µs/cm at 25ºC indicating that the groundwater is highly mineralized. The fractured zone groundwater quality is fresh in about 18%, as indicated by the EC value which is less than 750 µs/cm at 25ºC. In about 75% of the groundwater, the EC varies between 751 and 2250µs/cm at 25º C indicating that groundwater is moderately fresh and 10% of groundwater is between 2251 and 3000 µs/cm at 25º C indicating that the groundwater is slightly mineralized. Only in 2% ofgroundwatersamples the EC is more than 3000 µs/cm at 25ºC, which occupies the coastal part of the study area.

Table 8. Distribution of EC in the aquifer unit-I.

Ec (us/cm)	Percentage of sample (%)
0-750	39
>750-2250	47
>2250-3000	06
> 3000	08

3.4.2. Chloride:

About 81% of the groundwater samples of phreatic aquifer has the chloride concentration 0 to 250 mg/l and about 17% of groundwater sample has the chloride concentration 250 to 1000 mg/l. The distribution of chloride concentration in Aquifer-I is presented in **Figure 22** and **Table9.**

Table 9. Distribution of chloride concentration in aquifer

Cl (mg/l)	Percentage of sample
0 -250	81
>250-1000	17
>1000	2

3.4.3. Fluoride

The important fluorine-bearing minerals are fluorite (Calcium fluoride), apatite (Complex fluoride- bearing silicate), certain amphiboles and micas. The concentration of fluoride in groundwater is limited due to the low salinity of most fluoride in groundwater. It is limited due to the low solubility of most fluorides. The solubility of fluoride in pure water at $25^{o}C$ is only 8.7 ppm of fluoride. Groundwater in most areas contains less than 1.5 ppm fluorides, but in some areas i.e. Kalugumalai, Muthalapuram, Cheramadevi, Kadayanallur, Kurukkalpatti, Palayamkotai, Tirunelveli and Sankarankovilfirkas, the concentration is more than 1.5 ppm (Figure 23).

3.4.4. Nitrate

Nitrogen is a very minor constituent of rocks, but is a major constituent of the atmosphere. Nitrogen and oxygen of the atmosphere are combined by electrical charging during lightning and dissolve in rainwater. The average nitrate content in rainwater is reported to be 0.2 ppm (Riffenburg, 1926). In most part of the aquifer system the concentration of Nitrate is <45 mg/l which is well within the permissiable limit, whereas few samples falls in firkas like Tirunelveli, Kalakadu, Melapattam, Kurukalpatti, Deivasayalpuram and Srivenkateshwarapuram has concentration of Nitrate is > 45 mg/l (Figure 24). This is due to the mixing of sewaragewaterwith the ground water in urban areas and also the increase in concentration of Nitrate is due to the leaching effect of Nitrogen fertilizers applied in the agriculture field in the study area.

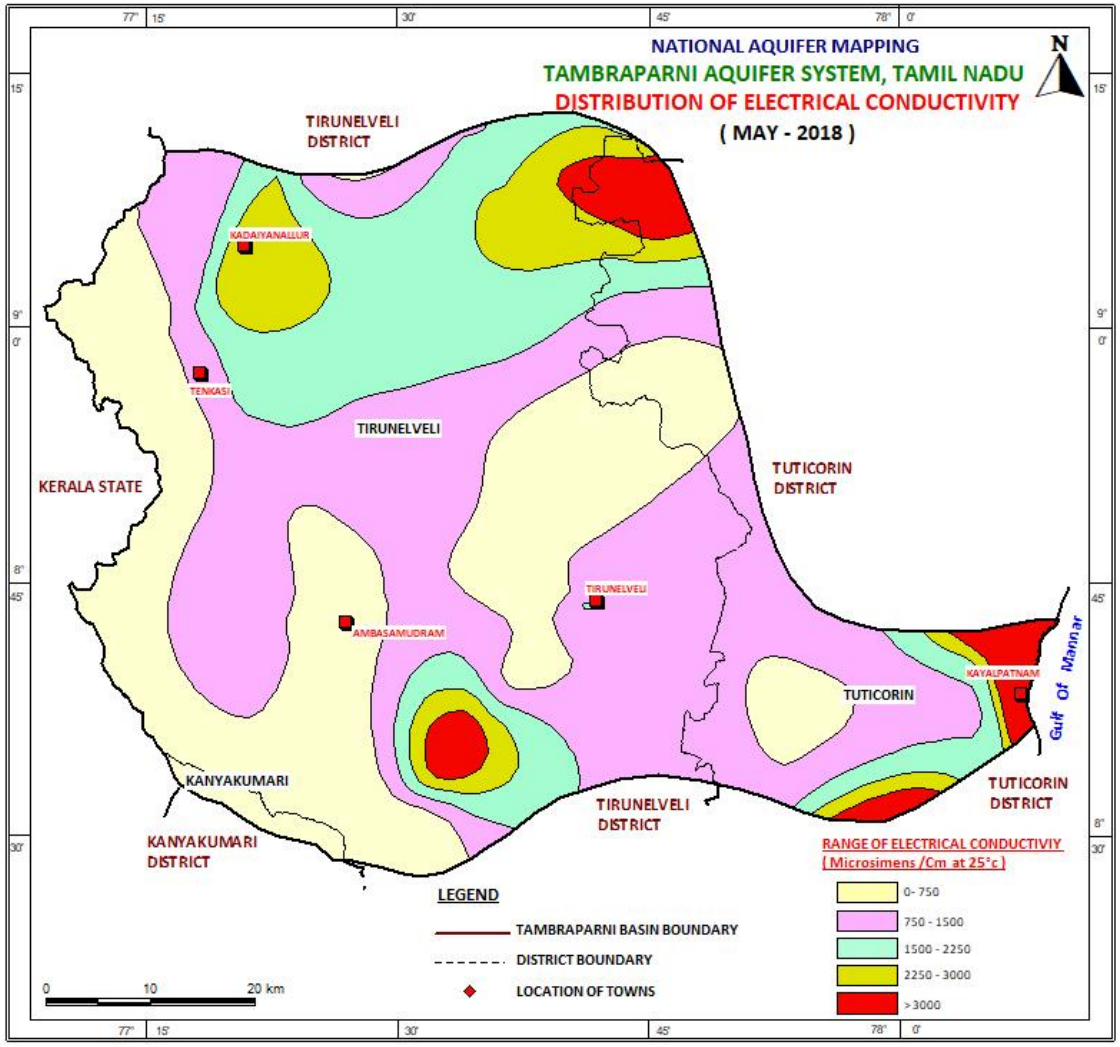


Figure 21. Distribution of EC in Aquifer I of the Tambraparni Aquifer system.

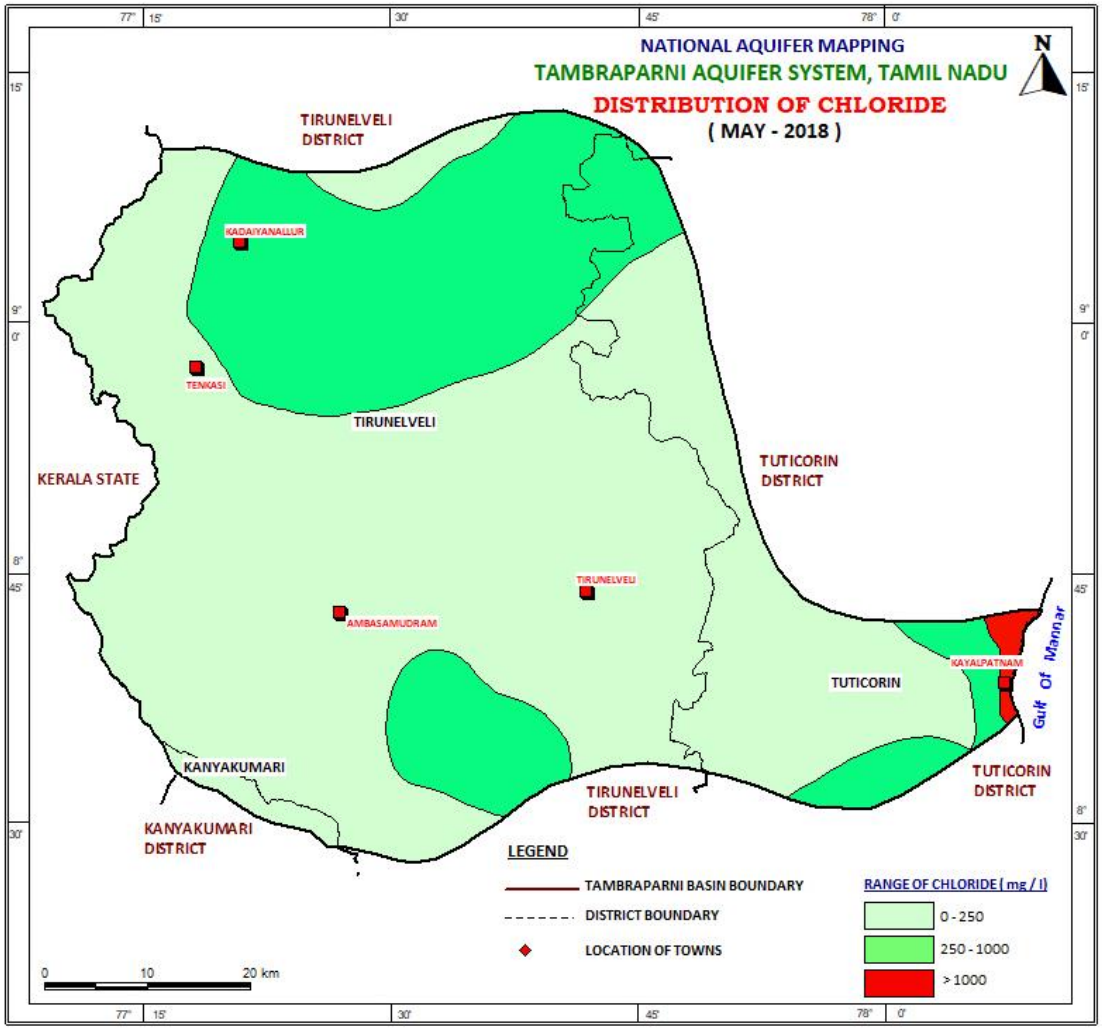


Figure 22. Distribution of Chloride in Aquifer-I of the Tambraparni Aquifer system

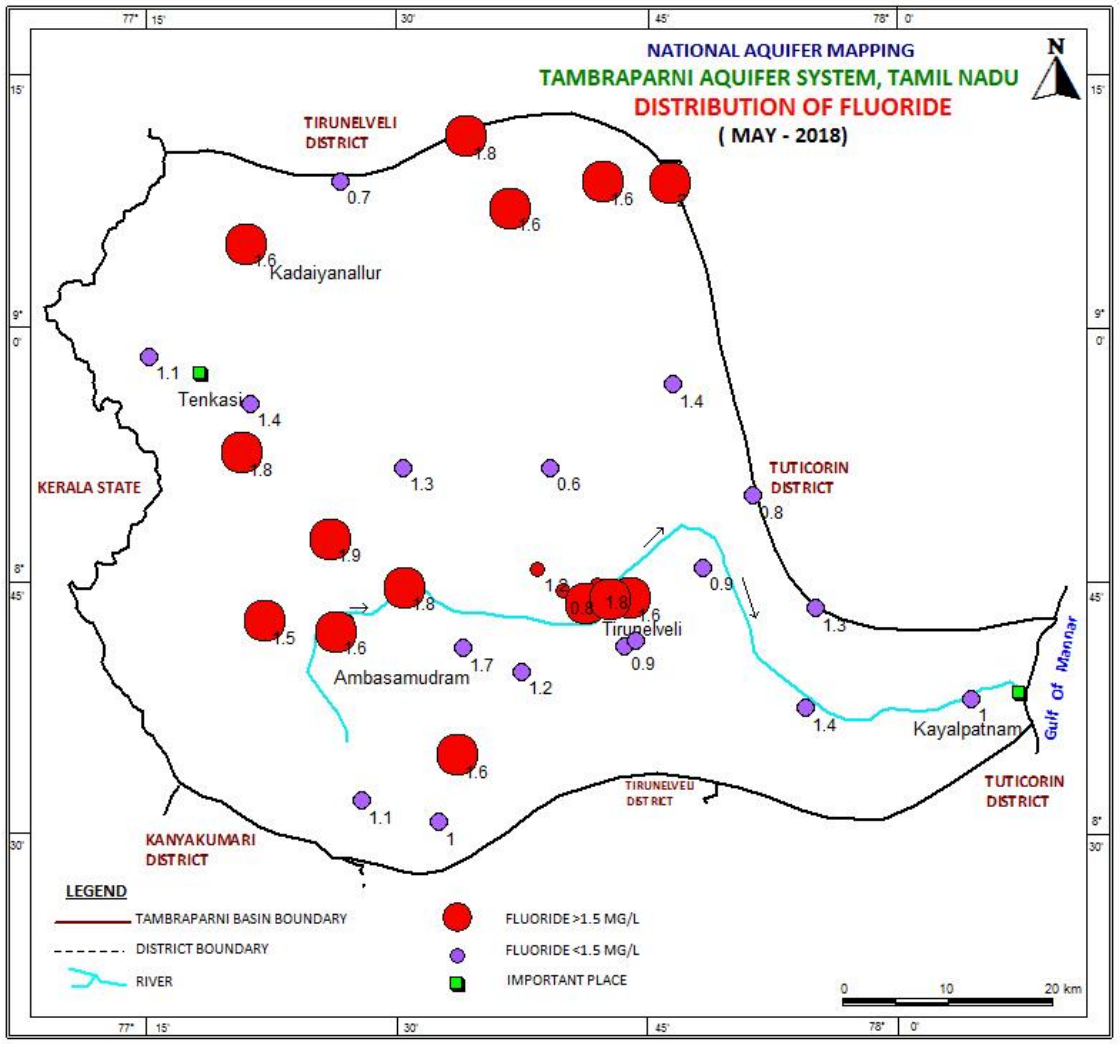


Figure 23. Fluoride concentration in Aquifer-I of the Tambraparni Aquifer system

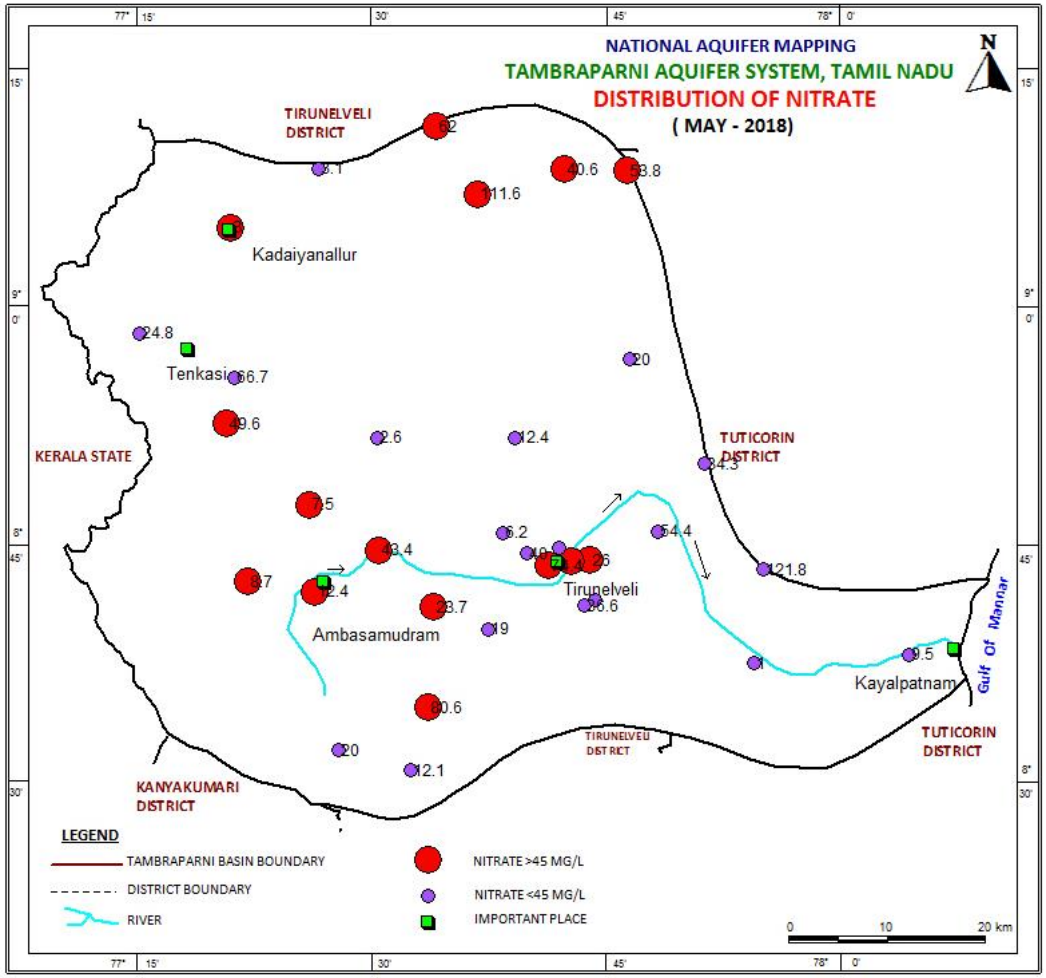


Figure 24. Nitrate concentration in Aquifer-I of the Tambraparni Aquifer system

3.5. Aquifer Maps

3.5.1. 2D&3D models showing Aquifer Dispossition:

Aquifer Disposition (Vertical & Lateral) is generated based on the inputs of data collected through geological, geophysical, hydrogeological, and hydrochemical studies. In particular the aquifer disposition and aquifer characterization has been brought mainly by analyzing the data collected from different groundwater agenesis such as 114Nos. of lithologs, 85 Nos. of VES data, water level data of 78 wells, 29 hydrograph of dugwells with long term trend, 16 piezometric head data of the piezometers tapping different aquifer units, 62hydrochemical data and field inputs gathered during the study period.2D & 3D aquifer disposition models of the aquifer system have been deciphered by using ROCKWORKS software and generated numbers of 2D cross section along different directions of the Tambraparni aquifer system. All such 2D cross sections were verified and the model was calibrated to bring out the 3D aquifer disposition of the aquifer system. The type cross sections generated in different direction of the aquifer system is given in **Figures 25, 26,27**& the 3D aquifer disposition is show in **Figure 28**.

4.0. GROUNDWATER RESOURCES:

The dynamic groundwater resources have been estimated as on 2017 based on the methodology suggested by Ground Water Estimation Committee (GEC) 2015.

The groundwater recharge is calculated both by groundwater fluctuation-specific yield method and by rainfall infiltration method. The annual replenishablegroundwater recharge is the summation of four components viz.,

i) Monsoon recharge due to rainfall
ii) Monsoon recharge from other sources
iii) Non-monsoon recharge due to rainfall
iv) Non-monsoon recharge due to other sources

Firka-wise dynamic groundwater resources have been taken from the approved resources estimation done as on March 2017, jointly by State PWD of Tamil Nadu and CGWB, to arrive at the total resources available in the study basin. A total of 51Firkas are falling in the study area.

4.1. Annual Extractable Groundwater Resources:

The annual extractable groundwater resources availability refers to the available annual recharge after allowing for natural discharge in the monsoon season in terms of base flow and subsurface inflow/outflow. This annual extractable groundwater resources includes the existing groundwater withdrawal, natural discharge due to base flow and subsurface inflow/ outflow in the monsoon season and availability for future development. As the groundwater development progresses the natural discharge gets suitably modified and comes down to negligible quantities due to interception by different groundwater structures. Hence, natural discharges in the monsoon season may not be considered and the total annual groundwater recharge may be taken as annual extractable groundwater resources.Theannual extractable groundwater resources of the basin for the year 2017 is arrived at 84,627 Ham, out of which the availability for 41 firkas of Tirunelvelidistrict is 65,324 ham, 10firkas of Thoothukudi is 19302 ham (**Figure 29**).

4.2. Annual Groundwater Extraction

The gross annual groundwater extraction has been assessed by using Unit draft method for irrigation draft component and by adopting formula suggested by GEC 2015 for domestic and industrial draft components. The existing annual groundwater extraction of the basin for the year 2017 is arrived at 40,845 Ham, out of which the groundwater draft for 41 firkas of Tirunelveli district is 35,681ham and 10firkas of Thoothukudi is 5,164ham.The total gross annual groundwater extraction of the aquifer system is 40845ham.against the annualextractablegroundwater resources of 84627 ham **(Figure 29).**

4.3. Stage of Groundwater Extraction and Categorization:

The stage of groundwater extraction is defined by

Stage of groundwater extraction (%) = (Existing gross annual groundwater extraction/ Annual extractable groundwater resources) x 100

Based on the stage of groundwater extraction four categories i.e. **a) Safe, b) Semi-critical, c) Critical and d) Over-exploited** have been suggested by GEC-2015.

The stage of groundwater extraction is calculated for all the 51 firkas of the aquifer system.

Based on the above categorization 15 out of the 51firkas of the Tambraparni aquifer system falls under over exploited and critical categories. In Tirunelveli district out of 41 Firkas 15 firkas falls in over exploited and critical categoriesand 26 firkas falls under semi-critical and safe categories. In Thoothukudi district out of 10 firkas, all 10 firkas falls in semi-critical and safe categories (**Figure 30**). The total stage of extraction of Tambraparni aquifer system is 48.26 %.

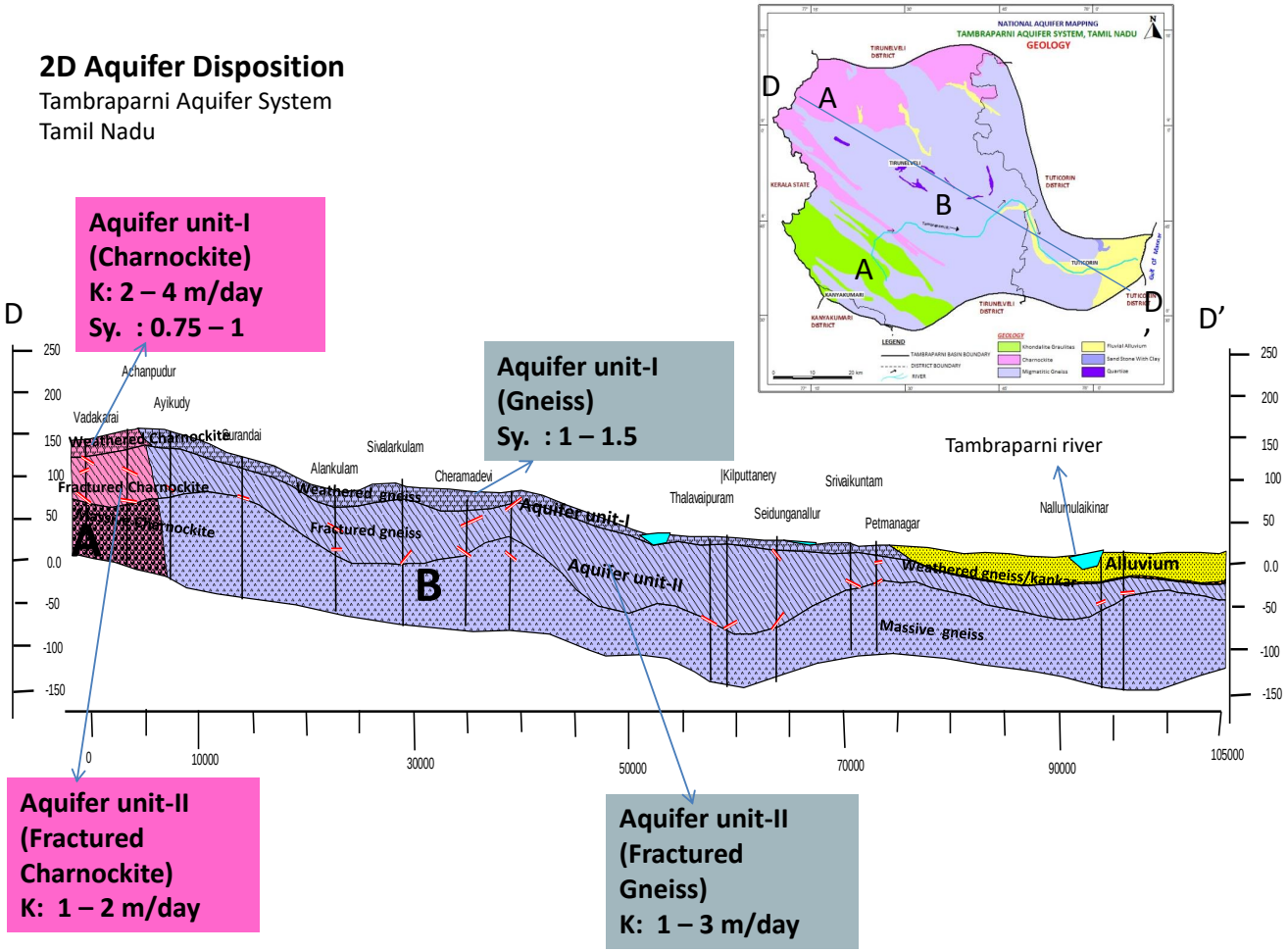


Figure 25. 2D disposition of the Tambraparni Aquifer system along NW-SE Direction.

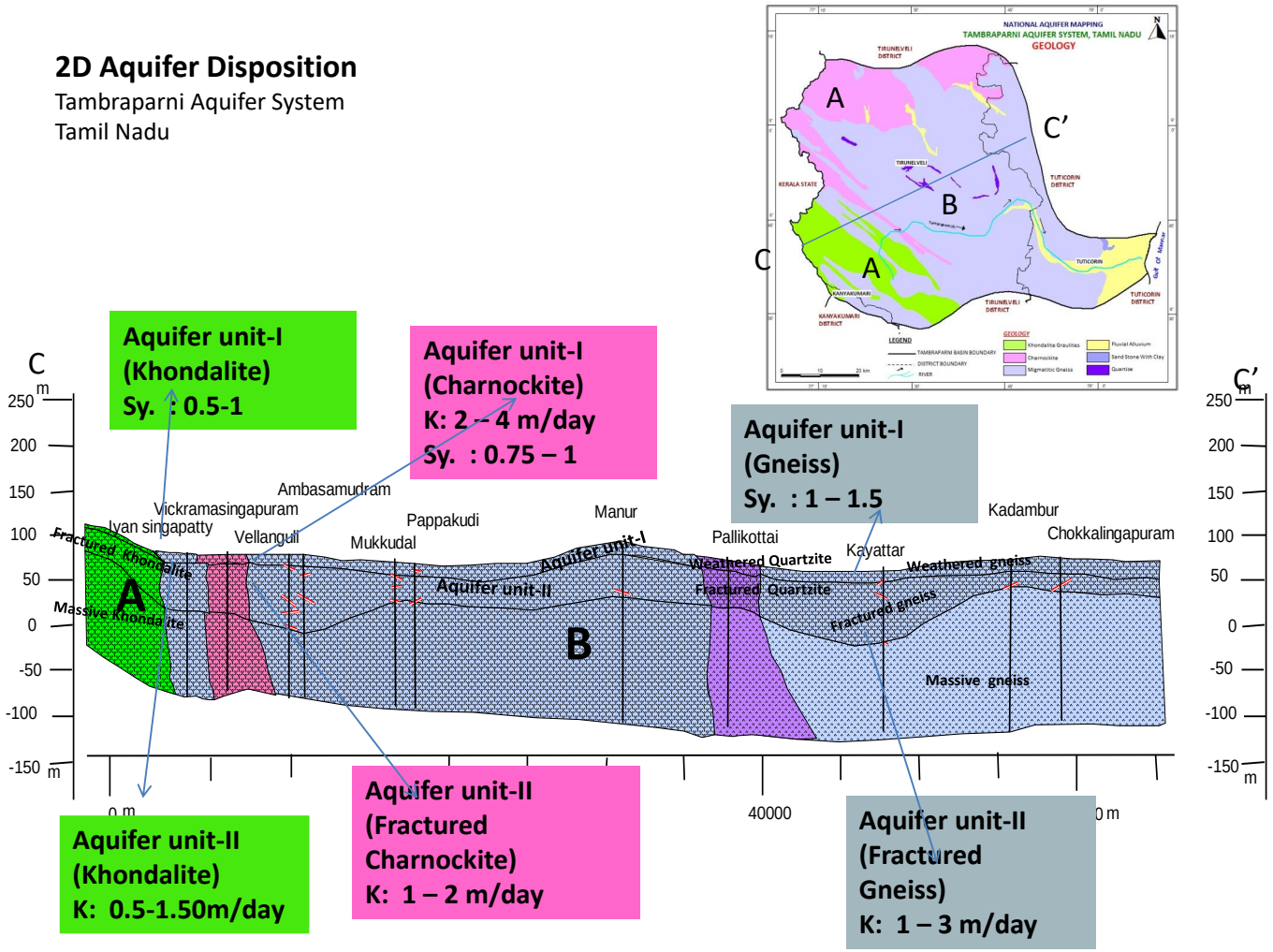


Figure 26. 2D disposition of aquifer system along northeast –West direction.

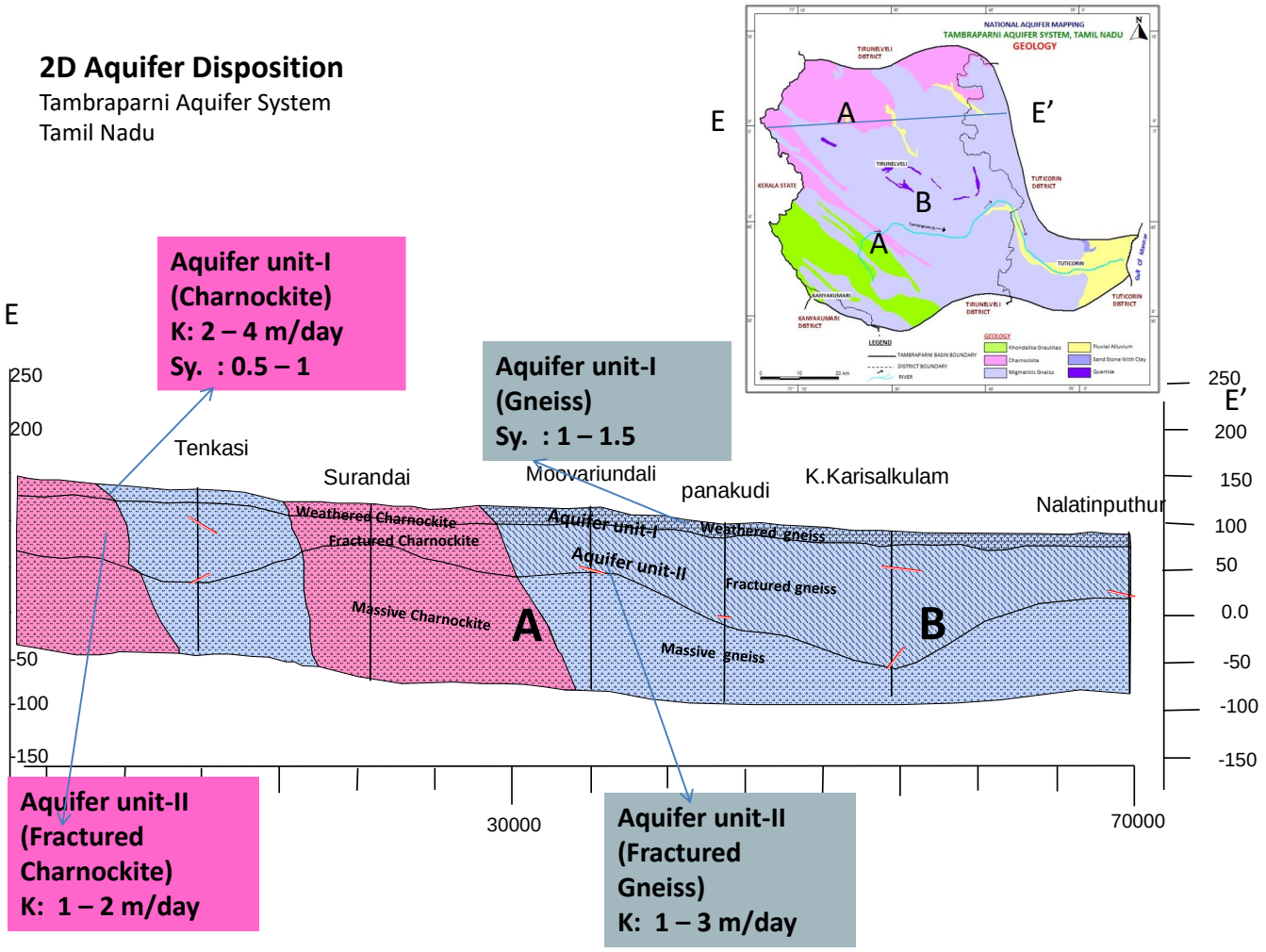


Figure 27. 2D disposition of aquifer system alongWest –East direction.

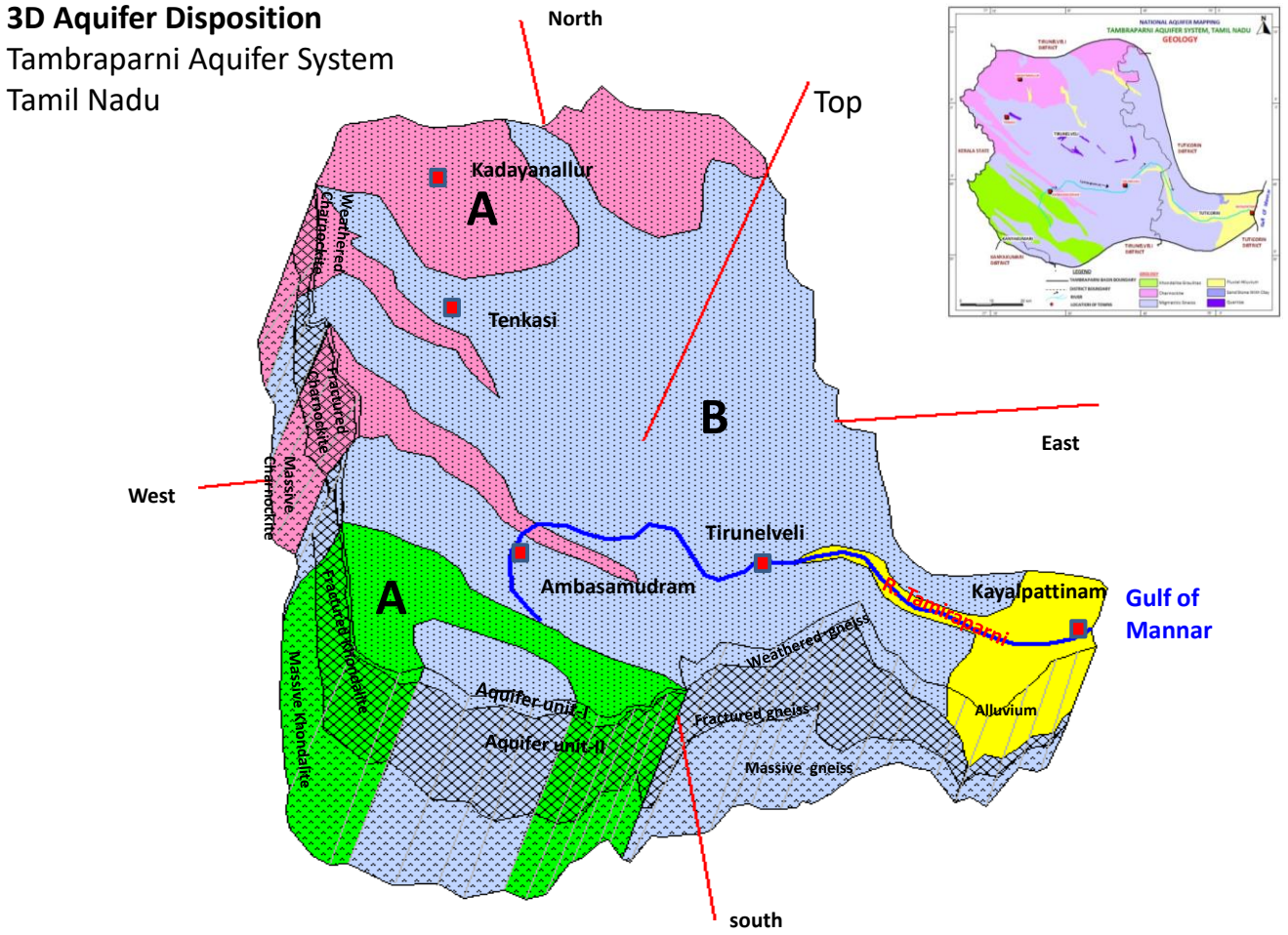
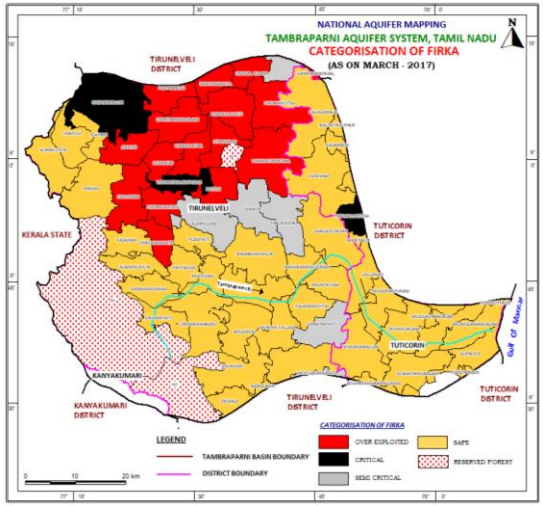


Figure 28. 3D disposition of aquifer system.

Groundwater resources and Stage of Groundwater extraction



Total Firkas – 51

Over Exploited - 13

Critical - 2

Semi Critical - 3

Safe - 33

District	2013			2017		
	Resources	Draft		Resources	Draft	Stage of GWE
THOOTHUKKUDI	20181.27	5378.74	26.65	19302.56	5163.77	26.75
TIRUNELVELI	60292.63	35425.06	58.76	65324.96	35681.20	54.62
Total Basin (ham)	**80473.90**	**40803.80**	**50.70**	**84627.52**	**40844.97**	
Total Basin (MCM)	**804.74**	**408.04**		**846.28**	**408.45**	**48.26**

Figure 29. Stage Groundwater Extraction of Tambraparni Aquifer system

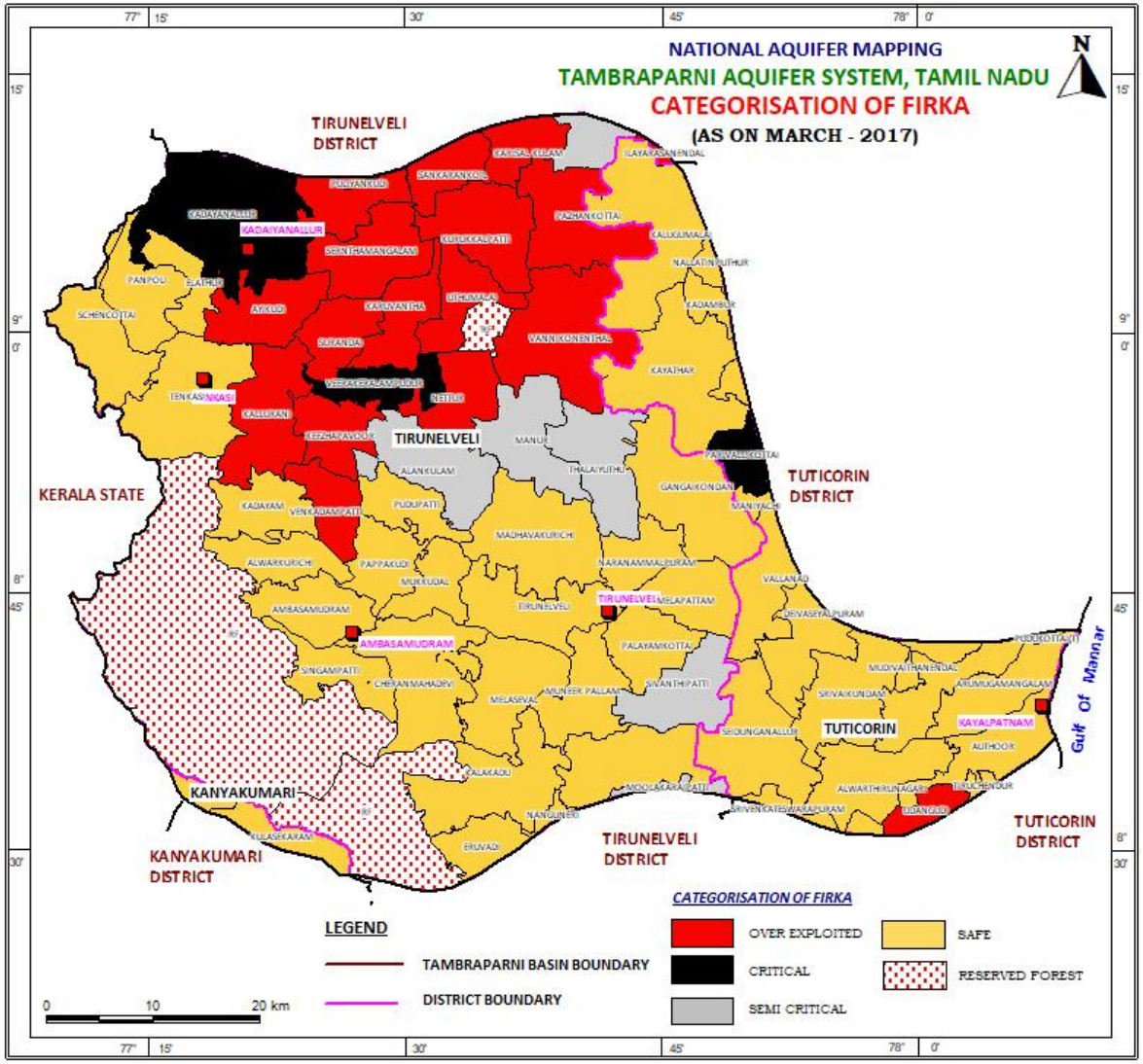


Figure 30. Categorisation of firka – Tambraparni aquifer system

5.0. GROUNDWATER RELATED ISSUES:

Groundwater is extensively utilized for irrigation in the entire basin area for the past two decades, especially in the 15 over-exploited and critical firkas out of the 51firkas of the study area. Anthropogenic contamination in the basin is restricted to the urbanized centers of Tirunelveliarea.

5.1.Geographical distribution & Resource Availability:

In the study areanorthern and northwestern partis reeling under over development. Over all out of 51firkas of the study areas 15firkas are over exploited and critical.In these areas the groundwater has been extensively developed by constructing groundwater abstraction structures like dug wells, dug cum borewells and borewells. Groundwater development in these firkasis to be restricted

Further, there is ample scope for groundwater development in the 36 safe and semi-critical firkas. Whereas these area are under developed due to the poor aquifer system developed in the area. Based on the out put of the aquifer mapping studies a management plan is chalked out for the further management of resources available in the aquifer system.

5.2. Massive formation and Poor Aquifer:

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 occurs within 40-60 m bgl and the frequency of occurrence of fractures are promising in these depth zone. In some area the fracture system exist upto the depth of 197 m bgl, but the frequency of occurrence of fractures in these depth ranges is low. In Region B-Gneiss rock terrain most of the fractures occurs within the depth range of 60-80 m bgl. In Granitic Gneiss region most of the fractures area confined to 100 – 150 m bgl. Comparatively Charnockite are more massive than granitic gneiss and it occupies about 30% of the study basin. In these areas water scarcity problem exist and the people are struggling to meet their domestic demands. Fracture analysis chart in Hard rock area of the Tambraparni aquifer system is given in **Figure 31.**

5.3. Groundwater quality issues:

Threat of groundwater pollutionexistsall along the river course of Tambraparni, especially near the urban centres. Central Pollution Control Board (CPWB) has notified the polluted stretch for the River Tabraparni from Pappankulam to Arumuganeri (80 km) classified under Priority-V based on the consolidated sample report of GEMS (Global Environmental Monitoring System) and MINRAS (Monitoring of Indian National Aquatic resources system).

High EC and Cl values are reported in few pockets of the aquifer system and also few samples are reported for high F and NO_3.

5.4. Future Demand Scenario and Stress on Aquifer system:

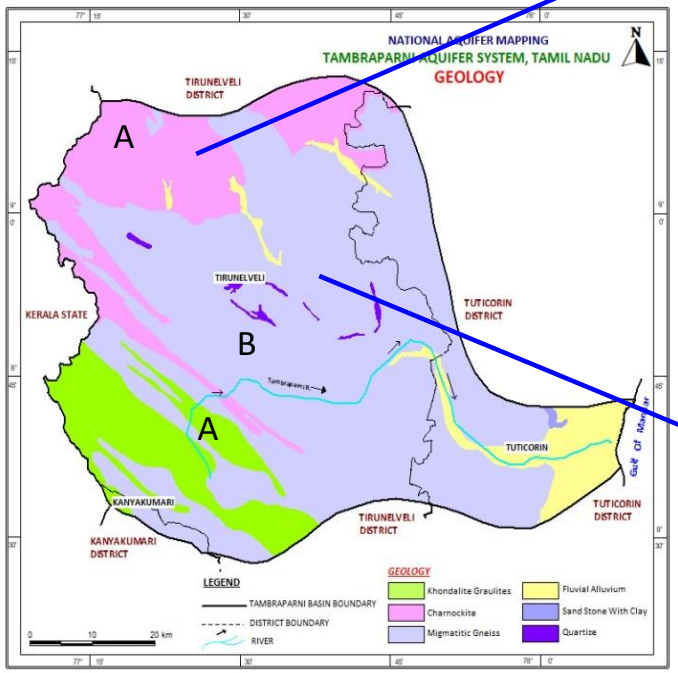
Future groundwater demand projected for domestic utilization upto the year 2025 is calculated as 22 MCM. This will have minimal additional stress on the aquifer system compared to the existing groundwater draft. However, draft can be regulated through increasing the water efficiency practices in irrigation sector. Already the dependency on groundwater for domestic

and drinking needs is decreasing in groundwater contaminated areas as the alternative surface/ river sources are being harnessed.

Tambraparni Aquifer System – Fracture analysis

No. of Bore Wells analysed : 66

Depth of Bore Wells (28 nos). : > 150 m bgl



Charnockites & Khondalite region-A

No. of Bore Wells analysed : 25

Most of the fractures occurs within : 40-60 mbgl

Frequency of occurrence of fracture upto : 197 mbgl

Nil Fracture : 0 Wells

- 0 - 50 m depth : 13 Wells
- 50– 100 m depth : 05 Wells
- 100 – 150 m depth : 03 Wells
- 150 – 197 m depth : 04 Wells

Granite Gneiss region -B

No. of Bore Wells analysed : 25

Most of the fractures occurs within : 60-80 mbgl

Frequency of occurrence of fracture

Nil Fracture : 02 Wells

- 0 - 50 m depth : 18 Wells
- 50– 100 m depth : 09 Wells
- 100 – 150 m depth : 05 Wells
- 150 – 197 m depth : 07 Wells

Figure 31. Fracture analysis chart in Hard rock area of the Tambraparni aquifer system.

6 .0. MANAGEMENT STRATEGIES

The groundwater management strategies are inevitable either when there is much demand to the resource than the available quantity or when the quality of resource deteriorates due to contamination in a given geographical unit. In recent years groundwater resources are used extensively for irrigation in the study area. In addition, to meet the domestic requirements of the fast growing urban agglomerations and establishment of Industries in the coastal area of the study area the administrators are compelled to allocate a considerable quantum of resource which otherwise is being used for irrigation purpose. So, the urbanization and Industrialization has a negative impact on the food production as well as grabbing the employment of the agricultural laborers. Also the limited groundwater resources available in the less fractured and jointed aquifer system of the study area, unequal distribution of groundwater resources in these areas creates more demands for the resources. Hence, it is the need of the hour to formulate sustainable management of the groundwater resource in a more rational and scientific way.In the present study area of Tambraparni aquifer system, the sustainable management plan for groundwater is being proposed after a thorough understanding of the aquifer disposition down to a depth of 200m bgl in the hardrock area.

6.1Sustainable Management Plan

The groundwater resource of 15 Over Exploited and Critical firkas of the aquifer system are estimated.Gross groundwater extraction of 408 MCM is estimated for the entire study area as per the GEC 2015 against the annual extractable groundwater reources 846 MCM. Excess groundwater was drawn from the groundwater system of the 15 Over Exploited and Critical firkasout of 51firkas of the study area. Therefore, the usage of groundwater has to be reduced by 30 to 50 percent of the existing draft for the sustainability of the resource. Or else the availability has to be augmented through artificial recharge methods to bridge the gap between draft and availability. The draft can be reduced through application of water efficiency methods in irrigation sector and through changing the irrigation practices from wet to dry cash crops.

6.2Augmentation Plan

Augmentation of groundwater can be achieved through construction of percolation ponds and recharge shafts where the top soil zone is clayey which does not allow infiltration. Normally it can be achieved through capturing surface runoff. Surface water transfer also can be planned in the absence of surface runoff during droughts. It needs uncommitted runoff from the adjoining localities to transport to the needy areas through diversion channels.

In the study area northwestern, central part and in few pockets of eastern parts are subjected to Over-exploitation. Normally due to over exploitation of groundwater the water levels are depleting in this zone. The natural rainfall recharge is insufficient to recoup the extracted groundwater.Artificial Recharge and Water Conservation Plans are proposed in the OE&Criticalfirkasof the basin through utilizing the uncommitted surface runoff of 166 MCM.

6.2.1. Artificial Recharge Plan

Based on the water level monitoring in different seasons across the basin, as well as after having better understanding of the disposition and extent of the aquifer system through exploratory drilling, pumping tests etc., the potential volume of void space available within the weathered zone of first aquifer of the 15 Over Exploited and Criticalfirkashas been estimated as 360 MCM. But the annual uncommitted runoff is only 166MCM which is less than 50% of required water to fill the available void space of aquifer-I. Artificial recharge and Water conservation plan is prepared for the over exploited and criticalfirkas of the basin area through harnessableannual uncommitted runoff of 33 MCM only with a total out lay of 49crore rupees.

The suggested artificial recharge structures are mainly masonry check dam, Nala bunds, Recharge ponds and Recharge Shafts in addition to removal of silt in the surface tanks. Selection of the site locations of these structures are based on the critical analysis of the hydrogeological, geophysical and exploration data of the basin**(Figure 33).** Particularly geomorphological and drainage aspects are being given more weightage in selection of the Artificial Recharge structures.

A total number of 52 check dams, 229nala bunds, 334 recharge shafts and 1300 recharge ponds are proposed in the OE and critical firkas of the basin. A total number of 132 Recharge Rejuvenation ponds are selected for desilting followed by construction of recharge shafts within the tanks. The expected recharge through these artificial recharge structures is in the order of 33 MCM (Figure 32).

The expected benefit by the recharge structures in the 15 Over Exploited and Critical firkasarea will be helpful to arrest decline in groundwater levels or increase pumping hours or increase in sustainability of well yield.

Supply Side Management	Present stage of GW Extraction of OE&C firkas (15 nos.) of the Basin: 130.487%	
ARTIFICIAL RECHARGE /CONSERVATION MEASURES		
Artificial Recharge Structures Proposed	Masonry Check dams :	52
	Nala bunds :	229
	Recharge shafts (Tanks:300) :	334
	Repair, Renovation and Restoration of water bodies with Recharge shafts (Tanks 132) :	132
	Recharge ponds(farm ponds)	1300
Tentative total cost of the project (Rs.)	:	49 Cr
Vol. of unsaturated zone available for Recharge (upto 3m bgl)	:	360 MCM
Uncommitted Surplus runoff	:	166 MCM
Harnessable runoff	:	161 MCM
Expected recharge	:	33 MCM
Expected outcome	Arrest Decline in Groundwater levels (or) Increase pumping hours (or) Increase in sustainability of well yield (or)	
Implication of supply side management proposal may bring down the stage of GW extraction : 110 %		

Figure 32. Supply side management of Tambraparni aquifer system.

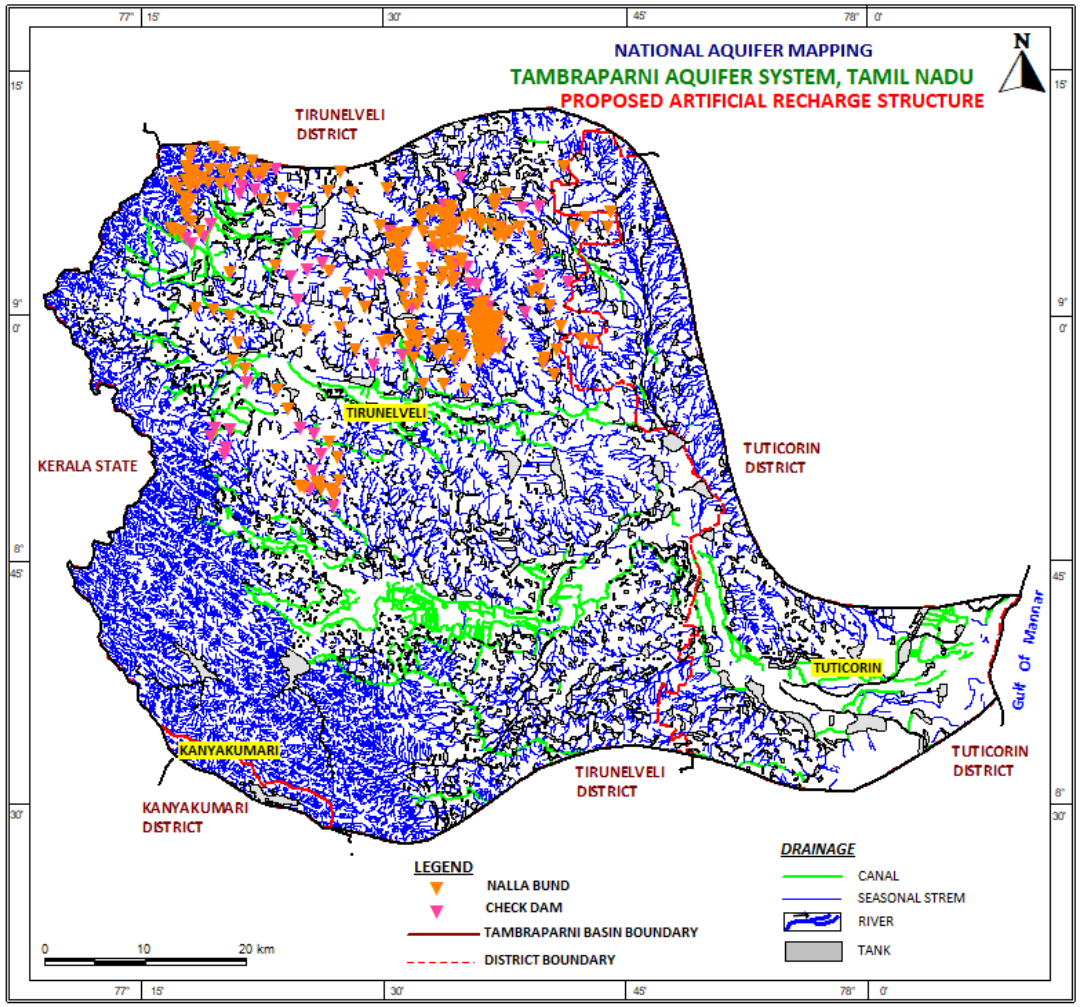


Figure 33. Location of Proposed Artificial Recharge sites in Tambraparni aquifer system

6.3. Demand side Management Plan

Demand side management can be accomplished through change in irrigationpattern. It is recommended to change the irrigation pattern for paddy, Sugarcane and Banana crops. The general practice for paddy irrigation is by flooding method. It is recommended for ridge and furrow method instead of flooding method in 50% area of the total paddy area44493 Ha. This would save groundwater annually of 8.08 mcm.Similarly for sugarcane and banana crops shift from flooding to drip irrigation would save 0.094 & 0.562 mcm respectively. The total water saved is 8.74 mcm**(Figure 34).**

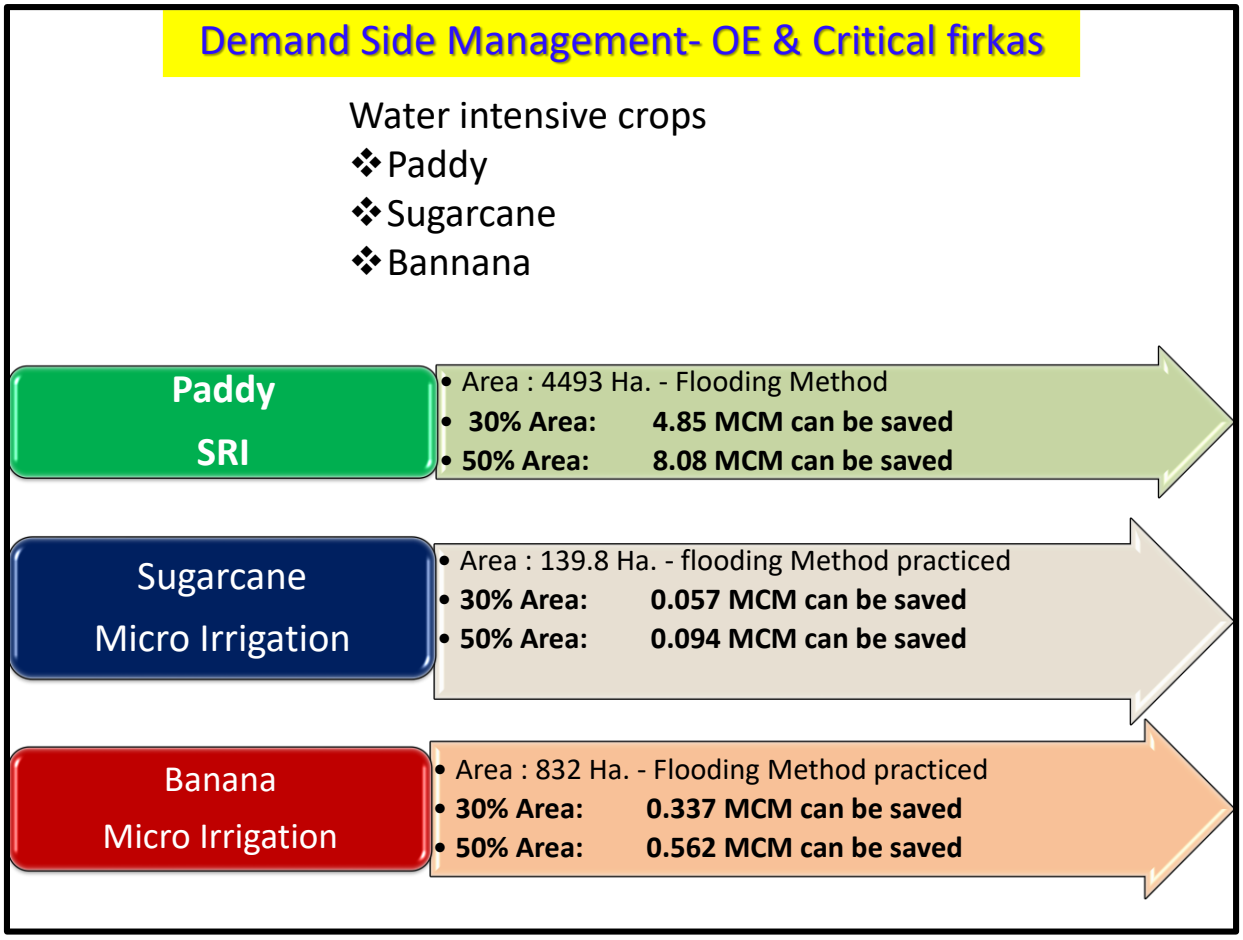


Figure 34. Demand side management of Tambraparni aquifer system.

The total cost for the change in the irrigation pattern for those water intensive crops would be 16.4crores. If Scenario 1 - 30% Area is changed then water saved would be 5.25 MCM. The cost would be 8.33crore and the Stage of Development would be lowered from 130 to 120 %. In case of Scenario II wherein 50% Area is changed then Water saved would be 8.74MCM and the Cost would be 16.4 crore. The stage of Development would be lowered from 130 to 114 %.

If both the supply side and demand side are managed by augumenting 33 mcm of water recharged with that of the 8.74 mcm water saved by adopting change in method of irrigation, it may be possible to bring down the existing stage of ground water extraction from 130% to 96%.

6.4. Future Demand Stress Aspects

In views of rapid urbanization the domestic water needs are increasing multifold. In this urbanization process the water wastage component is increasing mainly because of leakages through distributor system. Whereas in the agricultural irrigation sector the water demand mainly due to the enthusiasm of the farmers to increase the crop irrigation area.

Hence the policy makers at higher administrative level and rural development authorities at block level should educate the farmers in their jurisdiction in such a way that they should not venture to increase the farm irrigation area. Rather these authorities have to suggest high yielding crop varieties and high-value crops to grow with minimum water requirement with the technical guidance of local agricultural/ agronomic experts.

6.5. Strategies to overcome the future stresses

Future stresses are only hypothetical. If the sustainable management is taken up in a true spirit in consultation with local village level bodies the groundwater depletion will not occur in future. However, it is very difficult to overcome gluttonous user attitude thrives for fullest use of the resource to get maximum output. In this process the vital resource is lost. Therefore a thorough understanding of the consequences of indiscriminate usage of the water should be propagated among users mainly among farmers as they are bulk users of the resource in the study area.

Thedemand side strategies to overcome future stresses are mainly

- Promoting irrigation patternchange
- Agronomic Water Conservation
- Reducing Water use in Urban areas

Annexure-I

List of Proposed Artificial Recharge structures-Tambraparni aquifer sytem

ID	STRUCTURE	LONGITUDE (Degree Decimal)	LATITUDE (Degree Decimal)
1	Nalla Bund	77.34	9.00
2	Nalla Bund	77.31	9.01
3	Nalla Bund	77.34	9.04
4	Nalla Bund	77.39	9.05
5	Nalla Bund	77.33	9.01
6	Nalla Bund	77.29	9.09
7	Nalla Bund	77.29	9.08
8	Nalla Bund	77.30	9.09
9	Nalla Bund	77.30	9.10
10	Nalla Bund	77.30	9.11
11	Nalla Bund	77.30	9.12
12	Nalla Bund	77.30	9.13
13	Nalla Bund	77.31	9.13
14	Nalla Bund	77.32	9.15
15	Nalla Bund	77.31	9.14
16	Nalla Bund	77.32	9.13
17	Nalla Bund	77.33	9.13
18	Nalla Bund	77.34	9.15
19	Nalla Bund	77.33	9.15
20	Nalla Bund	77.34	9.15
21	Nalla Bund	77.34	9.14
22	Nalla Bund	77.35	9.14
23	Nalla Bund	77.36	9.15
24	Nalla Bund	77.37	9.16
25	Nalla Bund	77.38	9.15
26	Nalla Bund	77.31	9.08
27	Nalla Bund	77.28	9.09
28	Nalla Bund	77.28	9.09
29	Nalla Bund	77.30	9.14
30	Nalla Bund	77.31	9.14
31	Nalla Bund	77.38	9.12
32	Nalla Bund	77.38	9.14
33	Nalla Bund	77.29	9.13
34	Nalla Bund	77.29	9.11
35	Nalla Bund	77.30	9.12
36	Nalla Bund	77.37	9.14

37	Nalla Bund	77.30	9.16
38	Nalla Bund	77.30	9.15
39	Nalla Bund	77.31	9.15
40	Nalla Bund	77.30	9.14
41	Nalla Bund	77.28	9.13
42	Nalla Bund	77.33	9.17
43	Nalla Bund	77.35	9.16
44	Nalla Bund	77.33	9.17
45	Nalla Bund	77.30	9.17
46	Nalla Bund	77.36	8.94
47	Nalla Bund	77.35	8.95
48	Nalla Bund	77.40	8.90
49	Nalla Bund	77.35	8.97
50	Nalla Bund	77.52	9.05
51	Nalla Bund	77.51	9.05
52	Nalla Bund	77.52	9.02
53	Nalla Bund	77.52	9.03
54	Nalla Bund	77.48	9.01
55	Nalla Bund	77.50	8.97
56	Nalla Bund	77.51	8.97
57	Nalla Bund	77.52	9.05
58	Nalla Bund	77.51	9.05
59	Nalla Bund	77.42	8.82
60	Nalla Bund	77.43	8.83
61	Nalla Bund	77.44	8.87
62	Nalla Bund	77.47	8.90
63	Nalla Bund	77.39	8.92
64	Nalla Bund	77.54	9.10
65	Nalla Bund	77.54	9.10
66	Nalla Bund	77.55	9.10
67	Nalla Bund	77.55	9.11
68	Nalla Bund	77.56	9.10
69	Nalla Bund	77.57	9.11
70	Nalla Bund	77.57	9.11
71	Nalla Bund	77.57	9.10
72	Nalla Bund	77.57	9.10
73	Nalla Bund	77.57	9.09
74	Nalla Bund	77.57	9.09
75	Nalla Bund	77.58	9.09
76	Nalla Bund	77.57	9.09
77	Nalla Bund	77.56	9.09
78	Nalla Bund	77.56	9.08

79	Nalla Bund	77.56	9.08
80	Nalla Bund	77.56	9.07
81	Nalla Bund	77.57	9.07
82	Nalla Bund	77.58	9.08
83	Nalla Bund	77.58	9.07
84	Nalla Bund	77.57	9.08
85	Nalla Bund	77.59	9.10
86	Nalla Bund	77.59	9.10
87	Nalla Bund	77.60	9.09
88	Nalla Bund	77.60	9.10
89	Nalla Bund	77.61	9.09
90	Nalla Bund	77.62	9.08
91	Nalla Bund	77.62	9.11
92	Nalla Bund	77.61	9.11
93	Nalla Bund	77.62	9.12
94	Nalla Bund	77.57	8.95
95	Nalla Bund	77.56	8.96
96	Nalla Bund	77.58	8.96
97	Nalla Bund	77.57	8.97
98	Nalla Bund	77.57	8.98
99	Nalla Bund	77.55	8.98
100	Nalla Bund	77.56	8.96
101	Nalla Bund	77.56	8.96
102	Nalla Bund	77.54	8.97
103	Nalla Bund	77.59	8.92
104	Nalla Bund	77.58	8.96
105	Nalla Bund	77.58	8.97
106	Nalla Bund	77.57	8.97
107	Nalla Bund	77.54	8.93
108	Nalla Bund	77.54	8.98
109	Nalla Bund	77.53	8.98
110	Nalla Bund	77.56	8.93
111	Nalla Bund	77.58	8.97
112	Nalla Bund	77.73	9.09
113	Nalla Bund	77.71	9.10
114	Nalla Bund	77.70	9.09
115	Nalla Bund	77.73	9.10
116	Nalla Bund	77.66	9.07
117	Nalla Bund	77.66	9.08
118	Nalla Bund	77.69	9.15
119	Nalla Bund	77.63	9.12
120	Nalla Bund	77.66	9.07

121	Nalla Bund	77.63	9.08
122	Nalla Bund	77.64	9.09
123	Nalla Bund	77.62	9.08
124	Nalla Bund	77.62	9.09
125	Nalla Bund	77.63	9.08
126	Nalla Bund	77.51	9.06
127	Nalla Bund	77.51	9.06
128	Nalla Bund	77.52	9.06
129	Nalla Bund	77.51	9.08
130	Nalla Bund	77.51	9.08
131	Nalla Bund	77.45	9.04
132	Nalla Bund	77.50	9.09
133	Nalla Bund	77.53	9.08
134	Nalla Bund	77.52	9.08
135	Nalla Bund	77.52	9.07
136	Nalla Bund	77.43	9.08
137	Nalla Bund	77.51	9.08
138	Nalla Bund	77.46	8.99
139	Nalla Bund	77.42	8.98
140	Nalla Bund	77.46	9.02
141	Nalla Bund	77.53	8.99
142	Nalla Bund	77.54	9.01
143	Nalla Bund	77.54	9.02
144	Nalla Bund	77.54	9.03
145	Nalla Bund	77.54	9.05
146	Nalla Bund	77.56	9.04
147	Nalla Bund	77.57	9.04
148	Nalla Bund	77.58	9.06
149	Nalla Bund	77.56	9.07
150	Nalla Bund	77.57	9.05
151	Nalla Bund	77.57	9.05
152	Nalla Bund	77.57	9.03
153	Nalla Bund	77.52	9.01
154	Nalla Bund	77.54	9.03
155	Nalla Bund	77.58	9.05
156	Nalla Bund	77.54	9.09
157	Nalla Bund	77.55	9.08
158	Nalla Bund	77.56	9.04
159	Nalla Bund	77.60	8.95
160	Nalla Bund	77.61	8.96
161	Nalla Bund	77.60	8.96
162	Nalla Bund	77.61	8.96

163	Nalla Bund	77.61	8.96
164	Nalla Bund	77.60	8.97
165	Nalla Bund	77.60	8.97
166	Nalla Bund	77.60	8.97
167	Nalla Bund	77.61	8.97
168	Nalla Bund	77.61	8.96
169	Nalla Bund	77.62	8.96
170	Nalla Bund	77.62	8.97
171	Nalla Bund	77.62	8.97
172	Nalla Bund	77.61	8.97
173	Nalla Bund	77.61	8.97
174	Nalla Bund	77.61	8.98
175	Nalla Bund	77.60	8.98
176	Nalla Bund	77.61	8.98
177	Nalla Bund	77.61	8.98
178	Nalla Bund	77.61	8.98
179	Nalla Bund	77.60	8.98
180	Nalla Bund	77.60	8.98
181	Nalla Bund	77.60	8.98
182	Nalla Bund	77.61	8.99
183	Nalla Bund	77.60	8.99
184	Nalla Bund	77.60	8.99
185	Nalla Bund	77.59	8.99
186	Nalla Bund	77.59	8.99
187	Nalla Bund	77.60	9.00
188	Nalla Bund	77.60	8.99
189	Nalla Bund	77.61	8.99
190	Nalla Bund	77.61	8.99
191	Nalla Bund	77.61	8.99
192	Nalla Bund	77.62	8.99
193	Nalla Bund	77.62	8.99
194	Nalla Bund	77.62	9.00
195	Nalla Bund	77.61	9.00
196	Nalla Bund	77.61	9.00
197	Nalla Bund	77.60	9.00
198	Nalla Bund	77.60	9.00
199	Nalla Bund	77.60	9.01
200	Nalla Bund	77.60	9.01
201	Nalla Bund	77.60	9.01
202	Nalla Bund	77.61	9.00
203	Nalla Bund	77.65	9.02
204	Nalla Bund	77.66	9.03

205	Nalla Bund	77.67	9.01
206	Nalla Bund	77.68	8.99
207	Nalla Bund	77.71	8.98
208	Nalla Bund	77.72	8.97
209	Nalla Bund	77.68	8.96
210	Nalla Bund	77.67	8.95
211	Nalla Bund	77.67	8.96
212	Nalla Bund	77.68	8.94
213	Nalla Bund	77.47	8.96
214	Nalla Bund	77.53	8.96
215	Nalla Bund	77.53	8.97
216	Nalla Bund	77.53	8.98
217	Nalla Bund	77.44	9.13
218	Nalla Bund	77.46	9.15
219	Nalla Bund	77.40	9.12
220	Nalla Bund	77.50	9.13
221	Nalla Bund	77.47	9.12
222	Nalla Bund	77.43	8.83
223	Nalla Bund	77.44	8.82
224	Nalla Bund	77.42	8.82
225	Nalla Bund	77.45	8.82
226	Nalla Bund	77.45	8.82
227	Nalla Bund	77.45	8.83
228	Nalla Bund	77.45	8.85
229	Nalla Bund	77.51	9.06
1	Check Dam	77.35	9.12
2	Check Dam	77.34	9.13
3	Check Dam	77.30	9.07
4	Check Dam	77.30	9.08
5	Check Dam	77.32	9.08
6	Check Dam	77.36	9.13
7	Check Dam	77.32	9.09
8	Check Dam	77.41	9.04
9	Check Dam	77.42	9.05
10	Check Dam	77.39	9.15
11	Check Dam	77.37	9.13
12	Check Dam	77.37	9.14
13	Check Dam	77.34	8.86
14	Check Dam	77.34	8.86
15	Check Dam	77.32	8.87
16	Check Dam	77.33	8.88
17	Check Dam	77.34	8.88

18	Check Dam	77.36	8.93
19	Check Dam	77.50	9.04
20	Check Dam	77.49	9.04
21	Check Dam	77.41	8.88
22	Check Dam	77.43	8.88
23	Check Dam	77.58	9.14
24	Check Dam	77.56	9.11
25	Check Dam	77.64	9.11
26	Check Dam	77.66	9.11
27	Check Dam	77.41	9.08
28	Check Dam	77.44	9.05
29	Check Dam	77.51	9.09
30	Check Dam	77.41	9.01
31	Check Dam	77.60	9.03
32	Check Dam	77.59	9.03
33	Check Dam	77.57	9.04
34	Check Dam	77.58	9.05
35	Check Dam	77.59	9.05
36	Check Dam	77.55	9.07
37	Check Dam	77.53	9.01
38	Check Dam	77.66	9.04
39	Check Dam	77.65	9.00
40	Check Dam	77.69	9.03
41	Check Dam	77.62	8.97
42	Check Dam	77.61	8.99
43	Check Dam	77.61	9.01
44	Check Dam	77.61	9.01
45	Check Dam	77.49	8.95
46	Check Dam	77.52	8.96
47	Check Dam	77.41	9.11
48	Check Dam	77.45	8.80
49	Check Dam	77.45	8.82
50	Check Dam	77.42	8.82
51	Check Dam	77.43	8.84
52	Check Dam	77.44	8.86

Annexure-II

Groundwater availability and stage of ground water extraction of the firkas of Tambraparni Aquifer system

S.No	District	FIRKA NAME	Annual Ground water availability (Ha.m)	Existing Gross Ground Water extraction for Irrigation(Ha.m)	Existing Gross Ground Water extraction for domestic and industrial water supply(Ha.m)	Existing Gross Ground Water Draft for All uses(Ha.m)	Provision for domestic and industrial requirement supply to 2025(Ha.m)	Net Ground Water Availability for future irrigation development(Ha.m)	Stage of Ground Extraction %
1	THOOTHUKKUDI	Alwarthirunagari	2924.91	728.00	37.97	765.97	46.64	2150.27	26
2	THOOTHUKKUDI	Arumugamangalam	1936.31	124.80	58.98	183.78	72.46	1739.05	9
3	THOOTHUKKUDI	Authoor	2678.64	536.40	60.33	596.73	74.11	2068.12	22
4	THOOTHUKKUDI	Deivaseyalpuram	1210.06	138.00	40.01	178.01	49.16	1022.90	15
5	THOOTHUKKUDI	Kalugumalai	1576.04	530.40	46.83	577.23	57.53	988.12	37
6	THOOTHUKKUDI	Kayathar	1349.37	907.20	37.61	944.81	46.21	395.96	70
7	THOOTHUKKUDI	Perungulam	1896.55	68.00	21.95	89.95	26.96	1801.59	5
8	THOOTHUKKUDI	Seidunganallur	2079.29	534.40	53.51	587.91	65.74	1479.15	28
9	THOOTHUKKUDI	Srivaikundam	2315.14	682.60	38.56	721.16	47.37	1585.16	31
10	THOOTHUKKUDI	Vallanad	1336.25	472.00	46.22	518.22	56.78	807.47	39
11	TIRUNELVELI	ALANKULAM	1615.10	517.60	85.25	602.85	94.43	1003.07	37.33
12	TIRUNELVELI	Alwarkurichi	10320.46	754.75	15.26	770.01	18.18	9547.53	7.46
13	TIRUNELVELI	Ambasamudram	2834.42	108.25	6.96	115.21	8.29	2717.89	4.06
14	TIRUNELVELI	AYIKUDI	1174.75	1649.60	49.08	1698.68	58.46	-533.31	144.60
15	TIRUNELVELI	Cheranmahadevi	2766.60	425.25	29.04	454.29	34.59	2306.76	16.42
16	TIRUNELVELI	Elathur	800.36	190.95	45.67	236.62	54.41	555.00	29.56
17	TIRUNELVELI	Gangaikondan	1039.89	384.90	26.40	411.30	31.45	623.54	39.55
18	TIRUNELVELI	Kadayam	1892.76	880.75	96.86	977.61	115.38	896.63	51.65
19	TIRUNELVELI	Kadayanallur	3967.86	3895.60	37.31	3932.91	44.45	27.81	99.12
20	TIRUNELVELI	Kalakadu	2095.70	941.15	12.88	954.03	15.35	1139.20	45.52
21	TIRUNELVELI	Kallurani	1781.35	2237.90	125.28	2363.18	149.24	-605.79	132.66
22	TIRUNELVELI	Karuvantha	690.70	1164.75	42.71	1207.46	50.88	-524.92	174.82
23	TIRUNELVELI	KEEZHAPAVOOR	1172.31	1365.90	22.75	1388.65	27.10	-220.68	118.45
24	TIRUNELVELI	Kurukkalpatti	891.69	1293.00	46.21	1339.21	55.05	-456.35	150.19
25	TIRUNELVELI	Madhavakurichi	968.90	528.93	32.34	561.26	38.52	401.45	57.93
26	TIRUNELVELI	Manur	1383.14	1066.20	38.48	1104.68	45.84	271.10	79.87
27	TIRUNELVELI	MELAPATTAM	1372.19	123.20	46.36	169.56	55.23	1193.76	12.36
28	TIRUNELVELI	Melaseval	2004.23	574.60	15.26	589.86	18.18	1411.45	29.43
29	TIRUNELVELI	Mukkudal	1243.52	104.80	96.86	201.66	115.38	1023.34	16.22
30	TIRUNELVELI	MUNEER PALLAM	1453.33	440.80	23.31	464.11	27.77	984.76	31.93
31	TIRUNELVELI	NARANAMMALPURAM	985.04	263.20	32.92	296.12	39.21	682.63	30.06
32	TIRUNELVELI	NETTUR	849.68	1043.88	44.96	1088.83	48.01	-242.21	128.15
33	TIRUNELVELI	PALAYAMKOTTAI	1091.45	159.20	8.91	168.11	10.61	921.63	15.40

34	TIRUNELVELI	Panpoli	1350.94	489.85	20.38	510.23	24.27	836.81	37.77
35	TIRUNELVELI	Pappakudi	559.83	111.60	2.36	113.96	2.81	445.42	20.36
36	TIRUNELVELI	Pazhankottai	850.80	1963.80	49.99	2013.79	59.54	-1172.55	236.69
37	TIRUNELVELI	POOLAM	1149.19	583.55	31.49	615.04	37.52	528.13	53.52
38	TIRUNELVELI	PUDUPATTI	700.16	242.00	39.21	281.21	46.71	411.45	40.16
39	TIRUNELVELI	SCHENCOTTAI	1557.55	134.30	14.12	148.42	16.82	1406.43	9.53
40	TIRUNELVELI	SERNTHAMANGALAM	707.17	972.60	19.04	991.64	22.68	-288.12	140.23
41	TIRUNELVELI	Singampatti	2600.44	213.00	7.53	220.53	8.97	2378.47	8.48
42	TIRUNELVELI	SIVANTHIPATTI	825.30	657.60	41.87	699.47	49.88	117.81	84.75
43	TIRUNELVELI	Surandai	773.56	1181.70	6.12	1187.82	7.29	-415.43	153.55
44	TIRUNELVELI	Tenkasi	2220.76	833.25	19.34	852.59	23.04	1364.47	38.39
45	TIRUNELVELI	Thalaiyuthu	884.17	661.45	19.70	681.15	23.47	199.25	77.04
46	TIRUNELVELI	Tirunelveli	2094.86	595.20	31.72	626.92	37.79	1461.87	29.93
47	TIRUNELVELI	Uthumalai	968.07	1284.40	15.32	1299.72	18.25	-334.59	134.26
48	TIRUNELVELI	VANNIKONENTHAL	1210.94	1401.15	10.98	1412.13	13.08	-203.29	116.61
49	TIRUNELVELI	Veerakeralampudur	1088.36	1060.33	4.62	1064.95	5.51	22.53	97.85
50	TIRUNELVELI	Veerasigamani	583.40	1035.13	9.61	1044.73	11.45	-463.17	179.08
51	TIRUNELVELI	VENKADAMPATTI	804.05	783.43	37.25	820.68	44.38	-23.75	102.07

Groundwater exploration and fracture analysis

Annexure-III

Sl.No	Location & Well No	Longitude	Latitude	casing depth	Lithology	1st fracture - Depth range		Discharge lps	2nd Fracture - Depth range		Discharge lps	3rd Fracture - Depth range		Discharge lps	4th Fracture - Depth range		Discharge lps	5th Fracture - Depth range		Discharge lps
1	Sivagiri(EW)-3801	77.49	9.24	18	Charnockite	6.75	16.75	2.5												
2	Vasudevanallur(EW)-3802	77.49	9.24	15	Charnockite	6	15	3.1												
3	Vasudevanallur(OW)	77.49	9.24	15	Charnockite	6	15	1.43												
4	Sankarankoil(EW)-3804	77.54	9.15	12	Charnockite	10	10.5	0.77(Arrested By pipe)	20.2	21.2	0.1									
5	Thiruvengadam(EW)-3803	77.66	9.26	12.5	Charnockite	3	4	1(Arrested By pipe)	20.3	21.3	0.1									
6	Kuruvikulam(EW)-3805	77.68	9.18	8.5	Charnockite	19.3	20.3	0.25	160.6	161.6	0.35									
7	Melnilathanallur(EW)-3808	77.6	9.01	11.5	Charnockite	106.7	107.8	Moisture												
8	Cheranmadevi(EW)-3812	77.51	8.67	5	Granite Gneiss	80.4	90.4	Moisture	145.3	146.3	6.8									
9	Cheranmadevi(OW)	77.51	8.67	11.5	Granite Gneiss	127	128	6.883	135.2	136.2	8.4	141.3	142.3	10.12						
10	Vellanguli(EW)-3811	77.47	8.68	11.5	Granite Gneiss	48.7	49.8	Moisture	95.5	98.6	0.71	159.6	160.6	1.8	165.7	166.7	3.34	179.9	181	8.4
11	Vellanguli(OW)	77.47	8.68	12.8	Granite Gneiss	37.6	38.6	0.2	163.6	164.6	1.26	174.8	175.8	3.34	182.9	184	4.35			
12	Taruvai(EW)-3813	77.68	8.67	16.5	Granite Gneiss	43.6	44.7	0.15												

13	Pappakudi(EW)-3814	77.52	8.75	24.5	Granite Gneiss	32	40	14.13												
14	Pappakudi(OW)	77.52	8.75	43	Granite Gneiss	22	23	1.00(Arrested Bypipe)	84.3	85.3	0.5									
15	Pottalpudur(EW)-3810	77.39	8.8	6	Garnetiferrous Gneiss	9	10	5.5	76	78	6.883									
16	Achanpudur(EW)-3806	77.3	9.02	18	Charnockite	12	13	3.0(Arrested By Pipe)	104.7	105.7	4.08	120.9	122	9.41						
17	Achanpudur(OW)	77.3	9.02	23	Charnockite	12	13	0.50(Arrested By Pipe)	73.1	74.2	1.9	92.5	93.5	4.6	127	128	8.48			
18	Pavurchatram(EW)-3809	77.38	8.92	7.8	Charnockite	17.2	18.2	0.2												
19	Vadakarai-Kilpidagai(EW)-3807	77.27	9.05	23	Granite Gneiss	23.3	24.3	0.44	69.1	70.1	1.21	85.3	86.4	1.5						
20	Nanguneri(EW)-3816	77.65	8.52	4	Calc Granulite	183	184	0.5												
21	Moolaikaraipatti(EW)-3817	77.77	8.53	11.6	Hornblende Biotite Gneiss	86	87	Moisture												
22	DalapathySamudram(EW)-3815	77.64	8.43	12	Granite Gneiss	9	10	1.50(Arrested by pipe)	17.6	18.6	0.25									
23	Kalakadu(EW)-3819	77.57	8.53	14.5	Granite Gneiss	62	63	0.5	80.4	87.4	0.75									
24	Rajapudur(EW)-3820	77.58	8.42	14.2	Khondalite	16.2	17.2	0.2	76.2	77.2	3.34									
25	Rajapudur(ow)	77.58	8.42	16	Khondalite	18	19	4.36	72	73	6.883									

26	Panagudi(EW)-3821	77.58	8.32	12	Granite Gneiss	69	70	0.25												
27	Mahendrapuram(EW)-3824	77.68	8.26	18	Granite Gneiss	37.6	38.6	0.44	64	65	1	90.4	91.4	1.5						
28	A.V.Thomas Mandapam(EW)-3826	77.68	8.19	21	Quartzo feldspathic Gneiss &Khondalite	62	63	0.25												
29	Silattikulam-3822	77.72	8.3	12	Khondalite	17.2	18.2	Moisture	27.4	28.4	0.5									
30	Sivalaperi-3818	77.81	8.79	12	Biotite Gneiss 7 Charnockite	10	11	1.00(Arrested Bypipe)	171.8	172.8	Moisture									
31	A.Sathankulam(EW)	77.74	8.58	18	Granite Gneiss	96	97	0.078												
32	Alagappapuram(EW)	77.84	8.41	11.5	Granite Gneiss	Dry														
33	Kothaicheri(EW)	77.61	8.45	11.5	Granite Biotite Gneiss	52	53	0.316	95	97	0.731	153	155	7.3						
34	Thalaiyuthu(EW)	77.72	8.8	3.5	Granite Biotite Gneiss	7	8	0.441	42	43	0.731	105	106	1.48	206	208	3.05			
35	Manur(EW)	77.64	8.84	14.5	Granite Biotite Gneiss	58	60	2.5												
36	Ukkirankottai(EW)	77.6	8.92	24.85	Granite Biotite Gneiss	41	42	0.014	137	138	0.078									

37	K.Karisalkulam(EW)	77.7	9.07	12	Granite Biotite Gneiss	30	31	0.316	198	199	0.731									
38	South Panavadali(EW)	77.61	9.03	11	Gneiss	58	58.5	1	180	180.5	3.34									
39	Kulasekaramangalam(EW)	77.47	9.08	20.9	Charnockite	197.5	198	1.8												
40	Kovilur(EW)	77.49	9.31	10.9	Charnockite	21	21.5	1												
41	Idinthakarai(EW)		8.17	5.5	Gneiss	22.12	23.74	0.078	44.98	46.6	0.592									
42	Kudankulam(EW)		8.17	17.5	Gneiss	16.12	17.1	Moisture	44.98	46.6	Moisture	94.32	95.62	0.078	128.8	130.42	0.25			
43	Vijayapathy East(EW)	77.76	8.2	18.2	Gneiss	60.22	61.84	0.014	90.7	92.32	0.05									
44	AlagarKuthankuli(EW)	77.78	8.24	6	Gneiss	19.12	20.12	0.078	34.36	35.36	0.215	40.98	42.98	0.316						
45	Kuttapuli(EW)	77.58	8.08	8.4	Gneiss	36.36	37.36	0.014	77.08	78.08	0.136									
46	Ovari(Idayankudi)(EW)	77.87	8.38	19.4	Gneiss	29.74	31.36													
47	3801PZ Tiruvengadam	77.64	9.25	11	Charnockite	Dry Well														
48	3802PZ Sankarankoil	77.56	9.21	11	Granite Gneiss	13.2	13.5		16.25	16.4										
49	3803PZ Vasudevanallur	77.41	9.24	24	Granite Gneiss	26.89	26.95		32.97	33.1										
50	3804PZ Puliangudi	77.4	9.22	18.9	Charnockite	32.97	33.5													
51	3805PZ Kadayanallur	77.35	9.07	12.8	Charnockite	16.25	16.35		37.53	37.85										
52	3806PZ Panpoli	77.25	9.02	22.5	Charnockite	25.35	25.75		34.49	35.1										
53	3807PZ Thenkasi	77.31	9.98	8	Charnockite	39.5	49.8													
54	3808PZ Kilpaur	77.38	8.92	3	Charnockite	35	35.2													

55	3809PZ Kadayam	77.41	8.83	6	Charnockite	49.5	49.8													
56	3810PZ Ambasamudram	77.44	8.72	10.25	Quartzite	23.85	24		34.4	34.6										
57	3811PZ Mukkudal	77.52	8.73	9	Quartzite	13.21	13.3		25.3	25.8		29.93	30.1		29.93	30.1				
58	3812PZ Charanmadevi	77.58	8.83	10	Granite Gneiss	43.61	45.1													
59	3813PZ Alankulam	77.47	8.9	13.5	Charnockite	52.73	52.95		57.29	57.35										
60	3814PZ Devarkulam	77.64	8.97	10.5	Charnockite	61.85	62.5													
61	3815PZ Manur	77.63	8.85	9	Charnockite	29.93	30.5													
62	3816PZ Tiruthu	77.84	8.81	10.65	Charnockite	14.72	15													
63	3817PZ Tirunelveli	77.72	8.71	12.8	Granite Gneiss	42.5	42.75													
64	3818PZ Marudhakulam	77.72	8.58	9	Quartzite	19.29	20.5		39.5	39.8										
65	3819PZ Kalakadu	77.6	8.48	0.8	Quartzite	37.5	37.9		39.93	40.2										
66	3820PZ Valliyur	77.62	8.39	12	Granite Gneiss	17.87	18		29.93	30.5										
67	3821PZ Tiruvembalapuram	77.76	8.25	9.5	Granite Gneiss	45.13	45.5													
68	3822PZ Kudankulam	77.58	8.22	9.5	Granite Gneiss	45.1	45.5													
69	3823PZ N.V.Narayanam	77.79	8.53	19	Gneiss	43.5	43.8													
70	3824PZ Chettikulam	77.62	8.17	21.1	Quartzite	29.93	30.5													
71	3825PZ Nanguneri	77.7	8.49	12.5	Granite Gneiss	49.7	49.9													

72	Maniyachi(EW)-5006	77.9	8.86	17	Biotite, Gneiss	14	15	0.5												
73	Seidunganallur(EW) - 5010	77.84	8.66	10	Granite Gneiss and Charnockite	44	44.7	0.1	128	129	0.25									
74	Puliyankulam(EW)-5018	77.88	8.49	23	Granite Gneiss and Charnockite	-														
75	Puliyankulam(EW)-5819	77.88	8.49	38	Granite Gneiss and Charnockite	63	64	6	82	83	7.1									
76	Puliyankulam(OW-I)	77.88	8.49	42	Khondalite and Charnockite	48.7	49.8	3.34	54.8	55.9	6.2	67	68.1	8.4	75.2	76.2	12			
77	Puliyankulam(OW-II)	77.88	8.49	28	Khondalite and Charnockite	46.7	47.7	2.5	64	66	4.36	67	68.1	11.05						
78	Peykulam(EW)-5013	77.9	8.52	-	-	-														
79	Sattankulam(EW)-5014	77.92	8.45	22.75	Khondalite and Charnockite	17.2	18.2	9.24 (Arrested)	24.3	25.4	3.45	27.4	28.4	9.24	38.6	39.6	11.05	75.2	76.2	13.05
80	Sattankulam(OW-I)	77.92	8.45	22	Khondalite and Charnockite	21.3	22.5	3.34	24.3	25.3	6.19	27.4	28.4	7.62	32.4	33.4	12.02			
81	Sattankulam(OW-II)	77.92	8.45	27	Khondalite and Charnockite	63	64	0.5	74.2	75.2	0.75	87.4	88.4	10						
82	Srivaikuntam(EW)-5012	77.91	8.63		Granite Gneisses	24.3	25.4	3.84	29.4	30.4	6.2									
83	Subrahmaniyapuram(EW)	77.9	8.63		-	5	6	1												
84	Muditanendal(EW)-5009	77.94	8.72	13	Charnockite	87.4	88.4	Moisture												

85	Kilputtaneri(EW)-5008	77.82	8.72	8.5	Charnockite	69	70	Moisture	192	193	0.5									
86	Chokkalingapuram(EW)-5	77.89	9	19	Granite Gneiss Charnockite	37.6	38.6	1												
87	Pasuvandanai(EW)-5005	77.97	8.99	21	Granite, Gneiss	21.3	22.3	1.5	27.4	28.4	2									
88	Kovilpatti(EW)-5001	77.87	9.18	14	Charnockite	117.9	118.9	0.15												
89	Tittankulam(EW)-5002	77.91	9.18	19.3	Charnockite	91.4	92.5	Moisture only												
90	Vilattikulam(EW)-5003	78.17	9.14	24.5	Charnockite	24.5	30	3.34	60.9	62	4.28									
91	Vilattikulam(OW)	78.17	9.14	24.5	Charnockite	79.1	80	1	89.4	90.4	1.5									
92	Vadalakari(EW)-5004	78.21	9.19	20	Charnockite	10	12	2(Arrested)	30.4	31.5	1.5									
93	Serakulam(EW)	77.82	8.57	12	Granite Biotite Gneiss	47	49	1.2	68	69	2.5	154	155	3.1						
94	Kayattar(EW)	77.78	8.95	11.5	Charnockite	16	16.5	0.014	24	25	0.078	89	90	2	155	156	1.2			
95	Melamadam(EW)	78.03	8.87	47.5	Pegmatite	63	63.5	0.014	74	74.5	7	96	96.5	12						
96	Umarikottai(EW)	77.99	8.81	5.5	Gneiss	12.5	13	0.215	24	25	4.36									
97	Nalatinputhur(EW)	77.82	9.14	13	Charnockite	6.2		Dry	67.2	75	0.078									
98	5001PZ Pudur	78.14	9.31	5.5	Charnockite	14.7	14.9		54.2	54.4				0.1						
99	5002PZ Ettayapuram	77.98		12.2	Charnockite	17.5	17.6		23.8	23.9		28.8	28.9	1.48						
100	5003PZ Nallatinputhur	77.84	9.16	9.15	Quartzite	36	36.1							0.078						
101	5004PZ Villiseri	77.85	9.06	18.3	Charnockite	42.9	43							0.078						
102	5005PZ Kdambur	77.85	9	12.2	Charnockite	28	28.1							0.316						
103	5006PZ Maniyachi	77.9	8.87	14.05	Gneiss	15.85	15.95							0.014						

104	5007PZ Petmanagar	77.95	8.65	12.2	Granite Gneiss	37.53	37.65							0.215					
105	5008PZ Peyaikulam	77.9	8.52	11	Charnockite	36.4	36.5							0.218					
106	5009PZ Sattankulam	77.9	8.43	9.15	Gneiss	48.17	48.27							0.027					
107	5010PZ Pudukottai	78.05	8.75	14.65	Charnockite	71	71.1							0.021					
108	5011PZ Thailapuram	77.85	8.61	13.75	Gneiss	26.89	27.05							0.024					
109	5012PZ Kalugumalai	77.72	9.15	14.6	Charnockite	23.85	24							0.014					

Chemical analysis data of Tambraparni aquifer system (May 2018), Tamil Nadu Annexure-IV

LR.NO	DISTRICT	LOCATION	LAT	LONG	PH	EC	TH	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	NO3	F
1	Tirunelveli	Abishekapatti	8.7625	77.640278	6.6	169	50	16	2	14	4	NIL	49	21	10	6	1.2
2	Tirunelveli	Alangulam1	8.8625	77.505556	7.1	1320	370	80	41	124	15	NIL	354	234	34	3	1.3
3	Tirunelveli	Alwarkurichi	8.7916667	77.433333	7.4	673	280	40	44	23	2	NIL	244	60	38	8	1.9
4	Tirunelveli	Ambasamudram1	8.7	77.438889	7.1	481	160	40	15	28	8	NIL	153	50	19	12	1.6
5	Tirunelveli	Cheranmadevi (A)	8.6838889	77.565833	7.5	1456	290	44	44	196	2	NIL	403	220	58	24	1.7
6	Tirunelveli	Govt.Eng College	8.6855556	77.726944	7.2	996	390	76	49	37	1	NIL	232	142	48	37	0.9
7	Tirunelveli	Idaikkal	8.5333333	77.465278	7.0	320	110	36	5	23	4	NIL	116	21	24	20	1.1
8	Tirunelveli	Kadayanallur1	9.0833333	77.35	7.6	2940	1050	148	165	196	6	NIL	232	659	336	3	1.6
9	Tirunelveli	Kalakkadu	8.5125	77.541667	7.3	570	230	40	32	28	4	NIL	183	71	39	12	1.0
10	Tirunelveli	Kuttam	8.3166667	77.941667	7.4	765	290	52	39	41	8	NIL	244	78	43	43	1.5
11	Tirunelveli	Manur1	8.8625	77.652778	7.0	277	90	28	5	23	4	NIL	61	43	19	12	0.6
12	Tirunelveli	MerjaraPallivasal	8.7402778	77.665556	7.1	674	220	40	29	51	4	NIL	183	89	24	40	0.8
13	Tirunelveli	Mullikulam	9.1833333	77.447222	7.0	95	35	10	2	5	2	NIL	31	14	5	3	0.7
14	Tirunelveli	Naduvapatty	9.2416667	77.801389	7.0	370	150	56	2	16	4	NIL	122	35	29	19	1.0
15	Tirunelveli	Nanguneri2	8.3166667	77.579167	7.3	1060	250	44	34	124	3	NIL	354	142	24	10	1.9
16	Tirunelveli	Nelliappar temple	8.7280556	77.688333	7.5	1546	380	44	66	168	20	NIL	464	156	96	74	1.5
17	Tirunelveli	Ngo A Colony dw	8.6911111	77.738333	7.3	1475	460	68	70	115	7	NIL	391	213	96	19	1.4
18	Tirunelveli	Ovari	8.2866667	77.893889	7.6	1160	260	44	36	138	12	NIL	317	177	43	23	1.2
19	Tirunelveli	P.chatram	9.1183333	77.6125	7.3	2370	750	116	112	200	5	NIL	238	425	288	112	1.6
20	Tirunelveli	Palayamkottai	8.7333333	77.733333	7.4	1486	440	40	83	121	5	NIL	323	227	96	26	1.6
21	Tirunelveli	Papakudi	8.7438889	77.508333	7.5	818	325	48	50	30	12	NIL	293	64	38	43	1.8
22	Tirunelveli	Papanasam1	8.7111111	77.368056	7.1	824	260	52	32	62	11	NIL	183	135	53	9	1.5
23	Tirunelveli	PoothatanKudieruppu	8.5783333	77.560278	7.1	3800	840	140	119	506	5	NIL	452	744	432	81	1.6
24	Tirunelveli	R.Pattinam	8.9255556	77.354167	7.5	1614	500	84	70	138	5	NIL	378	255	77	67	1.4
25	Tirunelveli	Radhapuram1	8.2666667	77.684722	7.3	450	150	40	12	35	4	NIL	153	43	29	25	1.9
26	Tirunelveli	Sankarankoil2	9.2083333	77.558333	7.4	1403	380	56	58	145	6	NIL	415	156	96	62	1.8

27	Tirunelveli	Sencottai	8.9722222	77.252778	7.6	558	230	52	24	23	4	NIL	183	71	24	25	1.1
28	Tirunelveli	Sivagiri	9.3402778	77.427778	7.2	237	80	20	7	18	2	NIL	61	32	19	12	1.1
29	Tirunelveli	Syed Beedi Company	8.7322222	77.713056	7.6	868	270	48	36	69	3	NIL	268	106	29	39	1.5
30	Tirunelveli	Tachchnallur	8.7458333	77.7	7.3	1969	750	136	100	115	2	NIL	391	418	62	35	1.8
31	Tirunelveli	Thiraviyarnagar	8.8769444	77.345833	7.4	844	350	68	44	24	7	NIL	244	71	58	50	1.8
32	Tirunelveli	Thiruthu	8.7633333	77.805556	7.2	1045	380	72	49	60	1	NIL	183	184	48	54	0.9
33	Tirunelveli	Valliyoor	8.3555556	77.658333	7.3	1559	480	156	22	122	27	NIL	433	220	67	62	0.5
34	Tirunelveli	Vannikonendal	8.6611111	77.625	7.1	435	150	64	4	24	8	NIL	122	43	29	19	1.2
35	Tirunelveli	Vasudevanallur2	9.2416667	77.408333	7.4	1255	480	120	44	93	3	NIL	513	156	29	16	1.6
36	Tuticorin	Devachayalpuram	8.7344444	77.919444	7.2	1243	570	140	53	61	9	NIL	330	128	154	122	1.3
37	Tuticorin	Eppodumvendramdw	9.0277778	78.044444	7.4	4400	660	160	63	412	23	NIL	427	525	432	74	1.6
38	Tuticorin	Ettaiyapuram	9.1263889	78	7.5	1620	420	104	39	180	23	NIL	421	135	288	12	0.8
39	Tuticorin	Kalluranidw	9.1430556	77.771944	7.4	4140	650	112	90	656	3	NIL	525	347	1056	54	2.0
40	Tuticorin	Kalungumalai	9.1444444	77.705556	7.4	3360	1010	212	117	299	5	NIL	311	666	432	41	1.6
41	Tuticorin	Karisalkulam	9.15	78.166667	7.6	1060	420	92	46	46	3	NIL	384	106	38	41	1.3
42	Tuticorin	Kayattar	8.9444444	77.775	7.4	538	200	76	2	23	16	NIL	220	35	34	20	1.4
43	Tuticorin	Kovilpatti	9.175	77.875	7.3	1873	610	172	44	147	5	NIL	452	248	77	157	0.9
44	Tuticorin	Kulasekharaptnm	8.4	78.054167	7.4	1160	370	76	44	92	8	NIL	305	128	96	62	0.5
45	Tuticorin	Kurukkuchalai	8.9305556	78.091667	7.5	1847	470	112	46	207	3	NIL	452	142	336	15	1.4
46	Tuticorin	Maniyachi1	8.8333333	77.895833	7.4	1220	330	80	32	127	12	NIL	482	106	48	34	0.8
47	Tuticorin	Mettupanaiyurdw	8.9105556	78.170833	7.2	709	275	76	21	30	8	NIL	244	71	39	4	0.8
48	Tuticorin	Mukkanidw	8.6341667	78.073611	7.3	1375	550	148	44	58	10	NIL	433	177	77	10	1.0
49	Tuticorin	Muppilipattidw	8.9011111	78.025556	7.3	1447	510	160	27	85	20	NIL	445	177	48	68	0.9
50	Tuticorin	Nagalapuram	9.2333333	78.130556	7.3	1700	510	172	19	161	4	NIL	311	305	144	37	1.1
51	Tuticorin	Nazareth	8.4375	77.973611	7.0	6190	2200	672	126	460	16	NIL	256	801	1584	270	1.0
52	Tuticorin	Saidunganallur	8.4958333	77.833333	7.1	1102	450	112	41	46	8	NIL	214	170	82	75	1.1
53	Tuticorin	Sathankulam-n	8.4444444	77.9	7.3	3440	690	248	17	483	8	NIL	476	588	384	157	1.2
54	Tuticorin	Srivaikundam1	8.625	77.908333	7.4	549	210	56	17	23	7	NIL	183	50	41	1	1.4
55	Tuticorin	Tiruchendur-e	8.4944444	78.122222	7.3	3260	540	128	53	483	23	NIL	421	510	384	175	1.2

56	Tuticorin	Tiruchendur-w	8.4958333	78.120833	7.4	1210	370	100	29	104	17	NIL	433	142	67	5	1.1
57	Tuticorin	Tuticorin1	8.8083333	78.138889	7.4	11700	1950	280	304	1840	2	NIL	598	1950	2592	28	1.8
58	Tuticorin	Udangudidw	8.4341667	78.029167	7.1	11710	5050	1060	583	391	36	NIL	104	3970	265	2	1.3
59	Tuticorin	Vembur	9.325	78.081944	7.6	772	290	52	39	34	5	NIL	323	50	21	13	1.5
60	Tuticorin	Vilathikulam	9.125	78.168056	7.5	1426	180	32	24	239	3	NIL	427	177	77	25	1.2