केन्द्रीय 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

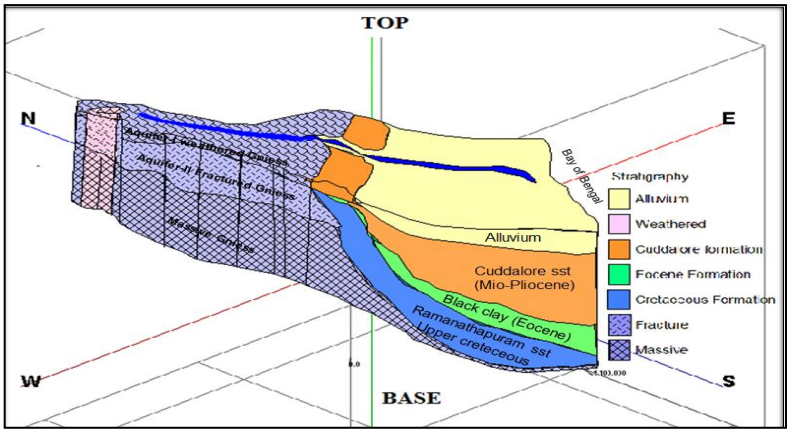
for Pambar-Kottakaraiyar Aquifer System
Tamil Nadu

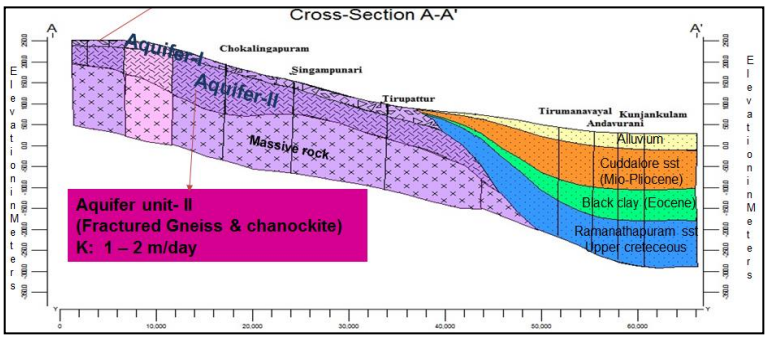
दक्षिण पूर्वी तटीय क्षेत्र, चेन्नई

South Eastern Coastal Region, Chennai

सरकारी उपयोग के लिए

REPORT ON
AQUIFER MAPPING AND AQUIFER MANAGEMENT PLAN FOR PAMBAR - KOTTAKARAIYAR 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 REJUVENA
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 Pambar - Kottakaraiyar aquifer system covering an area of 4323 sq.km. The basin comprises of water stressed Dindigul, Madurai, Pudukottai, Ramanathapuram and Sivaganga districts of Tamil Nadu. Four firkas 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 and 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 Pambar - Kottakaraiyar aquifer system. Main aquifer units that exist in the study area, namely 1. Weathered zone at the top followed by a discrete anisotropic fractured/fissured zone at the bottom in the western and southern parts of the study area. 2. Alluvium in the central and eastern portions underlined by compact conglomerates of the Gondwana formationIn 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 it resources effectively in the Nambiyar aquifer system.

Dr A Asokan
Regional Director

EXECUTIVE SUMMARY

Integrated hydrogeological studies were conducted in the Pambar - Kottakaraiyar Aquifer system wherein large number of existing data pertinent to geology, geophysics, hydrogeology, hydrology, hydrochemistry were collected, synthesised and analysed to bring out this report. This report mainly comprises the lateral and vertical extents of the aquifers with their geometry, aquifer properties of the study area which are considered to be measuring scales for groundwater availability and potentiality. Keeping these parameters in view a sustainable management plan has been suggested through which the groundwater needs can be fulfilled in a rational way.

The Pambar - Kottakaraiyar aquifer system experiences semi-arid climate with 924 mm annual normal rainfall covering 4323 km^2 area in Dindigul, Madurai, Pudukottai, Ramanathapuram and Sivaganga districts of Tamil Nadu. About 65% of the geographical area is under agricultural activity of which 80% is groundwater irrigation. The main crops irrigated are- paddy, sugarcane, groundnut, maize, cotton, ragi and other minor crops such as turmeric, vegetables and flowers.

Main aquifer units that exist in the study area, namely 1. Weathered zone at the top followed by a discrete anisotropic fractured/fissured zone at the bottom in the western and southern parts of the study area. 2. Alluvium in the central and eastern portions underlined by compact conglomerates of the Gondwana formation. Groundwater occurs under unconfined condition in the weathered zone and in the alluvial formation and unconfined to semi-confined conditions in the conglomerates and fractured/fissured zone. The predominant water levels are in the range of 5 to 20 m bgl during pre-monsoon season and 2 to 10 mbgl during post-monsoon season of 2018. The net annual ground water availability is 943.11 MCM and the gross groundwater draft is 189.649 MCM and the stage of groundwater development is 20%.

The major issues in the aquifer systems are decline in groundwater levels and low sustainability, threat of sea water intrusion along the coastal part of the aquifer system, groundwater contamination by industries, urbanisation and huge demand for groundwater to cater growing Chennai city population and low yielding aquifer units. Seawater intrusions observed in the south of Devipattinam. The sea water intruded area is more during high tide and less during low tide.

In hard rock regions aquifer systems can be conceptualized as weathered zone down to ~30m with average thickness of 18 m and fractured zone between 30 to 190 m bgl. The weathered zone is disintegrated from the bed rock (upper part–saprolite zone) and partially/semi weathered in the lower part (sap rock zone) with transmissivity varying between 4 and 32.3 m^2/day and specific yield of 0.5 and 3%. The fractured zone is fractured gneiss (or) Charnockite which occur in limited extent, associated sometime with quartz vein. The average transmissivity of this zone varies between 3.5 and 45.2 m^2/day and storativity varies from 0.002 to 0.01. In alluvial regions the first aquifer unit comprising of sand, gravel has thickness ranging from 5 to 50 m with yields ranging from 68 to 140 m^3/hr and transmissivity values ranging from 1271 to 4180 m^2/day. Gondwana formation comprising of compact conglomerates underlie the alluvial formation and have poor yields ranging from 2 to 27 m^3/hr with transmissivity values ranging from 2.2 to 143.2 m^2/day.

Fast growing urban agglomerations share groundwater which otherwise is being used for irrigation purpose resulting in either shortage for irrigation needs or creates excessive draft to meet both the demands in groundwater potential areas. The study formulates management strategies for supply side as well as demand side. The supply side measures include construction of artificial recharge structures of 7 Check dams, 21 nala bands 5 recharge shafts in addition to the 50 ponds earmarked for rejuvenation with recharge shafts in all the OE and Critical firkas of

the basin. The estimated cost for construction of these structures is to be Rs 3.875 Crores. The estimated recharge to groundwater system through these structures will be in the order of 2.03 MCM with an additional area of Paddy: 7438 ha or Sugarcane: 5950 ha (or) Banana: 11900 ha (or) Irrigated Dry crops: 23800 ha. Demand side management is also recommended by change in irrigation pattern from flooding method to Ridge & furrow for paddy and flooding to drip for sugarcane and banana crops. This intervention would save 23.94 ham of water annually. By carrying out both supply and demand side interventions the stage of groundwater development would be lowered from 106 to 90%.

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 is to be conducted among user groups and valid suggestions may be incorporated in the regulatory acts.

REPORT ON AQUIFER MAPPING AND AQUIFER MANAGEMENT PLAN FOR PAMBAR - KOTTAKARAIYAR AQUIFER SYSTEM, TAMIL NADU

CONTRIBUTORS' PAGE

Principal Author

Dr. M. Panneer, Scientist - B

Groundwater Exploration		
Dr. M. Panneer	:	Scientist - B
Shri. A.Sakthivel	:	Scientist - B
Shri. A. Ravi		Scientist - D
Shri. G. Venkatachalapathy	:	Assistant Hydrogeologist
Aquifer Disposition		
Shri. G. Venkatachalapathy	:	Assistant Hydrogeologist
Groundwater management plan		
Shri. A. Sakthivel	:	Scientist - B
Dr. M. Panneer	:	Scientist - B
Shri. A. Ravi	:	Scientist - D
GIS layers & Maps preparation		
Dr. M. Panneer	:	Scientist - B
Shri. G. Venkatachalapathy	:	Assistant Hydrogeologist
Shri. A.Sakthivel	:	Scientist - B
Mrs. M. Navaneetham	:	Draughtsman
Geophysical studies		
Dr. V. Arulprakasam	:	Scientist - D
Scrutiny of the report		
Smt. Mini Chandran	:	Scientist - D

Overall Supervision and Guidance

C. Paul Prabakar, Regional Director

AQUIFER MAPPING AND AQUIFER MANAGEMENT PLAN FOR PAMBAR - KOTTAKARAIYAR AQUIFER SYSTEM

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1.0 INTRODUCTION

National Project on Aquifer Mapping (NAQUIM) initiated by Ministry of Jal Shakti, Department 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, propose 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.

The water demand for domestic, irrigation, industries, livestock, power generation and other uses is governed by socio-economic and agricultural factors, including the present and future population size, income level, urbanization, market facilities, remunerative prices, cropping patterns, etc. The rationale of choosing a river basin as the unit for the planning is to optimize the use of water resources in that basin, matching with supply and demand. An analysis of the water balance, water utilisation and allocation plan for different competing water users form the core of a river basin plan. As groundwater continues to play an important role in the development of the human civilization, there arises a strong need for protecting groundwater from increasing threat of over extraction and contamination. The development activities over the years have adversely affected the ground water regime in many parts of the country. Hence, it is important to understand the aquifer system and its hydrodynamics so as to properly manage the groundwater resources. 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 the Pambar - Kottakaraiyar Aquifer system in a view to 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 result in better management of groundwater resources in vulnerable areas.

1.1 Objectives

The objectives of the aquifer mapping project in the Pambar - Kottakaraiyar aquifer system can broadly be stated as

- To define the aquifer geometry, type of aquifers and their lateral and vertical extents
- To determine the groundwater regime scenario
- To determine the hydrogeochemical characteristics of the aquifer units
- To decipher 2D and 3-D dispositions of the aquifer units.
- To estimate the availability of groundwater resources in the aquifer system
- To develop a sustainable 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 Central Ground Water Board 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 Tamilnadu Water supply and Drainage Board (TWAD), Public Works Department (PWD) and Agricultural Engineering Department (AED).

In order to bridge the data gap, data generation programme has been formulated in an organised way in the basin. Groundwater exploration work has been carried out 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 second, after generation of data at identified gaps. The resultant maps generated are more realistic aided with dense data points.

1.2 a. Issues

During aquifer mapping studies in the Pambar – Kottakaraiyar aquifer syatem, the major issues/threat identified (**Figure 1.1**) in the aquifer system are

i. In-situ salinity.
ii. Threat of sea water intrusion along coast.
iii. Highly compact – Low yielding aquifer units.
iv. Nitrate Contamination

In-situ salinity

High electrical conductivity values are obsereved at different depths, starting from 35m (Orasur EW) to 350m (Thiruvadanai). Cuddalore, tertiary and recent aquifers are affected by in-situ salinity. Embal, Mimisal and Ponpette blocks are afftected in Pudukottai district. Kannangudi, Puzhiyal Sooranam areas are affected in Sivaganga district. Pullur, R S Mangalam, Shollandur, Thondi and Mangalakudi blocks are affected in Ramanathapuram district.

Threat of sea water intrusion along coast

There is sea water intrusion threat along the coastal part of the aquifer system. Seawater intrusions observed in Mimisal, Manalmelgudi, Thondi and Thiruppalakkudi areas. The sea water intruded area is more during high tide and less during low tide.

Highly compact - Low yielding aquifer units

Low yielding aquifers, due to absence of primary, secondary porosity and compactness in Granite, Charnockite, Conglomerate and Quartzite. Very less discharge observed in both weathered and fractured aquifers. The transmissivity values of weathered and fractured aquifers are in the range 0.1 to 2.0 m^2/day. The specific yield values of weathered and fractured aquifers ranges between 0.01 to 0.1.

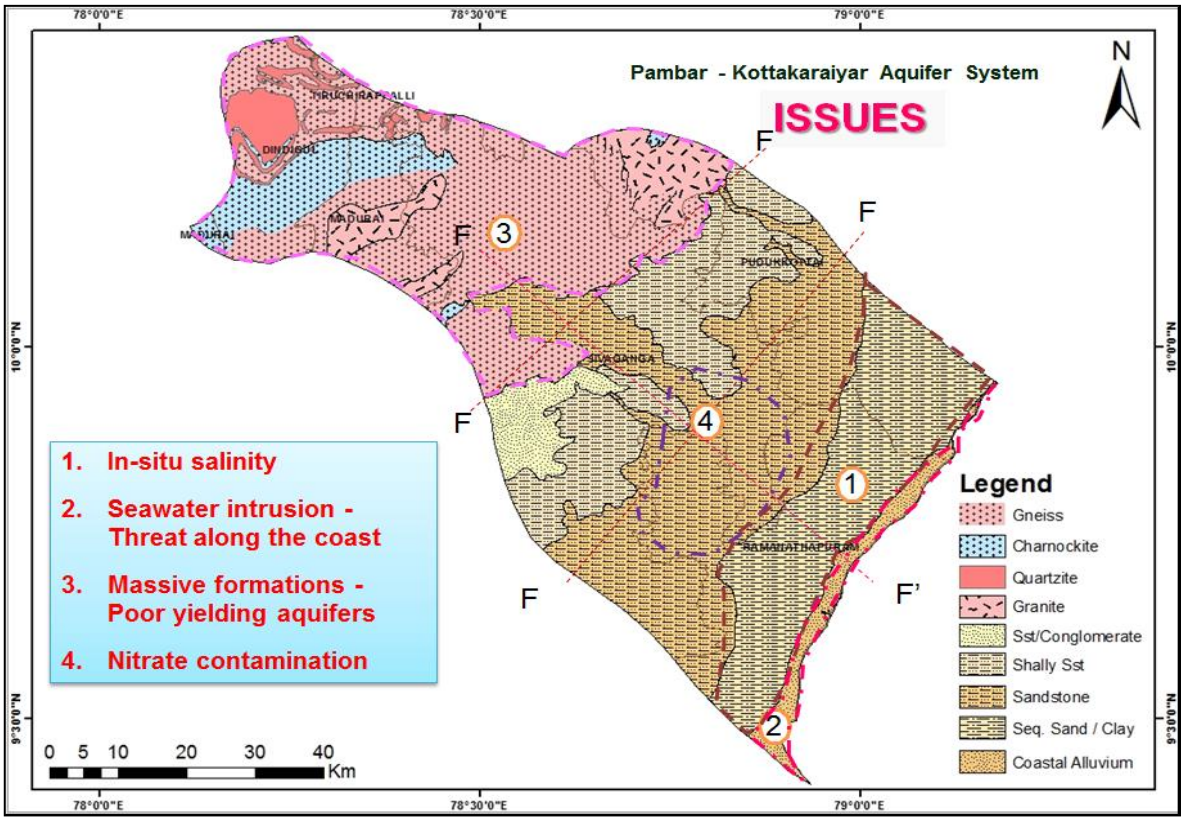


Figure.1.1. Issues pertaining to the Pambar - Kottakaraiyar Aquifer system

Nitrate Contamination

The source of Nitrate in groundwater includes surface leaching from wastewater and N-based fertilizers. Isolated pockets of Nitrate contamination above 45 mg/l are observed in Thiruvegampattu in Ramanathapuram District, Tirupathur and Singampunari in Sivaganga District and Avudayarkoil in Pudukottai District. The source of Nitrate contamination in this pocket is due to applied fertilizers in agricultural field and urban sewerage.

1.3 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 basin has been generated based on the GSI maps, geophysical data has 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 and 300 m bgl for hard rock & soft rock respectively. Hydrological and hydrometerological data has been collected from state PWD and Indian Meteorological Department (IMD). Drainage, Soil and Geomorphology of the sub basin was 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 planned through establishing key observation wells, pinpointing exploratory sites for drilling through in-house and outsourcing, collecting groundwater samples 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 basin estimated through groundwater balance method. Based on the above studies management strategies both on the supply side through augmentation of groundwater through artificial recharge and water conservation and on demand side through change in irrigation pattern have been formulated for sustainable management of the groundwater resource.

1.4 Study area

Among the 20 aquifer systems, the Pambar Kottakkaraiyar river basin is the seventh biggest basin based on the geographical location. The basin is delineated into three sub basins viz., Manimuttar, Pambar and Kottakkaraiyar. The total area of the basin is 4780 sq.km and the hilly area occupies 457 sq.km. Total mappable area 4323 sq.km. 42 Firkas are fully covered and the remaining blocks are partly covered. District and Firka wise area falling in the basin are furnished in **Table 1.1.**

The basin is located in between N. Latitude 10° 28’ 30” - 09° 27’ 15” and E. Longitude 78° 05’ 30” - 79° 10’ 30”. The basin is falling in Survey of India Topographic Sheets 58 J3, J4, J7, J8, J11, J12, J15, J16, 58 K5, K6, K9, K10, K13, K14, K15, 58 N4 and 58 O1&2 on 1:50000 scale. Pambar Kottakkaraiyar river basin is bounded by the Bay of Bengal in the east, Agniyar basin in the north, Cauvery and Vaigai basins in the west and Vaigai basin in the south**.** The Pambar Kottakkaraiyar basin spreads over parts of Dindigul, Madurai, Sivaganga, Pudukottai and Ramanathapuram districts and Sivaganga district covers major part of the basin.

The basin area is well connected with roads and railway lines. All the towns and villages are connected with village roads, district roads, State highways and National highways. The National Highway-NH 45B is passing through Kottampatti to southern districts of Tamil Nadu. National Highways from Pudukkottai to Manamadurai (NH 226), from Pudukkottai to Ramanathapuram (NH 210) and from Madurai to Tiruvadanai (NH 230) are passing through this basin and inter connected with State highways from Dindigul to Devakkottai (SH 35), from Sivaganga to Illayangudi (SH34), from Peravuruni to Illayangudi (SH 28), from Tiruppattur to Melur (SH 191) and from Nattam to Melur (NH 72) which are connected with village roads. Peravuruni to Manamadurai broad gauge railway line passes through this basin. The administrative map of the Pambar - Kottakaraiyar aquifer system is presented as **Figure 1.2**

Table 1.1. Districts and Firkas of the Pambar - Kottakaraiyar aquifer system

Sl. No.	District	Area (sq.km.)	No. of Firkas	No. of OE and Critical Firkas
1	Sivaganga	2419.	23	-
2	Ramanathapuram	812	7	-
3	Pudukottai	397	6	-
4	Dindugul	379	3	-
5	Madurai	316	3	1
Total		**4323**	**42**	**1**

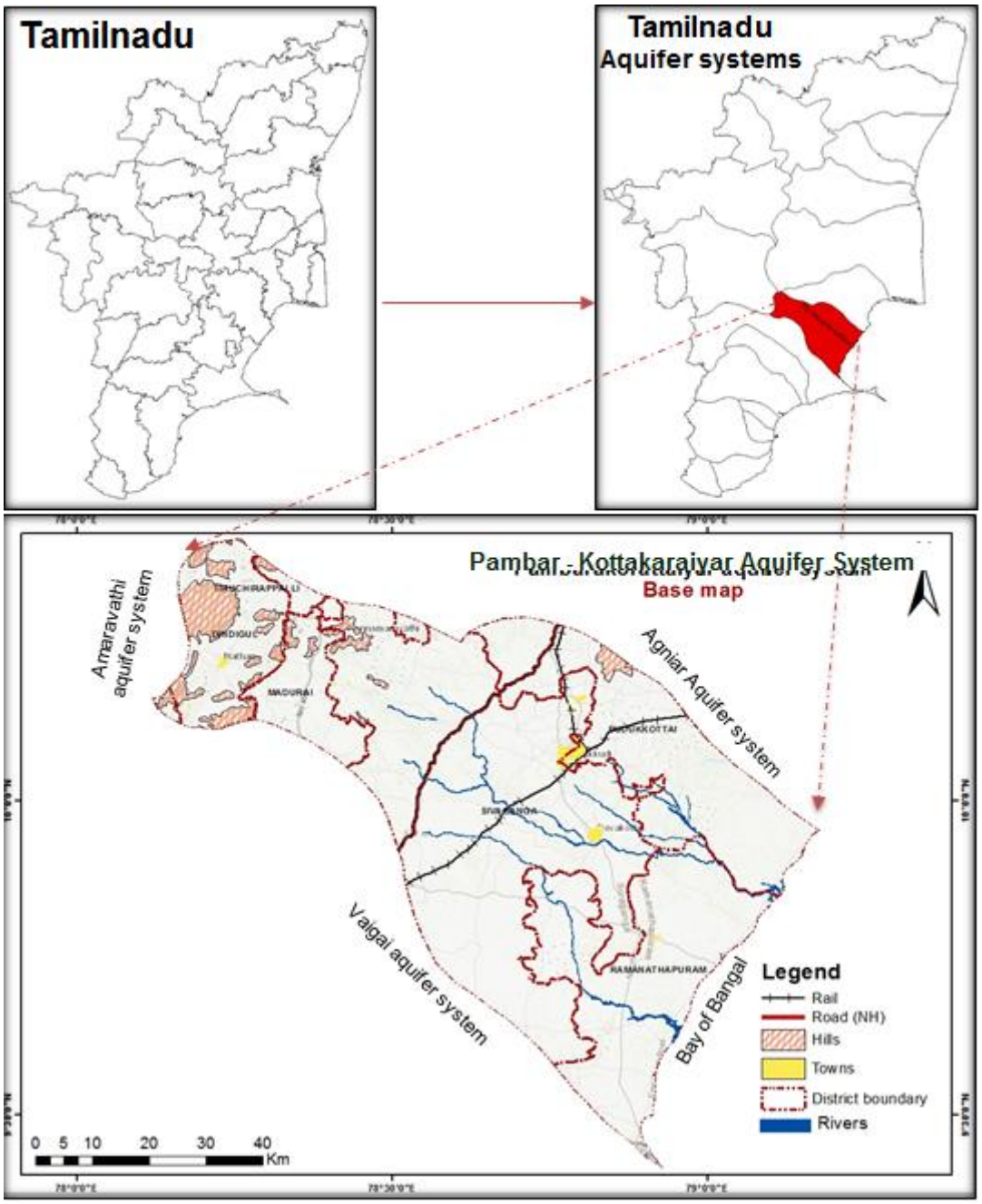


Figure 1.2: Administrative setup of the Pambar - Kottakaraiyar Aquifer System

1.5. Physiography and Drainage

There are three major rivers, Pambar, Manimuttar and Kottakaraiyar. Pambar, Kottakkaraiyar and Uppar rivers confluence with Bay of Bengal. **(Figure 1.3)** All these rivers are seasonal. Perumal Odai and Kannimarattu Odai are the tributary of Tirumanimuttar river. Ten Ar is the tributary of Pambar river. The Periyar Main Canal from Vaigai basin enters into this basin near Saruguvalapatti and flows into the Silandangudi tank. Another Periyar Main Canal enters at Uranganpatti and feeds water to Kurichchippatti tank. A canal from Vaigai River is feeding

water to the Rajasingamangalam tank. But there are 7602 small to medium water bodies such as tanks, ponds and Oorunis in the basin. Large, medium and small drainages have their outlet into tanks and rivers in this basin. The tanks are interconnected so as to feed the lower tank from surplus water of the upper tank. Most of the tanks are rainfed or non system tanks.

Based on the physiographic and catchment areas of the major rivers, the Pambar Kottakkaraiyar basin is divided into three sub basins namely Pambar, Manimuttar and Kottakkaraiyar.

Manimuttar sub basin is the largest among the three sub basins having the geographical area of 1850.61 sq.km. The upper part, north and north western part of the sub basin are covered by hills located in reserve forest. The river Manimuttar originates in the name of Tirumanimuttar at an altitude of +440 m MSL near Malaipatti village in the west of Erakalamalai reserve forest. The total length of this Manimuttar River is 19.09 km.

Pambar sub basin is the smallest sub basin among the three sub basins having an area of 1248.58 sq.km bounded by Agniyar river basin in the north, Bay of Bengal in the east and Manimuttar sub basin in the south and west. Pambanar River originates from the surplus course of Tirumayam tank. The river is narrow up to a distance of 19.72 sq.km and it is wide after Pakkiritakkal village and again it narrows after Narikkudi village eventually confluences with Palantamarai tank. Pambar, flows through Tiruppunavasal and finally confluences with the Bay of Bengal near Puttukkidapatam. There is no reservoir/ dam in this sub basin. More than 2400 small to large size water bodies, such as, tanks, ponds and Oorunis are available in this sub basin.

Kottakkaraiyar Sub Basin is bounded by the Vaigai basin in the east, Cauvery basin in the west and Bay of Bengal in the east. Total area of the sub basin is 1680.81 sq.km. Three rivers are flowing in this sub basin, namely, Sarugani Ar, also called as Kottakkaraiyar, Nattar and Uppar. Sarugani Ar originates from the surplus course of Perungudi tank. Kottakkaraiyar confluences with the Bay of Bengal near Karankadu and Ugandangudi. Another canal off taking from Vaigai River, east of Paramakudi, enters this sub basin south west of Saliyavaganapuram village, to feed water to Rajasingamangalam tank.This is one of the oldest intra-basin transfer. Before the canal reaches R.S.Mangalam tank, enroute it feeds other tanks.

The nominal topography is generally sloping towards the East and Southeast. The general trend of dip ranges from West to East. The Hydraulic gradient and the flow lines of ground and surface waters are towards east, the sea.

There are a number of systems and non-system rainfed tanks lying in the study area. These water bodies were very specifically useful in meeting the drinking water needs and rarely for irrigation and for industrial uses of many number of industries located around Kalpakkam and its urban agglomerate.

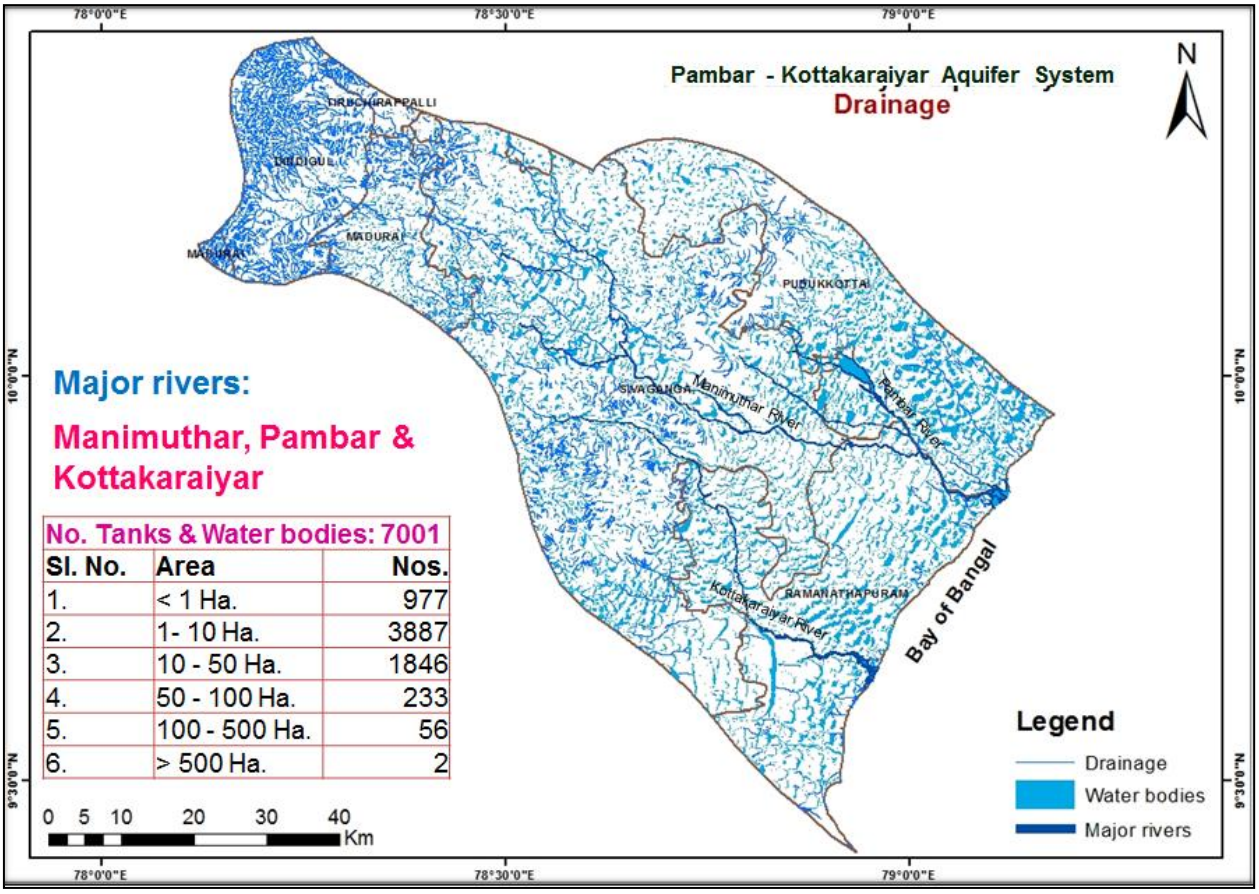


Figure 1.3. Drainage of the Pambar - Kottakaraiyar aquifer system

1.6. Geomorphology

The geomorphological study was carried out in the Pambar Kottakkariyar basin by interpreting the image by its characteristics such as tone, texture, shape, pattern and associated features etc. The following four major landforms were identified in the basin, based on its genesis. 1. Landforms of Structural Origin, 2. Landforms of Denudation Origin, 3. Landforms of Fluvial Origin and finally 4. Landforms of Coastal Origin

Landforms of Structural Origin

The structural landforms in Pambar Kottakkaraiyar basin includes structural hills and linear and curvilinear ridges. The structural landforms are noticed in the western part of the basin where the geology is of hard rock origin. The relevence to groundwater prospects is moderate along its valleys, subject to weathering.

Landforms of Denudation Origin

The Denudation landforms occur in the western and middle part of the basin and divided into various geomorphic units such as denudational hills, residual hills, pediments, inselberg complex, pediment, buried pediplain, shallow and moderate, weathered pediplain - shallow and moderate and laterite plain. The denudation process is active in these landforms. The denudation hills are formed, due to differential erosion and weathering, so that, a more resistant formation or intrution stand as mountains / hills with varying hard rock lithology. The groundwater prospects in inselberg are poor. Pediment is gently sloping and smooth. There will be no geologic structures over the terrain. The lithology is mainly laterites as capping over granite or meta sediments. Groundwater prospects will be poor since the capping is compact and impermeable.

Landforms of Fluvial origin

The characteristics of each geomorphic unit of fluvial origin are detailed. Valley fills are unconsolidated sediments, deposited by streams /rivers normally in a narrow fluvial valley. Depending upon the thickness of the fill, the occurence of groundwater varies; these units are promising for groundwater exploration. Alluvial plain is formed by extensive deposition of alluvium by major river systems. This unit is normally flat/gently undulating surface.These units constitute gravels, sand, silt and clay of varying lithology of sedimentary origin. Silt will be the dominating lithology. The flood plain in Pambar Kottakkaraiyar basin exists along the lower reaches of rivers. Deltaic plain with backwater is a gently sloping plain of large extent of area with thick sediments in fan shape, normally formed at the end of the river course.

Coastal Landform

The coastal plain is a regional land of low relief bounded seaward by the shore and landward by highlands, mainly formed due to coastal action. The lithology in Coastal Plain are sand, silt and clay. Groundwater in coastal alluvial aquifers are saline. The quality of ground water is saline except the groundwater occurring as perched water table. Tidal flat is a widened flat surface parallel to coast, and primarily comprise of unconsolidated materials like gravels, sands and silt with fine texture. The quality of water is poor / saline. Swale is a geomorphic unit of coastal origin. It is a shallow depression, sometimes swampy, in the midst of generally level land in an undulating ground. It is a long, narrow shallow trough like depression between two beach ridges and aligned roughly parallel to the coastline.

The major geomorphological units of Pambar – Kottakarayar basin is presented in **Figure 1.4.**

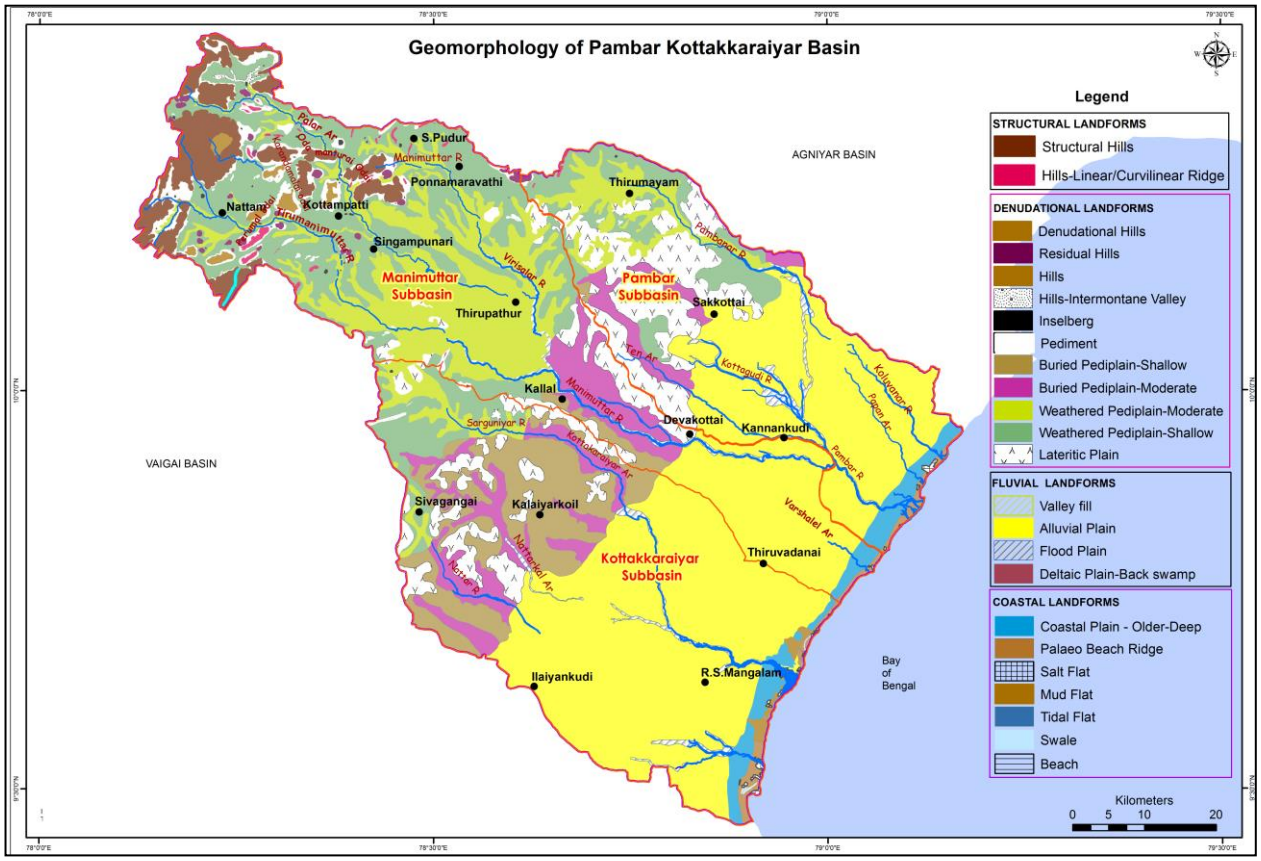


Figure 1.4. Geomorphology of the Pambar - Kottakaraiyar aquifer system

1.7. Land use and Land cover

The land use study of Pambar Kottakkaraiyar basin reveals that built up land comprises of rural and urban settlement pattern, industries, etc and appears in the imagery as a lighter tone. Built up land category covers an area of 154.76 sq.km, constituting 3.58 percent of the total geographical area. Agricultural practices are observed in major parts of the basin. 2656.5 sq.km area comes under agricultural land constituting about 60.45 percent of the total area. About 1063 sq.km area is under cultivable waste and forests, comprising about 24.6 percent of the total area and 423.5 sq.km area covered by water bodies, constituting 10.4 percent of total geographical area. About 43.2 sq km area falls in other category with 1 percent representation of the total geographical area. **(Figure 1.5)**

Surface water and groundwater are conjunctively used in this basin for irrigation. Paddy, banana and sugarcane are the major wet crops and sesame, groundnut, cholam, ragi etc are the major dry crops. Wet crops cultivation is done in around 1754.52 sq.km and dry crops in 514.25 sq.km. The area of cashew plantation is 31.58 sq.km and the groves are about 314.78 sq.km. Fallow land occupies an area of 1063.01 sq.km and salinity is observed in an area of 24.6 sq.km. Water bodies (tanks, ponds, and wet land/swamp) cover an area of 423.5 sq.km, all the water bodies have full capacity with large water spread area.

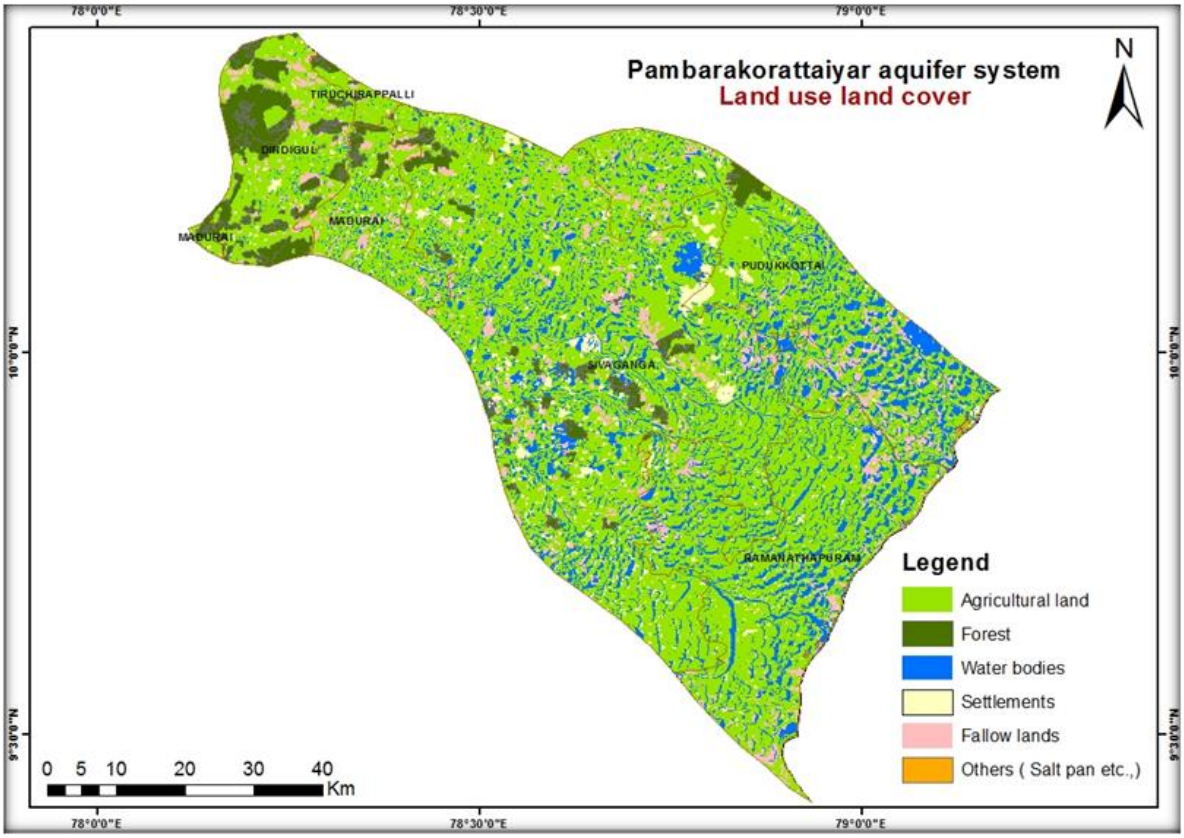


Figure 1.5. Land use/Land cover (level 3) of the Pambar - Kottakaraiyar aquifer system

1.8. Soils

Soils play a major role in hydrologic control of the infiltrating water. Soils are generally classified according to their colour, texture, fertilities and chemical combinations includes salts, minerals and the solution effect over them. The major soil types in the study area are red soil, black cotton soil, sandy loam and forest loam **(Figure 1.6).** Red soils 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 westward side. The red soils are suitable for agricultural purposes and hold moderate groundwater reserves.

Black cotton soil is clayey soil with high specific water retention capacity but poor in supporting agriculture. The rate of infiltration varies is very low in black cotton soil and the infilteraton values are ranges of 1 to 3 cm/hr. Sandy loam is alluvial soils comprising sand and sandy materials occurring on the beaches and 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. Forest loam is found where the area is covered by forest and reserve forest.

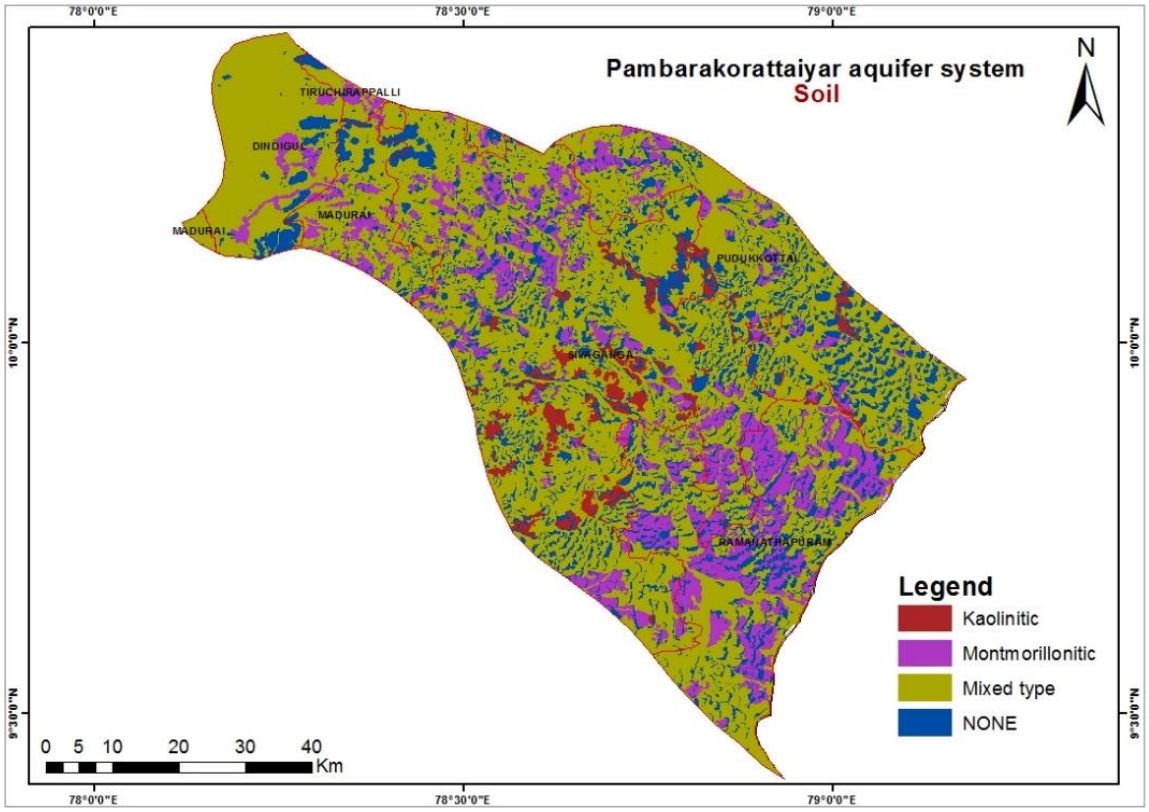


Figure 1.6. Soils of Pambar - Kottakaraiyar aquifer system

1.9. Slope

The slope of any terrain has a vital role in determining 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 facilitates high runoff allowing less residence time for rainwater to percolate. The DEM map of study area was prepared from the Cartosat DEM of 30 m spatial resolution **(Figure 1.7).** The elevation ranges in between +916 m MSL and 1.5 m MSL. The highest elevation place is observed at Jandamedu in Karandamalai reserve forest. The lowest elevation (+1.5 m) place is observed at south east of Tirupunavasal. There are several hills with their peak above +400 m MSL in the north, northeast, west, southeast and southwest parts of the basin and most of the hills are covered by reserved forests, viz., Ayyalur reserved forest ▲826 m, Mudumalai reserved forest ▲910 m and Kodangikutta reserved forest ▲673 m in the northern part of the basin. Vella malai reserve forest ▲697 m, Viramalai reserve forest ▲227 m, Punnamalai reserve forest ▲240 m, and Tottumalai reserve forest 143 m and Singirai reserve forests are in the northeastern part of the basin.

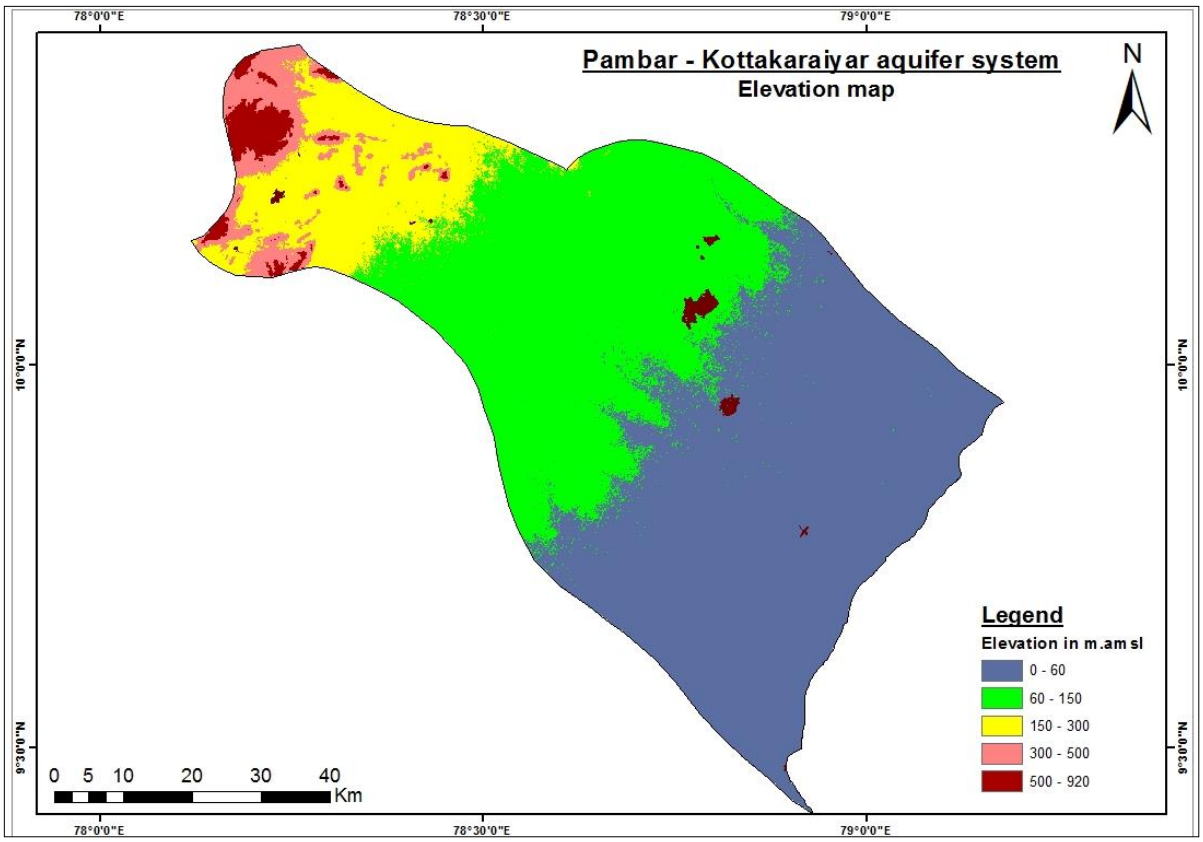


Figure 1.7. DEM of the Pambar - Kottakaraiyar Aquifer system

1.10. Agriculture

Agriculture is the main stay of the rural population in the entire study area. Data collected from Dept. of Statistics, Govt of Tamil Nadu (2019), Agricultural land occupies nearly 2656.5 sq.km i.e., 60.5% of the Pambar - Kottakaraiyar aquifer system area and spread throughout the basin with main water intensive crops irrigated which are paddy, sugarcane and banana covering about 1754.52 sq.km**.** The less water intensive crops irrigated are maize, tomato, groundnut, chilly and Jasmine. The other crops include cotton, ragi etc., and other minor crops are, turmeric, flowers and vegetables. Apart from this under plantation category Cashew planatations and Coconut, Mango and other trees come under groves category. The cropwise distribution of area in Pambar – Kottakaraiyar are presented in **Figure 1.8.**

The forest lands include reserve forest and open forest. Some of the land area is not suitable for either agriculture or for any other uses. Such land are unproductive due to the alkaline nature of the soil. Such types of landforms are also observed in the basin.

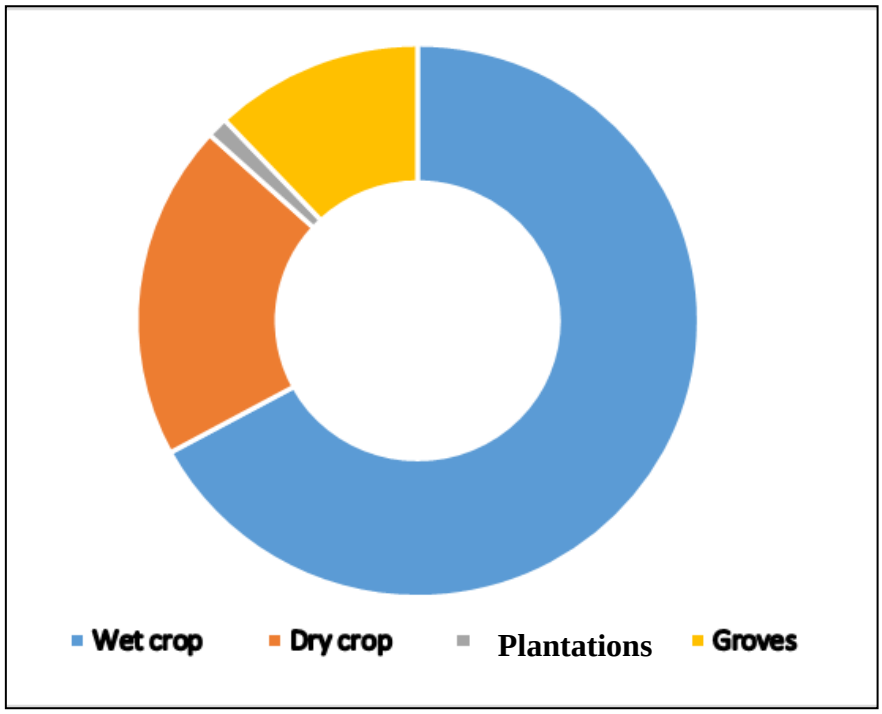


Figure 1.8. Crop-wise distribution in Pambar - Kottakaraiyar aquifer system

1.11. Irrigation

The total area irrigated under different crops is 1754.5 sq.km, out of the total geographical area of 4323 sq.km which accounts for 60.45%. Paddy is the main water intensive crop in the study area. Total requirement of water for irrigation is met from surface and groundwater resources. Total groundwater resources available for the entire basin is 811.9 MCM and agricultural demand is 1460.0 MCM. The remaining water demand is met through surface water resources. The total surface water available in the basin in tanks are about 648.0 MCM.

There is no major reservoir in this basin. The surface water is drawn for agricultural usage from tanks. About 7602 surface water tanks are available in the basin. The Raja Singa Mangalam tank of this basin is one of the biggest tanks in Tamil Nadu. Its bund is 20.8 Km long and has two large masonry weirs on either flanks to harness surplus flood flows. The Northern flood surplus flow of Rajasinga Mangalam tank is called Kottakaraiyar and the southern flood surplus flow of the tank is called Uppar River.

1.12. Geology

The geology of the Pambar-Kottakkaraiyar basin is primarily based on the maps published by the Geological Survey of India, interpretation of satellite data and the inferences derived from the lithology of investigation boreholes. The Pambar Kottakkaraiyar basin is bifurcated to two regions characterised by hard and soft rocks and delinated by a contact zone traversing in the middle of the basin. **(Figure 1.9)**

Hard rock formations occur in the upper reaches of the basin. The Hard rock region is comprised of Archaean complex suit. In Archaean crystalline rocks, the main rock types are Quartzite, Charnockite, Gneiss, Migmatite, Granitic and acidic rocks. Gneiss is the

predominant rock type among them which covers most of the hard rock region. Hornblende biotite gneisses widely occur in this area. Garnetiferous silimanite gneisses occur north east of Palakkurichi within the granite gneisses. Large bands of Quartzites are found in the western part near Nattam. Also isolated band is found north of Sivaganga. Migmatite is found in the northern portion of the basin in a small region. Charnockite is found mainly in the western portion and as a small patch in the eastern side. Also isolated occurrence of Charnockite is found along with quartzite in the hills located in the north of Nattam. Granitic rocks are found in both western and eastern side of the hard rock region.

Large massive pink granites, parallel to the foliation of gneissic rock occur south east of Nattam. Amphibolites and pyroxene granulites are found as xenoliths and occur as thin bands within gneisses, charnockite occurrences are found in Perumamalai and Manikampatti. Calc. gneisses and granulites occur sporadically in the Perumamalai hilly area along with Quartzites, isolated occurrence of crystalline limestone is occurs 5km east of Perumalmalai. Quartz are intruding the gneisses and Charnockite. They are found to occur at Ayittapatti and Kodukkonanpatti, south of Nattam. Quartz veins in Perumamalai and around Sendurai grades into rose quartz type. Highly weathered spheroidal gneissic rocks are found near a quarry in Nemathampatty.

In the lower reach of the basin, towards east and south to the contact zone, soft rock types makes the prominent lithology. Soft rock is comprised of Upper Gondwana sediments known as Sivagangai formation, Cuddalore formation and Gondwana formation known as ‘Sivaganga beds’ of upper Jurassic age overlies Archaean crystalline, not crop out on the surface anywhere in the basin Pudur, Sathanikottai, Andavurani, Tiruvadanai and Neyvayal, etc. Cuddalore formation crops out at Devakottai overlained by coarse grained sandstones, grits with clays and shales.

In the soft rock region, three prominent litho units comprising of altered sequence of sand, silt and clay makes successive layers from the contact zone towards south east. The sedimentation thickness increases from West to East.

Precambrian Rocks

The hard rocks include granite, gneissic complex, schists and chamockites associated with basic and ultra-basic intrusive. The gneissic rock constitutes the major rock type in the hard rock formations followed by Charnockite, Grantie, Quartzite and other intrusive rocks. These formations are highly compact and devoid of secondary porosity.

Intrusive rocks

A N30°E-S30°W trending, dark coloured continuous ridge of dolerite dykes are common in many places in the aquifer system. It is fine grained and shows multiple closely spaced joints (cooling cracks). The exposures are generally bouldery and weathered into reddish soil. Pegmatite and quartz veins occur as thin stringers cutting all the rock types of the area. Along zones of structural weakness such as shear and fault zones the density of quartz veins is more.

Table - 1.3. Geological succession of the Pambar - Kottakaraiyar Aquifer System

Group	System	Lithology	Groundwater relevance
Quaternary	Recent – Sub-recent	Soils, coastal /river Alluvium (sand & silt), Black Clay, Laterite	Moderate to very good porous aquifer system
Tertiary	Cuddalore Sandstone	Sandstone and shale	forms good aquifers
Mesozoic	Upper cretaceous Lower cretaceous	Calcareous Sandstone, arenaceous Limestone and Clay Sandstone with Shale.	Very low Porous aquifer.
Proterozoic	Sivaganga Beds (Upper Gondwana)	Shale and Sandstone Basel Boulder bed	Very low Porous aquifer.
Azoic	Archaean	Charnockites, Granites, Gneisses.	Weathered and Fractured Aquifer units.

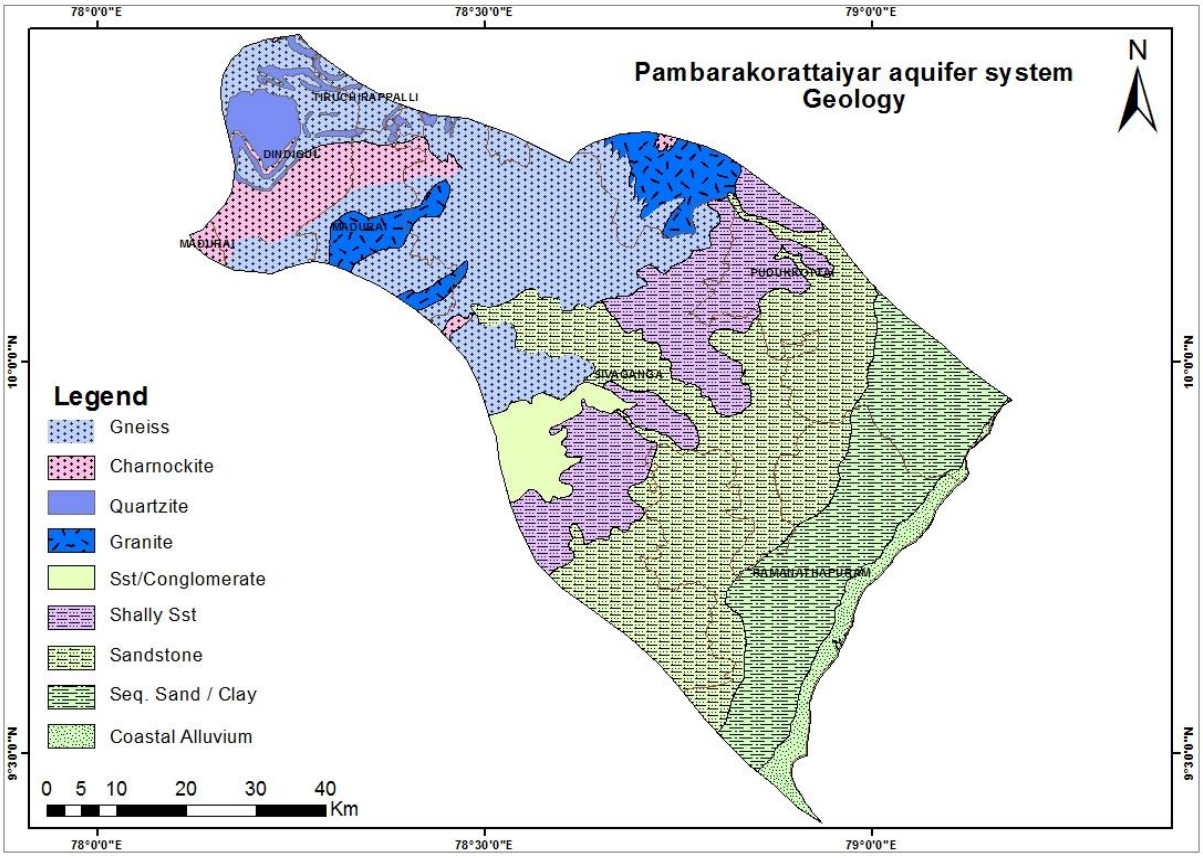


Figure 1.9. Geological map of Pambar - Kottakaraiyar Aquifer system

Upper Gondwanas

The formations comprise friable, white, speckled and reddish-brown mottled quartz grit, friable quartzose grits, which are white and brownish in colour becoming whiter at lower depths. Coarse laterite capping changes with depths into reticularly cellular, sandy clay grits. The formations are of very low porosity and permeability.

Upper & Lower Cretaceous

Major formations comprise of Calcareous Sandstone, Arenaceous Limestone and Clay in Upper Gondwana and Sandstone with Shale in Lower Gondwana. This bed consists of a mixture of rounded to sub-rounded boulders, cobbles, pebbles and gravel in a clayey sandy matrix and partly compacted. The formations are characteristic of very low porosity and permeability and forms poor aquifers.

Cuddalore Sandstones.

The Cuddalore formation of the Tertiary comprises of alternate bands of sand and clay. Sand is well sorted, rounded and loosly packed. The rocks belonging to this period have been assigned to the Miocene-Pliocene (Cuddalore) series but no fossil evidence of age has been found. This formation forms potential aquifer in the basin.

Quaternary

Laterite: The Tertiary friable sandstone and Gondwana series are commonly capped by scoriaceous and pisolitic laterite. It is noticed around Thrirukkazhikundram area. Its thickness ranges from 1.50 to 6.5 m and it occurs in the central portion of the study area with spatial distribution of around 38 sq.km

Alluvium

The youngest formations in the area are the alluvium, which was deposited on the worn-down and eroded surface of Tertiary. The alluvium consists of gravel, fine to coarse sand, clay and sandy clay of various shades of grey and brown. Commonly, the different types are intercalated (or) dovetailed in the form of lenses and pockets which point out the erratic geometry of the deposition, caused by the migration and varying flow velocities of old rivers. The wind deposited sand, in the form of irregular, low flat dunes ranging in width from less than 0.1 km to about a kilometer occur all along the coast, except where they are interrupted by the river outlets.

2.0. DATA COLLECTION AND GENERATION

After the data gap analysis, additional key wells establishment, water sample collections and other hydrogeological data are collected in field. During aquifer mapping studies, periodical data pertaining to groundwater levels, quality, pumping tests and slug tests were collected. In addition, geophysical data has been generated through conducting geo-electrical soundings after evaluation of data gap analysis. The data collected are synthesised and analysed for aquifer mapping studies.

2.1. Water level data

The periodical monitoring of groundwater levels 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 the Pambar - Kottakaraiyar Aquifer system area, 96 groundwater monitoring wells of CGWB and State department wells and 65 piezometers of CGWB (58 shallow and 7 deep) were monitored periodically. To fill data gap in the basin, 50 additional wells were established and monitored periodically during the pre and post monsoon period during the aquifer mapping study. This was useful to record the temporal and spatial changes in the aquifer system. The locations of monitoring wells are given in **Figure 2.1.**

2.2. Water Quality data

The groundwater quality of the Pambar - Kottakaraiyar aquifer system was studied by collecting water samples from dug wells and bore wells. Groundwater samples were collected from 28 locations, the sample locations in the Pambar - Kottakaraiyar aquifer system is presented in **Figure 2.2.** In addition to exisiting water quality details with CGWB, groundwater quality data has been collected from TWAD Board and State Ground and Surface Water Resources Data Centre (SG&SWRDC), Government of Tamil Nadu.

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 area is to decipher the sub surface conditions such as weathered and fractured layer resistivity and thicknesses and massive formations up to the depth of 200 m. A total number of 125 VES were carried out and geo-electric layers inferred through interpretation of the results obtained. The locations of the VES are presented in the following **Figure 2.3**. The interpreted VES data are used in preparing aquifer disposition and other hydrogeological intrepretation during the study.

2.4. Groundwater Exploration data

Data of 120 exploratory wells drilled in the Pambar - Kottakaraiyar aquifer system (86 Nos. CGWB and 34 Nos. State department wells) prior to National Aquifer Mapping project were compiled and analysed **(Figure 2.4).** Based on the data requirements, 12 Nos. of exploratory wells includes 9 wells in hard rock and 3 wells in soft rocks 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. Similarly wells drilled by state department, 34 Nos. wells drilled upto to the depth of 60 to 100 m bgl were used for deciphering the first aquifer.

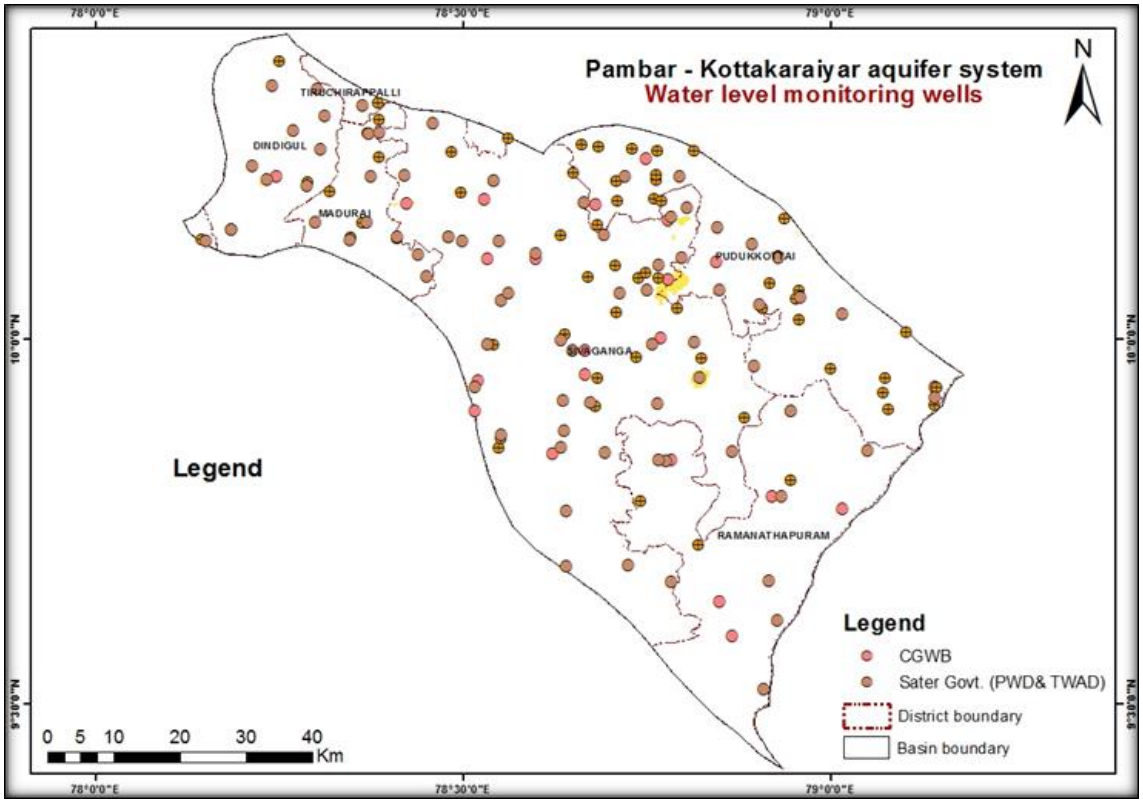


Figure 2.1 Locations of Groundwater Monitoring Wells

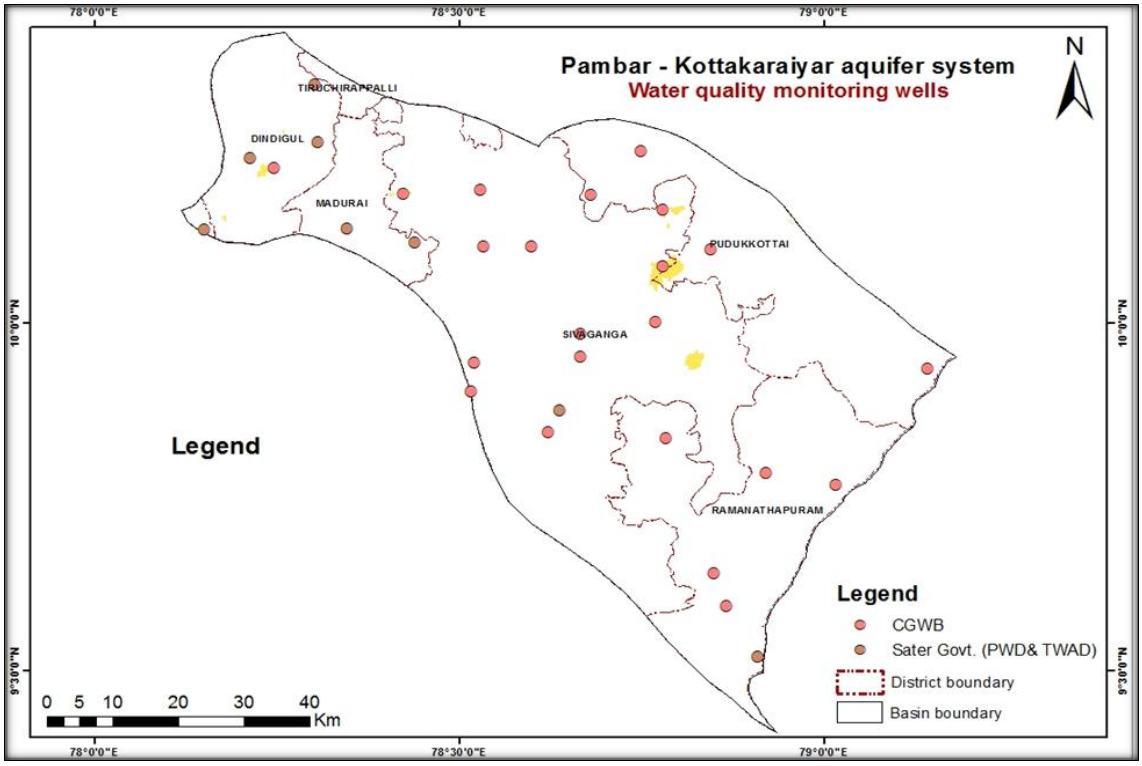


Figure 2.2. Locations of Groundwater quality Monitoring Wells

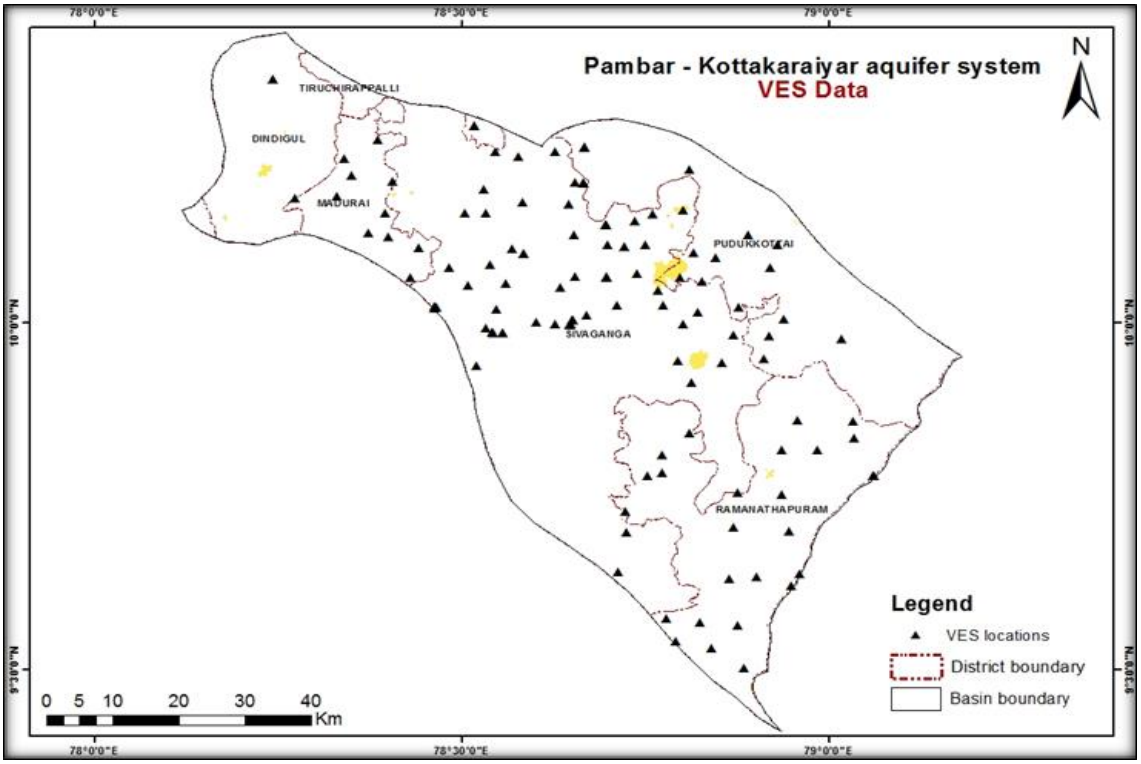


Figure 2.3. Locations of Vertical Electrical Sounding sites

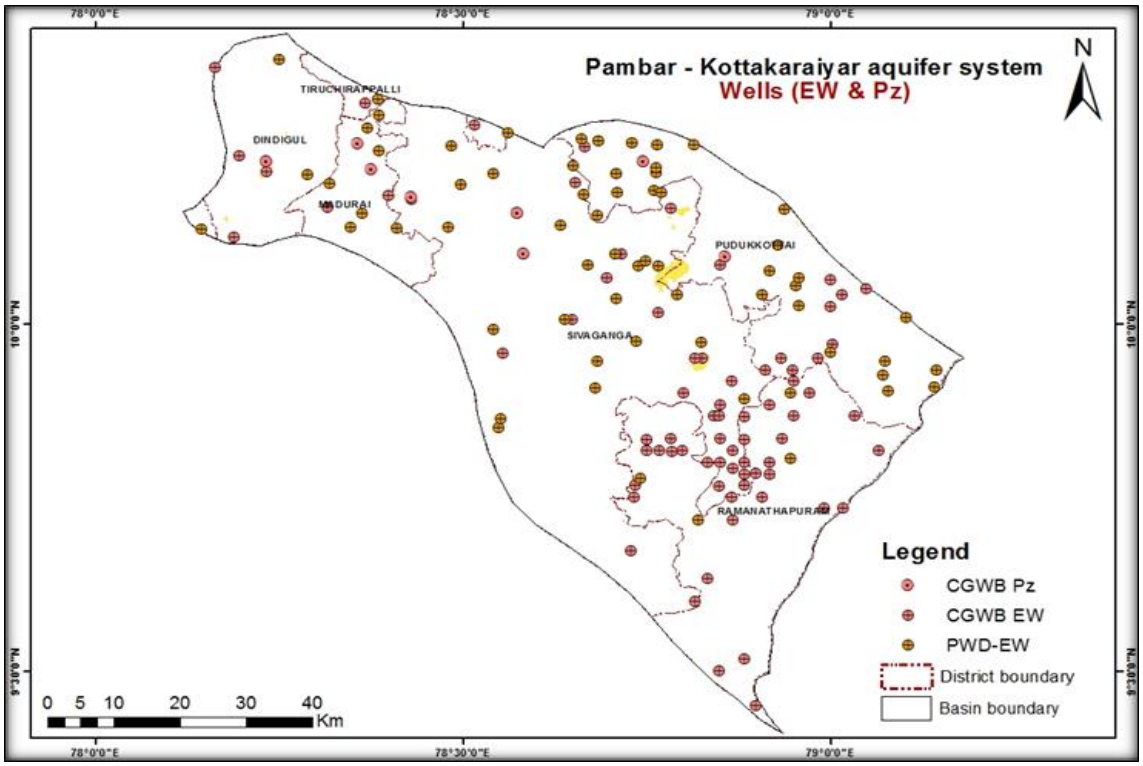


Figure 2.4. Locations of all Exploratory Wells

3. 0 DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

3.1. Hydrogeological Data Interpretation

I. HARD ROCK REGION:

Hard rock region comprising of gneissic, charnockite, quartzite and other intrusive rocks is found in the Pambar - Kottakaraiyar aquifer system. The Gniessic formation and Charnockites formation (hard rocks) form two aquifer units namely the weathered and fracture/jointed aquifer unit. The details of hard rock aquifers (Aquifer unit I - Weathered and Aquifer unit II – Fractured) are described below.

Aquifer Unit I – Weathered

The weathered aquifer unit occurs from the groundwater level and has a minimum thickness of 5 m and maximum thickness of 20 m with average thickness of 12 m. 2D disposition along west to south east **(Figure 3.1.)** clearly shows the vertical and lateral distribution of the gneissic and charnockitic formations. Yield of this weathered aquifer unit ranges from 1.5 to 20 m^3/hr. During monsoon period the wells tapping this aquifer unit sustain pumping for 2 to 4 hrs/day while during non-monsoon period (April to June) sustains for less than 1 hour/day. Groundwater occurs in unconfined condition. The aquifer parameter such as transmissivity in this aquifer unit ranges from 1.0 to 22.4 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 640 to 4380 µS/cm and is suitable for domestic uses.

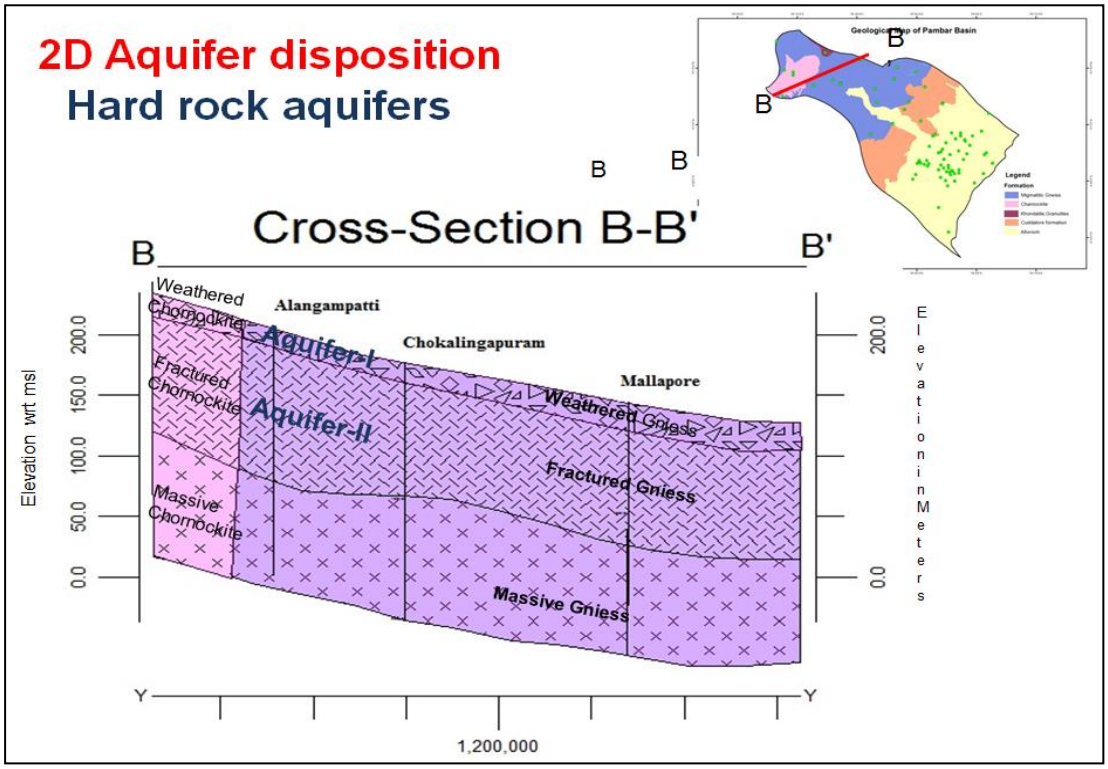


Figure 3.1. 2 dimension aquifer disposition of hard rocks

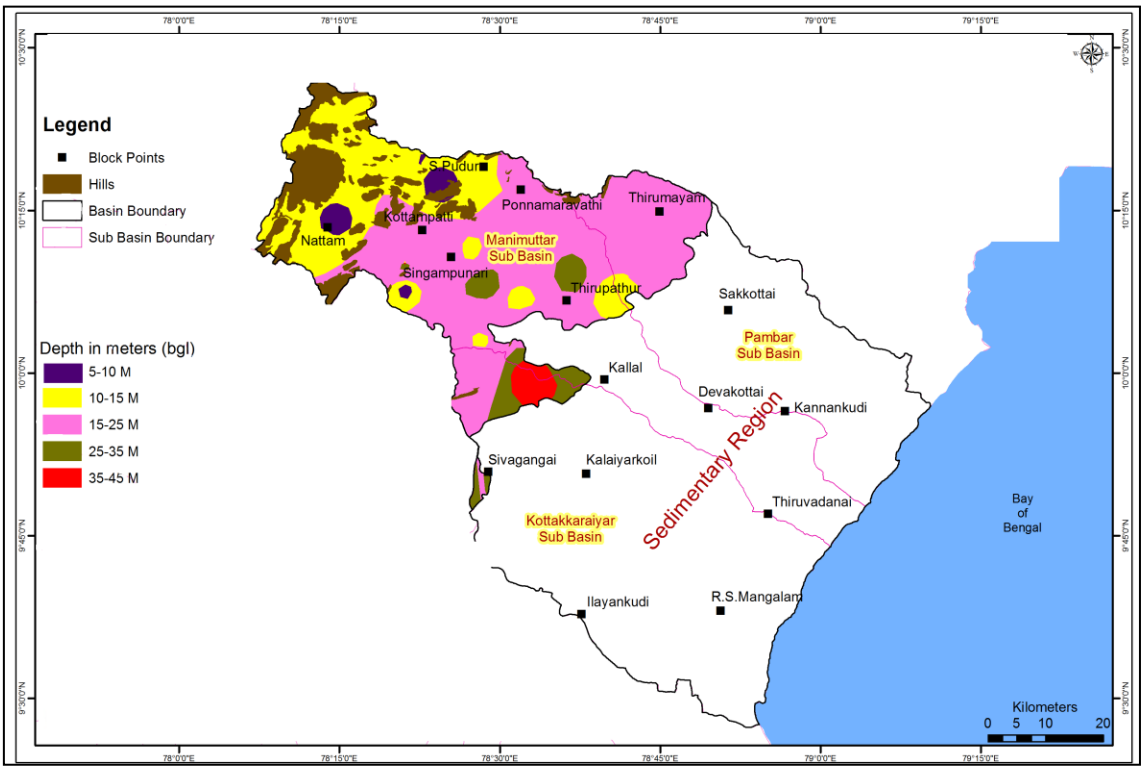


Figure 3.2. Weathered thickness map of hard rock aquifers

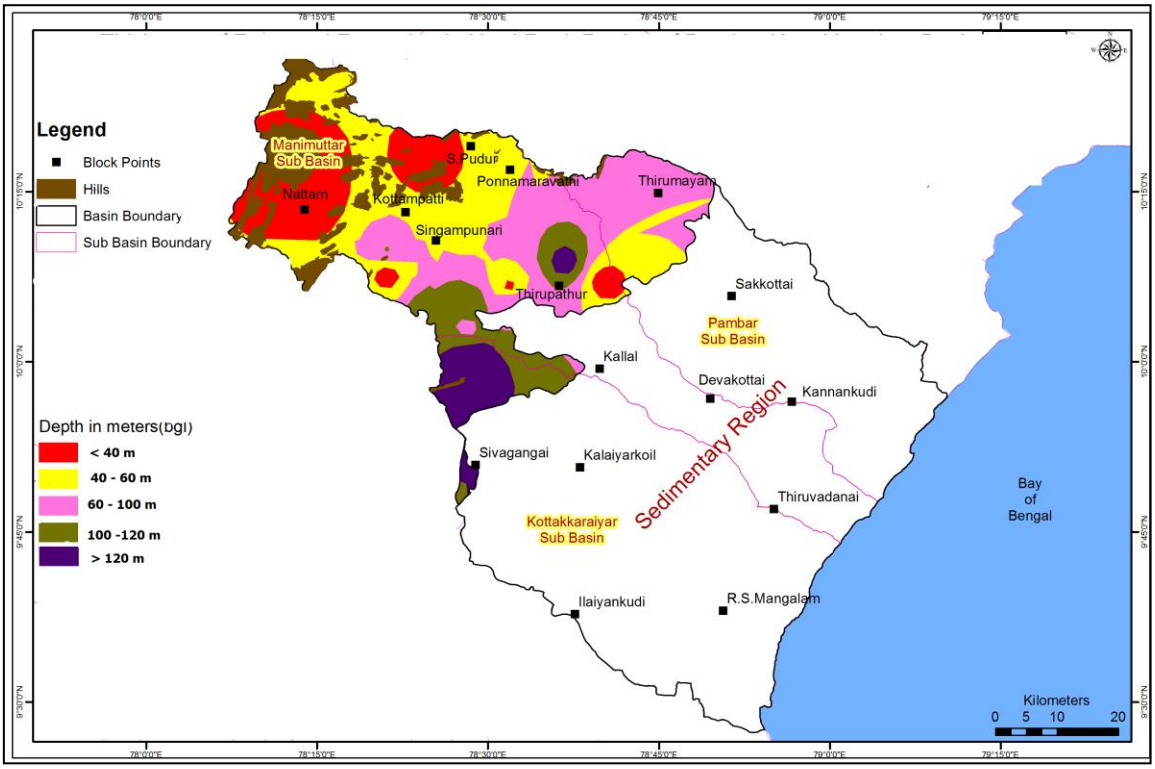


Figure 3.3. Fractured aquifer thickness map of hard rock aquifers

Aquifer Unit II (Fractured/Jointed):

This aquifer unit comprises of fractured and jointed gneissic, charnockites other intrusives formed due to tectonic activity. Top of this aquifer unit occurs from 12 to 30 m bgl. Based on the analysis of the 120 wells it is observed that there is a possibility of occurrence of 3 to 4 fractures/joints exists upto 180 m bgl in the gneissic region. In Charnockite regions 3 to 4 fractures are likely to be encountered and they exist only upto 120 m bgl. The yield of this aquifer unit II ranges from 1 to 51 m^3/hr. During monsoon period the wells tapping this aquifer unit sustains pumping for 3 to 5 hrs /day while during non-monsoon period (April to June) sustains for 1 to 3 hour/day. Transmissivity of this aquifer unit ranges from 1.2 to 140 m^2/day.

II. SOFT ROCK REGION:

Aquifer Unit I (C1); Alluvium and Cuddalore sandstone:

Aquifer Unit – I is a phreatic aquifer or Water table aquifer. This aquifer unit is composed of recent river alluvium, Coastal alluvium, Cuddalore sandstone and laterite formations. The thickness of the Aquifer Unit-I varies from 5 to 40 m in the area covered by river alluvium, about 30 to 50 m thick in the area covered by coastal alluvium and it is about 10 to 20 in area where the Cuddalore sandstone are exposed to the surface. The thickness of the aquifer unit I is less in the western portion and gradually increases towards east near the coast. The groundwater abstraction from the aquifer is mostly by dug wells and shallow tube wells. The diameter of the dug wells ranges from 0.8 to 4 m and the depth ranges from 3 to 25 m below ground level (mbgl). The dug wells are energized mostly by electric pumps and the groundwater extracted is mainly used for irrigation and domestic purposes.

The depth to the water level of the phreatic aquifer ranges between 0.8 and 18 mbgl and yield varies in different formation. Yield of the aquifer unit in the river alluvium varies from 2.4 to 65 m3 /hr. whereas in coastal alluvium area the yield varies from 39-132 m^3/hr and the yield varies from 3.5 to 7 m^3/hr in the phreatic unit of Cuddalore sandstone formations. The transmissivity of alluvial formation ranges between 210 and 1500 m^2/day and the specific yield ranges between 12 and 18 %. Whereas the transmissivity of Cuddalore sandstone formation ranges between 350 - 2500 m^2/day and its specific yield ranges between 8 to 13%.

Groundwater Quality in Phreatic Aquifers

The waters are generally alkaline with pH ranging from 7.0 – 8.15. The chemical quality of ground water in general is good and potable except in the coastal part of the aquifer system. i.e. in coastal part of Ramanathapuram, Sivagangai and Pudukottai districts the groundwater is saline. The quality deteriorates in eastern and south-eastern coastal part of the aquifer system.

A perusal of the iso-conductivity map **(Figure 3.4)** reveals that good quality groundwater with EC less than 750 micro siemens/cm at 25°C occur in the firkas of Embal, Kannangudi, Devakottai Puzhiyal, Saruguni Kalayarkoil and Nattrasankottai. These firkas are mainly covered under recent river alluvium. In the area covered by coastal alluvium i.e. firkas like R.S. Mangalam, Sholandhur, Thodi, Pulur, Mimisal, Ponpette and Mangalgudi. The groundwater quality is moderate with EC value of 2000-3000 micro siemens/cm.

High salinity with Electrical Conductivity (EC) more than 3000 microsiemens/cm at 25° C in ground water has been observed in parts of Sivagangai and Ramanathapuram district covering firkas like Ilayankudi, Sarugani, Mangalagudi, Thiruvadanai, Mimisal and Pullur areas. The

very high salinity with Electrical Conductivity (EC) of more than 5000 micro siemens/cm at 25°C in ground water has been observed in Avudadayarkoil, Mimisal, Thiruvadanai and Thondi areas.

The chloride in water is also having essentially the same distribution as that of Electrical Conductance in the area. Chloride concentration exceeding permissible limit of 1000 mg/l are seen in coastal aquifers in Sivaganga and Ramanathapuram districts. R.S. Mangalam, Thondi, Mimisal and parts of Anandhur and Puzhiyal firkas. **(Figure 3.5)** This may be due to the washing of salt from the upstream and also due to the insitu salinity of the formation.

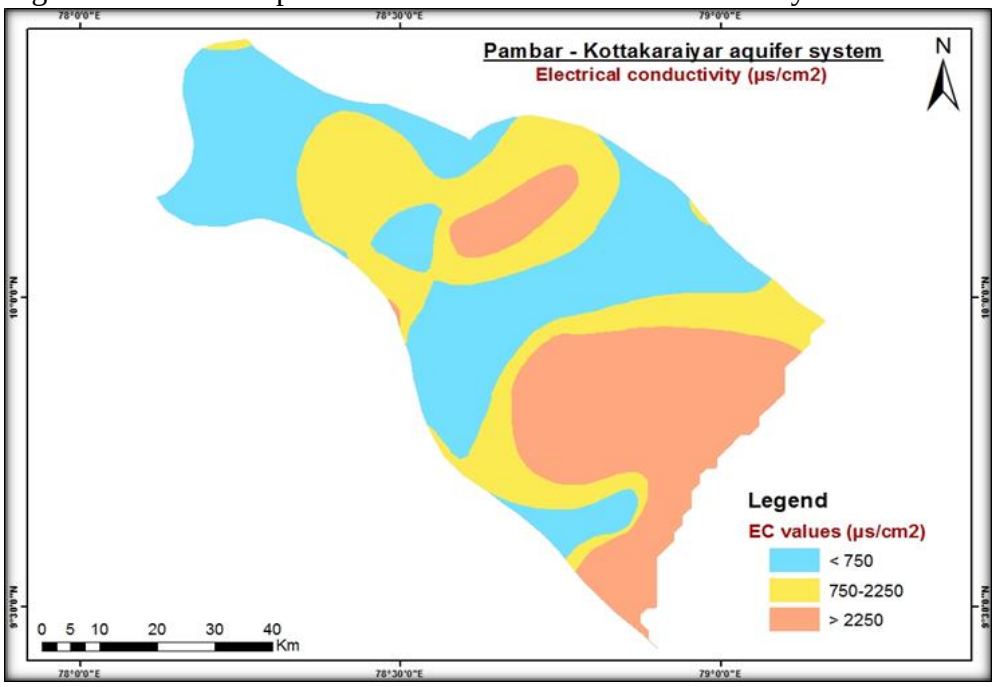


Figure 3.4 Distribution of Electical conductivity in phreatic aquifers (aquifer Unit I)

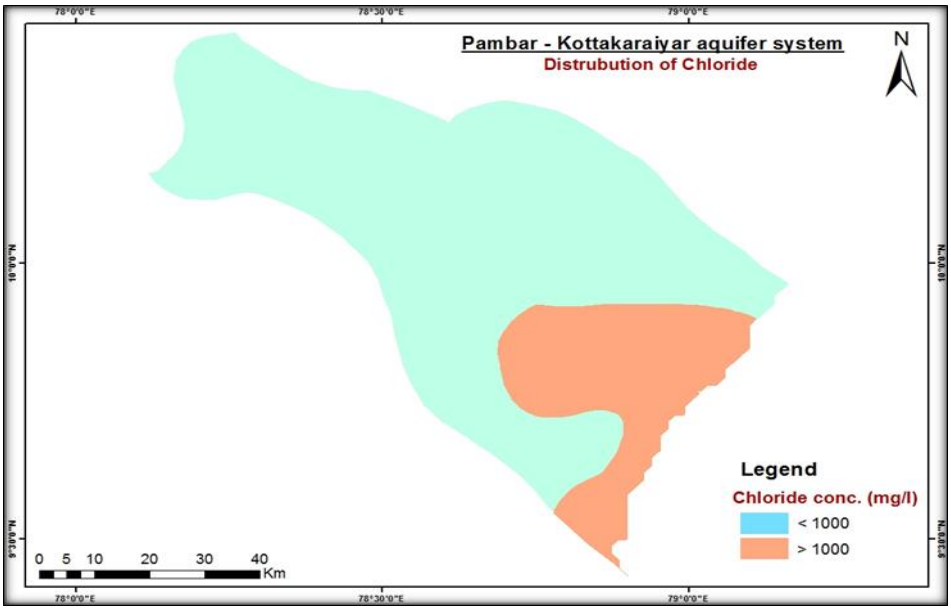


Figure 3.5. Distribution of Chloride ions in phreatic aquifers (Aquifer Unit I)

Aquifer Unit II (C2): Tertiary sandstone

Tertiary sandstone of the Pambar - Kottakaraiyar aquifer system consists of Cuddalore formation and Eocene formation.

Cuddalore Sandstone

Cuddalore Sandstone comprises of argillaceous sandstone, pebble bearing sandstone, ferruginous sandstone, grits and clay beds and are whitish, pinkish, reddish in colour which are friable in nature. The sands and sandstones of Cuddalore formations of Mio-Pliocene age comprise of fine to very coarse grained and are sub-angular to sub-round in shape, occasionally with rounded pebbles of quartz with diameters even upto 3 m. The Cuddalore sandstones occur beneath the alluvium formation and in place where alluvium formations are absent, they are exposed on the surface. The sandstone formation which lies below the unconfined unit of Cuddalore formation forms the aquifer unit II (C2) which is confined in nature. The clay layers separating the unconfined and confined unit of the Cuddalore sandstone are discontinuous at many places. The depth of occurrence of aquifer unit II is between 20 and 60 m bgl with thickness varying from 68 to >300 m. The thickness is less in the western portion and gradually increases towards east. Clay occurs as intercalations within the sandstones at some locations

The groundwater abstractions from the aquifer are by shallow tubewells, depth ranges from 40 to 80 mbgl and are energized by electric submersible pumps which are mainly used for irrigation and industrial purposes having EC < 2500 microseimens/cm. The piezometric level of the confined aquifer ranges between 15 and - 10 m with respect to mean sea level (msl) having yield between 10.8 to 66.6 m3 /day. The major source of recharge to the aquifer is rainfall and leakage from unconfined aquifer. The transmissivity ranges between 5 and 3615 m2 /day and storativity between 1.2 x 10 -3 and 4.1 x 10 -4 respectively. The chemical quality of groundwater from the Cuddalore sandstone aquifers is of the sodium-chloride type. The degree of mineralization of waters is high in the Ramanathapuram and Pudukottai Districts. Quality data of groundwater exploration of Cuddalore sandstone aquifers reveals that the E.C. values range from 3820 to 15540 micro seimens/cm. The mineralization of groundwater in the aquifer unit progressively gets concentrated from west to east in the boreholes. Groundwater in the western part of the Ramanathapuram is of Na-Cl-HCO3 type.

Eocene Sandstone

The Eocene formations composed of sandstones are made up of fine to coarse grained sand and pale grey in colour with occasional clay intercalations. Similar to the Cuddalore sandstones, Eocene sandstones are also friable in nature. They are shallow in the central part and deeper in the eastern part towards the sea. The occurrence of these formations is restricted to the eastern part of the Pambar - Kottakaraiyar aquifer system and found at a depth of 50 to 120 m below mean sea. In the eastern part the Eocene formations are found in greater depth. The Eocene sandstone formation forms aquifer which is confined in nature. The thickness is varying from 40 to 85 m. The groundwater in this aquifer unit is abstracted sparely for irrigation activity. Since last decade, tubewells have been constructed by farmers to tap groundwater from this aquifer for irrigation activity. This aquifer unit is highly potential and its yield varies from 65 to 85 m^3 /hr. The groundwater quality of this aquifer is good and fit for drinking, domestic, agriculture and irrigation purpose as the EC values ranges from 600 to 2200 microseimens/cm.

The transmissivity of the aquifer unit range between 300 and 2750 m^2 /day and the storativity ranges between 1.6 x 10^{-4} and 2.9 x 10^{-5} .

Aquifer Unit III (C3 Cretaceous sandstone)

Cretaceous sandstone which consists of litho units viz the top units of marker fossiliferous sandstone, which is flesh red in colour and compact in nature and the bottom consists of pinkish and greyish sandstone intercalated with clay and shale. These form the Aquifer unit III in the sedimentary area of the Gundar aquifer system and it occurs only at subsurface. Aquifer Unit III lies below the Aquifer unit-II and separated by confining clay layer which is discontinuous in many places. The Aquifer Unit-III occurs at a depth of 88 to 150 m bmsl. The thickness is less in the western portion i.e 40 m and gradually increases towards east extending more than 200 m. The groundwater abstraction from the aquifer through tubewells constructed to the depth of 220 to 350 mbgl.

The Aquifer Unit-III is highly potential and yields 55 to 85 m3 /hr. The transmissivity of aquifer varies from 50.25 to 604.00 m^2 /day with field permeability ranging from 2.810 to 27.00 m/day. Storage co efficient values as computed are indicative of confined condition of the aquifer and ranges from 5.54x10-4 to 2.72x10-5 . Further the pump test conducted in this area has brought to light the existence of barrier boundary conditions. For instance the pumping test conducted in the exploratory wells at Tiruvadanai, Pandakudi, Mandathukottai in adjoining Sivagangai district. The drawdown is rather high indicative of their proximity to the barrier boundary, thereby marking the limit of the extent of the confined aquifer.

3.2. Aquifer Maps

3.2.1. Aquifer Disposition

Based on the lithologs of the exploratory wells, VES data and the well inventory details collected during field studies as part of Aquifer Mapping studies, 3D **(Figure 3.6)** and 2D models **(Figures 3.7 to 3.10)** of the aquifer system of the basin has been deciphered by using Rockworks software. The data input for Rockworks is prepared in rockworks table format to generate 2D models of the basin along different selected sections.

*

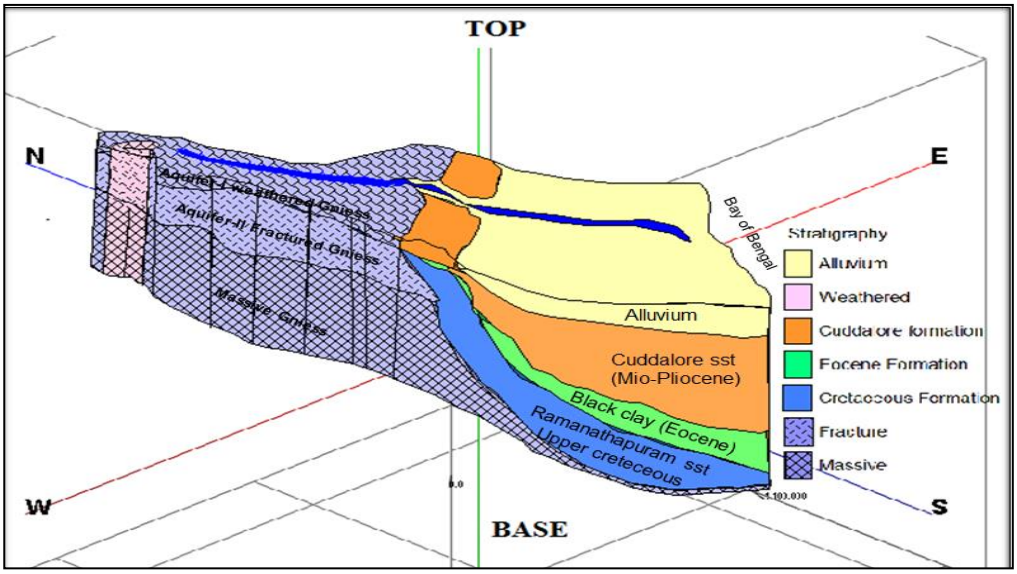


Figure 3.6. 3 Dimensional spatial distribution of the Pambar - Kottakaraiyar aquifer system.

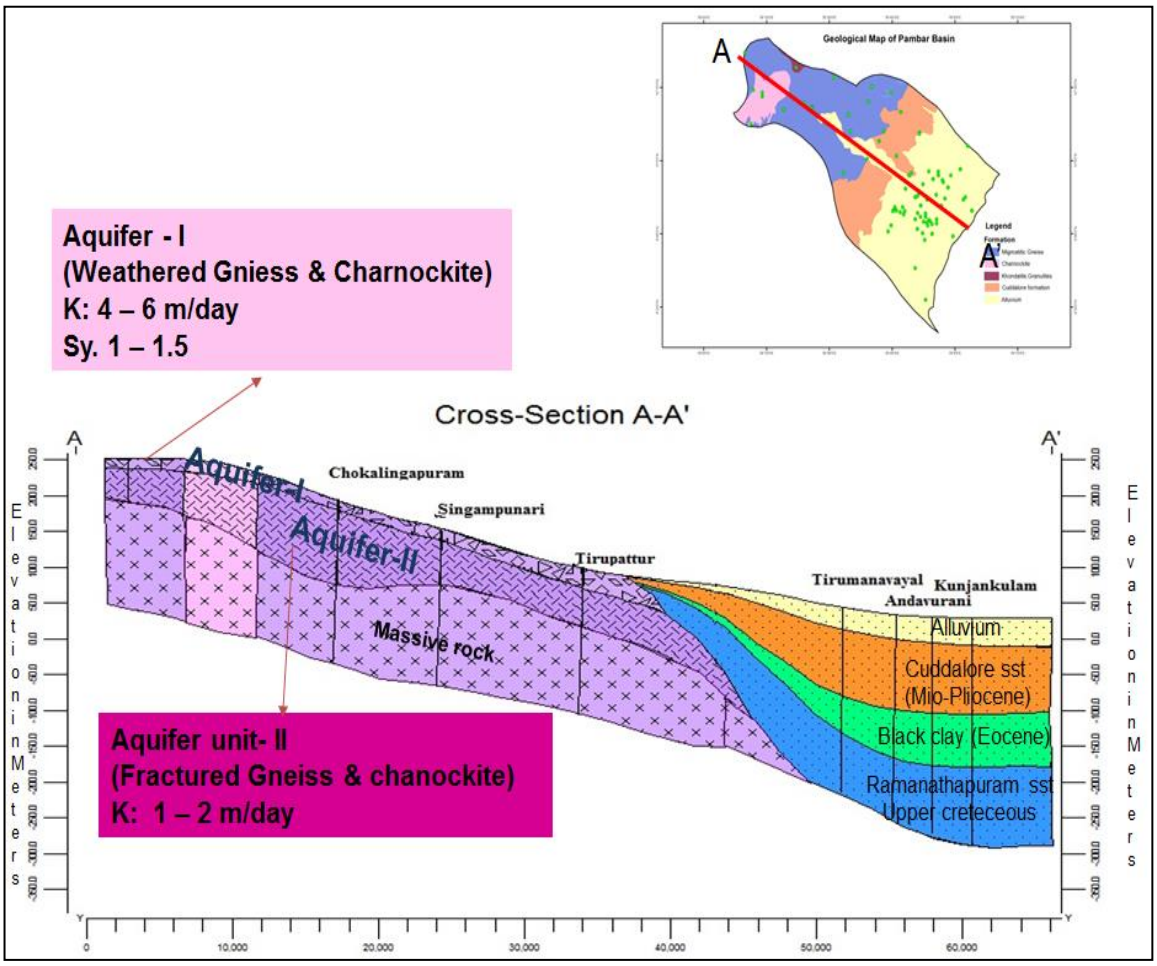


Figure 3.7: 2D aquifer disposition- Pambar Kottakaraiyar aquifer system along west east

The aquifer mapping study in the basin reveals that the presence of two distinct aquifer systems in the hard rock and Gondwana formations. Third aquifer is the alluvial aquifers consists of fluvial sand, occurs all along the Pambar - Kottakaraiyar river course.

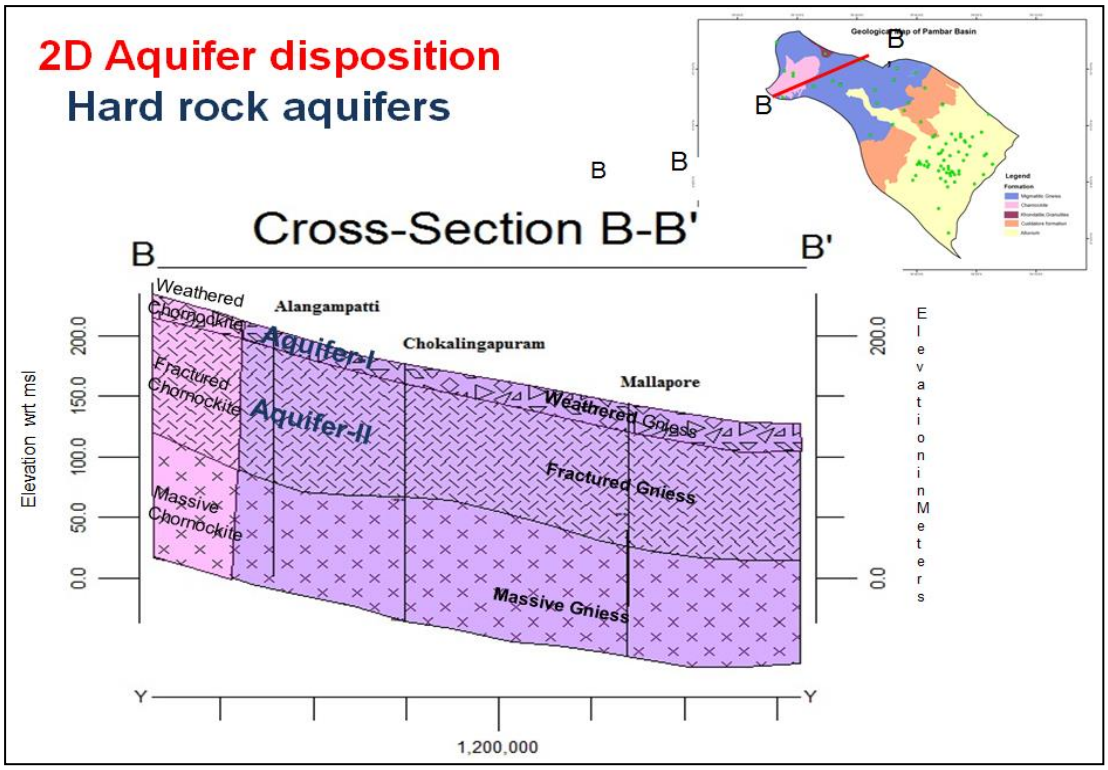


Figure 3.8. 2D aquifer disposition along northeast –west direction.

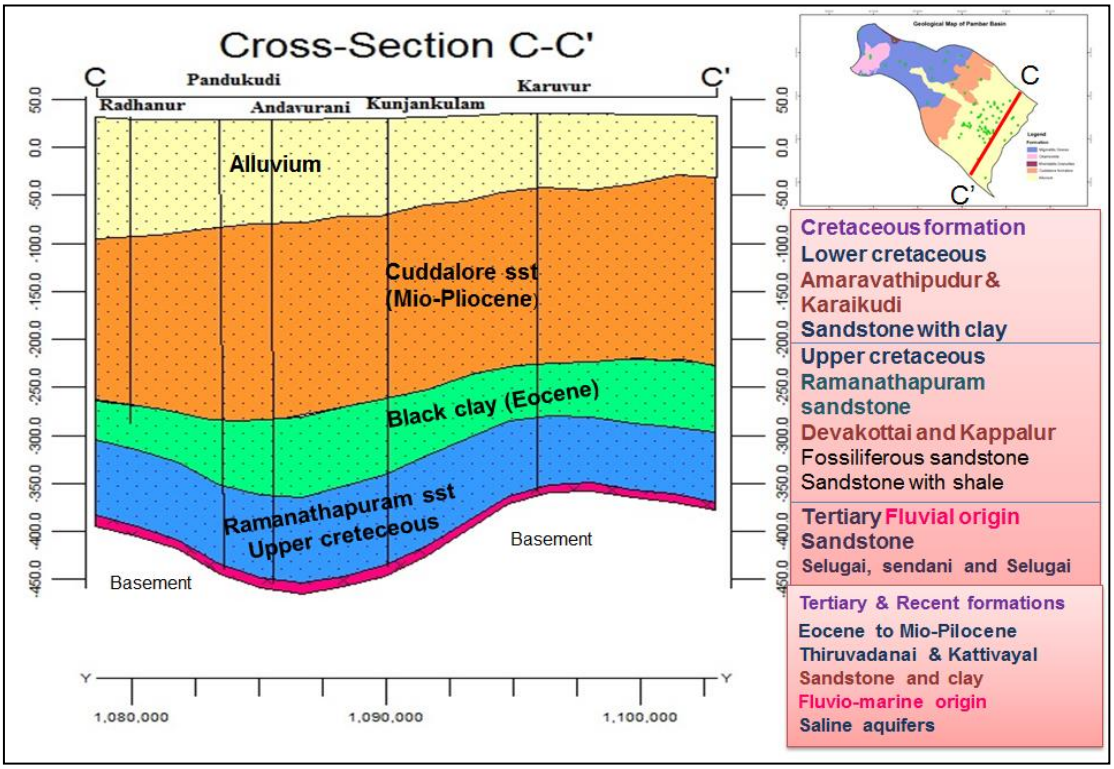


Figure 3.9. 2D aquifer disposition along North –South direction.

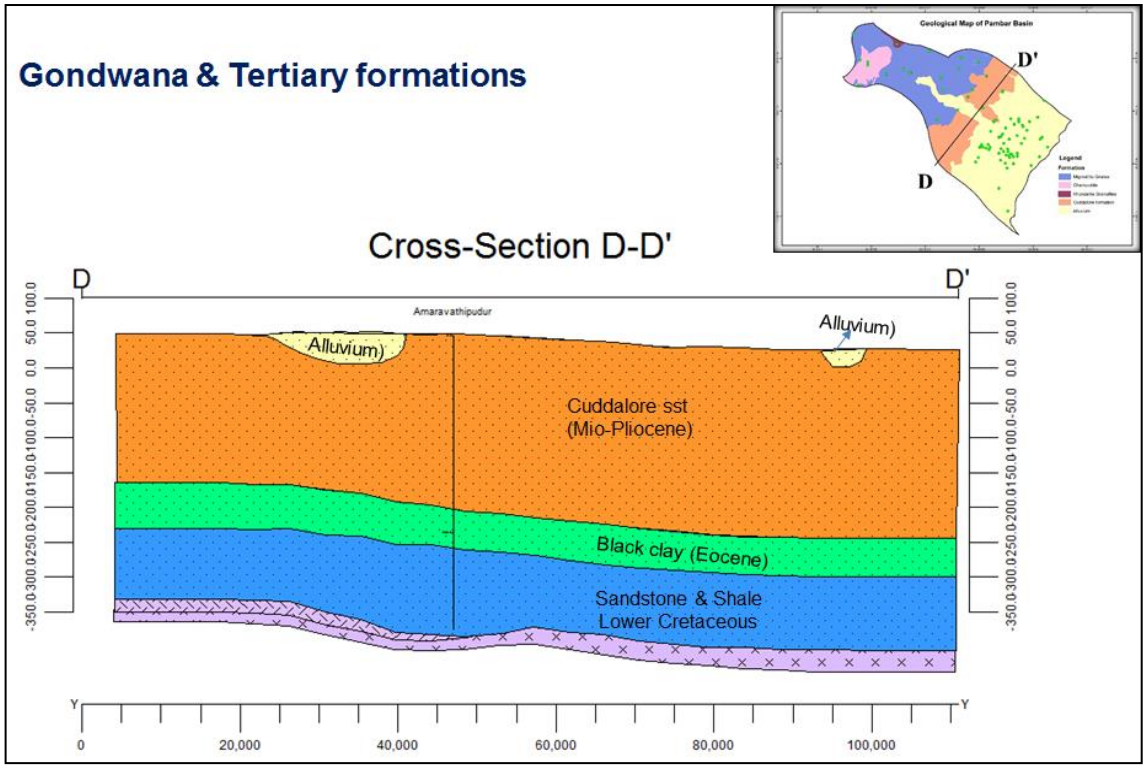


Figure 3.10. 2D disposition along north-north east-South-South west direction.

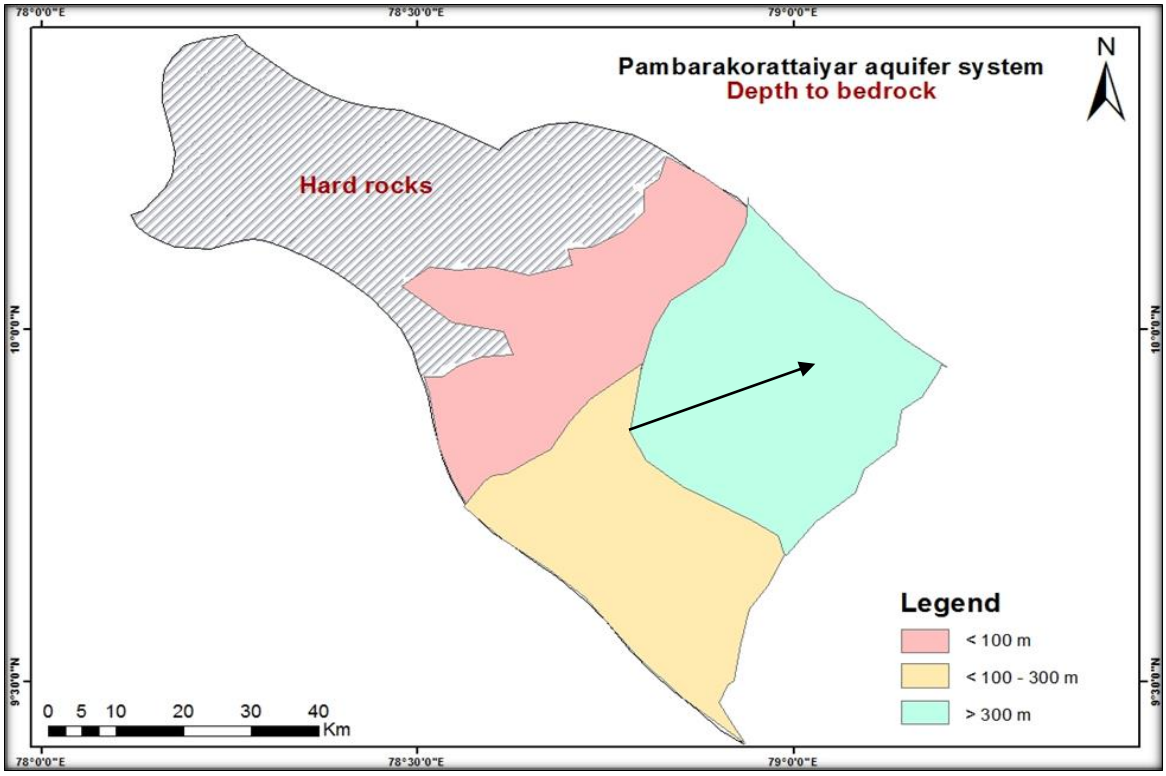


Figure 3.11. Depth to basement map. Arrow indicates depth to deeper basement.

3.3. Groundwater Level

During Aquifer Mapping studies in Pambar - Kottakaraiyar aquifer system 116 Groundwater monitoring wells which are monitored regularly are used along with 50 key wells established (**Figure -2.1**) in different formations in order to know the behaviour of the groundwater regime. The water levels were monitored from May 2014 to Feb 2016 (four times in a year). Based on the data of key wells inventoried and National Groundwater monitoring wells, the decadal average water level maps of pre-monsoon and post-monsoon were prepared for the area. The decadal water level average in the aquifer system has been analysed using the water level data of May 2008 and May 2017. and for post-monsoon decadal average water level January 2009 to January 2018 period was analysed. Decadal water level map for phreatic aquifer for pre and post is shown in **Figure 3.12** and **Figure 3.13** respectively. Decadal water level map for confined aquifer for pre and post is shown in **Figure 3.14** and **Figure 3.15** respectively.

The depth to water levels during pre-monsoon in the entire aquifer system remains in the range of less than 5 to 10 m bgl and 10 to 20 m bgl, whereas during post-monsoon the water level ranges become shallower compared to pre-monsoon, corresponding to rainfall recharge in the entire aquifer system.

3.3.1. Water Level Fluctuation

Water level fluctuation in an area between two periods is indicative of the net changes in the groundwater storage during the period in response to the recharge and discharge components and is an important parameter for planning sustainable groundwater development. As both southwest and northeast monsoons are active in the area, the fluctuation recorded in groundwater levels of January 2018 in comparison to the water levels of May 2017 indicate the extent of replenishment of the shallow aquifer due to the monsoon rainfall.

3.4. Hydrogeology of Pambar - Kottakaraiyar aquifer system

The principal aquifers in the Pambar - Kottakaraiyar aquifer system are weathered, fractured and alluvial aquifers. Primary porosity in the aquifers are negligible and secondary porosity developed due to tectonic disturbances leads to form good aquifers. Gondwana rocks behave as poor yielding aquifers and crystalline and alluvial formations forms good and productive aquifers. In sedimentary formation, maximum aquifer depth of 417.12 to 420.22 m is found in the borehole of Tiruvadanai which is in sandstone formation.

The Gondwana aquifers, comprising shale, sandstone and boulder bed, occur at shallow depth as water table aquifers and also in some places it is under confined conditions as deep aquifers. Cretaceous formations which comprises calcareous sandstone and sandstone intercalated with shale. Aquifer parameter values have been determined by aquifer performance test. The general yield of boreholes in crystalline formation is 2-5 lps to 250 lps.The minimum transmissivity value in hard rock region is less than 1 m2 /day and maximum is 65 m^2/day. The minimum storativity in hard rock region is 2.16 x 10^{-5} to 4.9 x 10^{-5} and maximum is 1.32 x 10^{-3} .The general specific yield is less than 2 %. In soft rock formation, the general yield of boreholes ranges from 75 lps to500 lps. The minimum transmissivity value in soft rock region is 1-10 m^2 /day and maximum is 500 m^2 /day.The minimum storativity in sedimentary rock is 2.5 x 10^{-5} and maximum is 3.59 x 10^{-4} . The general specific yield is around 12 %. Artesian aquifers are

noted in the past and one such borehole under artesian condition is reported at R.Velangudi village, west of Puduvayal in Karaikudi to Trichy road.

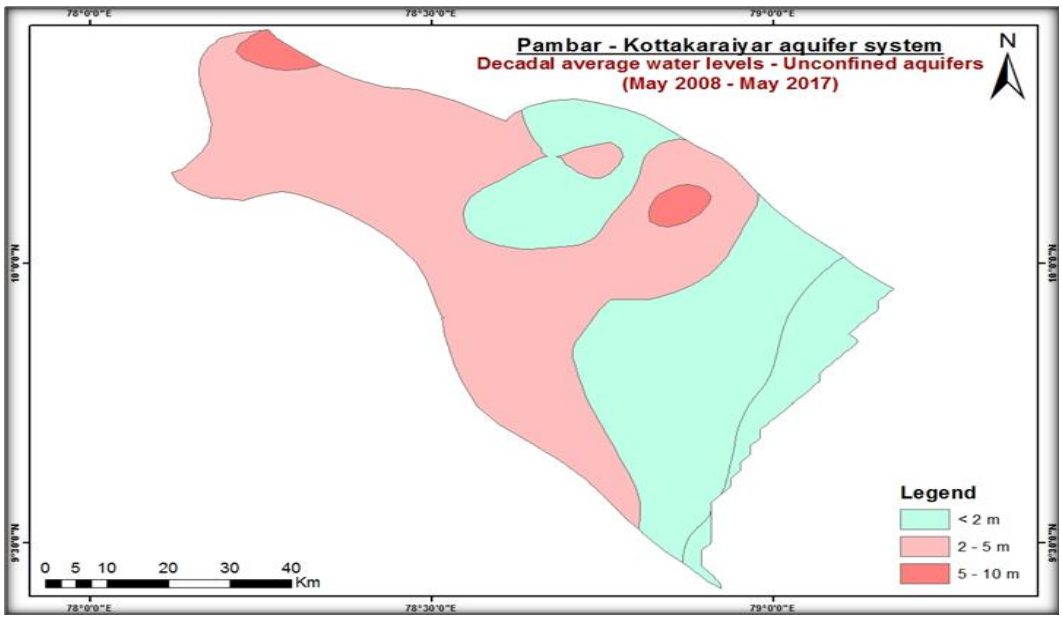


Figure 3.12. Decadal average water levels of unconfined aquifer during pre monsoon.

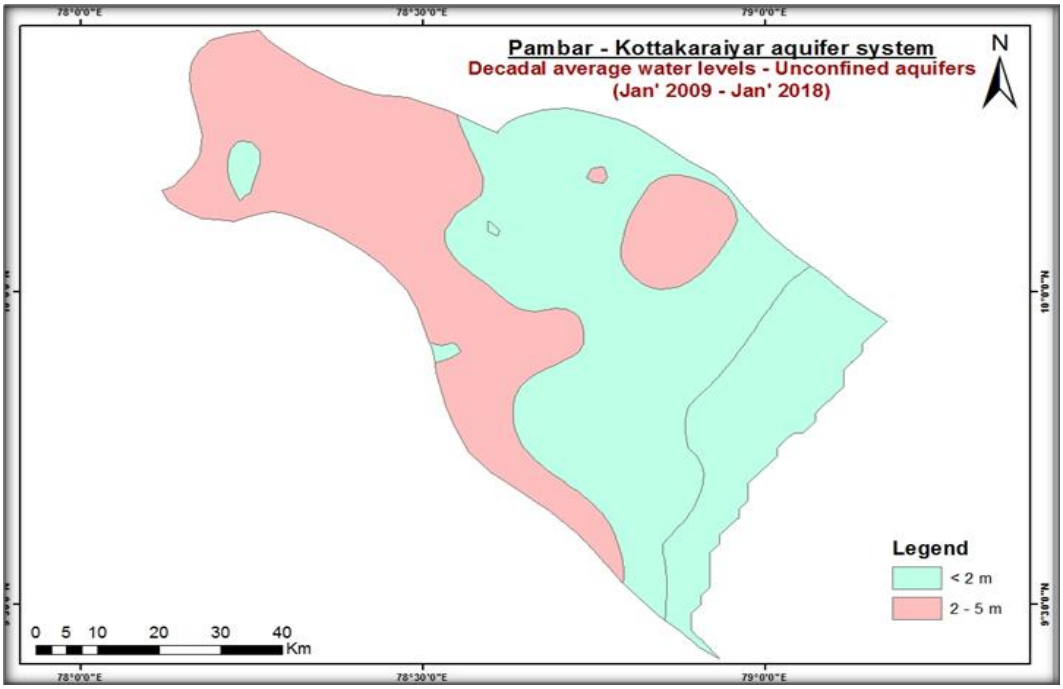


Figure 3.13. Decadal average water levels of unconfined aquifer during post monsoon.

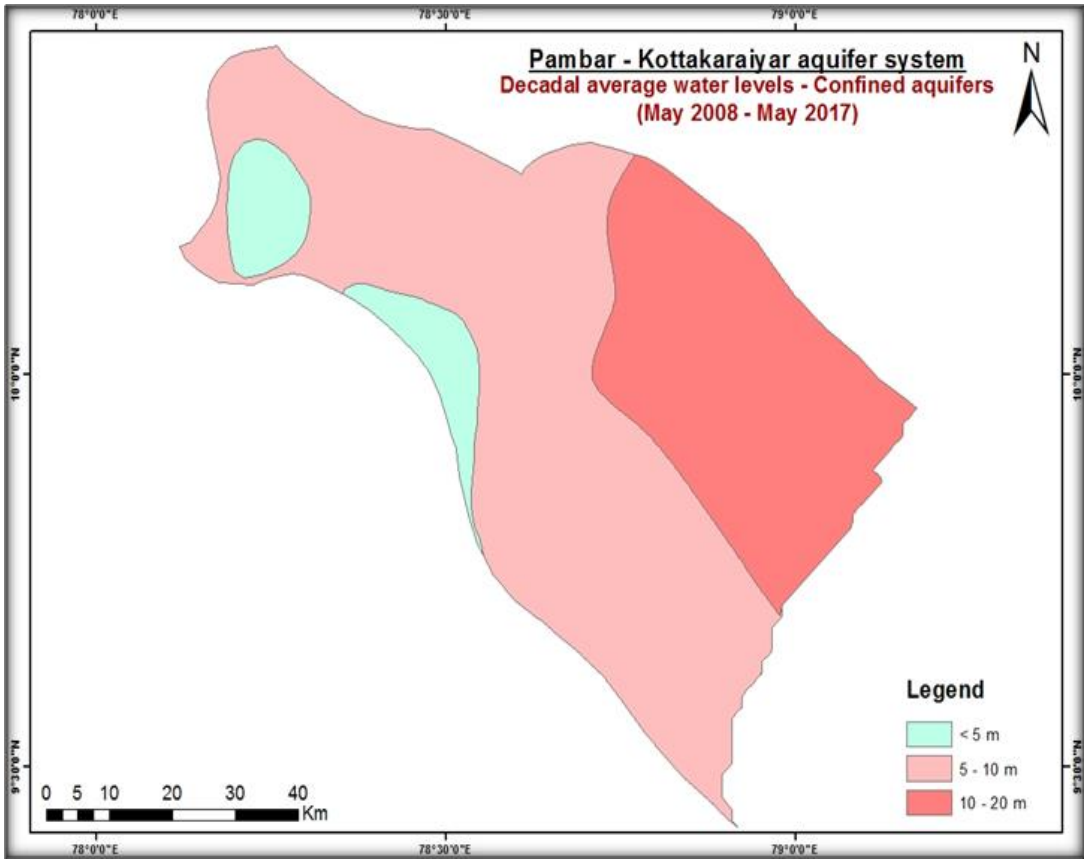


Figure 3.14. Decadal average water levels of confined aquifer during pre monsoon.

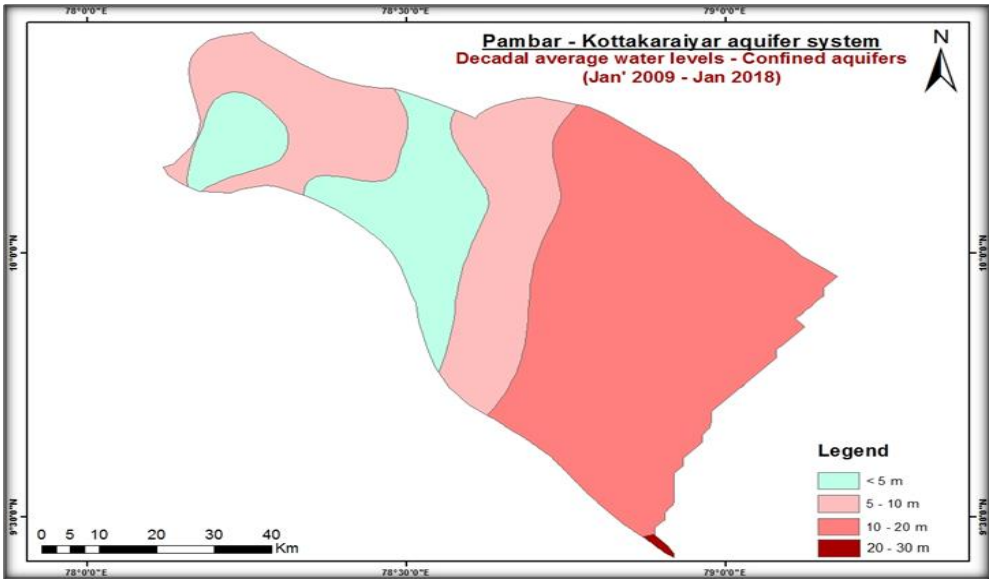


Figure 3.15. Decadal average water levels of confined aquifer during post monsoon .

4.0 GROUNDWATER RESOURCES

4.1 . Groundwater Draft

The gross groundwater draft has been assessed by using Unit draft method for irrigation draft component and by adopting formula suggested by GEC 1997 for domestic and industrial draft components.

The total net groundwater availability in aquifer system is 94331.1 ham whereas the net groundwater draft is 18964.9 ham. The existing gross groundwater draft in Dindigul, Madurai Pudukottai, Sivaganga and Ramanathapuram districts are 3321.3 ham, 3273.4 ham, 2552.4 ham, 9398.6 ham and 419.2 ham respectively and the net groundwater availability of the basin in Dindigul, Madurai Pudukottai, Sivaganga and Ramanathapuram districts are 4596.6 ham, 4760.7 ham, 17086.9 ham, 54758.1 ham and 12749 ham respectively. The groundwater resources of Pambar - Kottakaraiyar aquifer system are tabulated below.

Table: 4.1 Groundwater resources of Pambar - Kottakaraiyar aquifer system.

District	Resources (ha m)			
	2013		2017	
	NGWA	Draft	NGWA	Draft
Dindigul	4309.1	3360.5	4956.6	3321.3
Madurai	5629.9	3274.4	4760.7	3273.4
Pudukottai	17777.8	2309.4	17086.9	2552.4
Ramanathapuram	11637.0	434.5	12749.0	419.2
Sivaganga	56482.6	11864.7	54758.1	9398.6

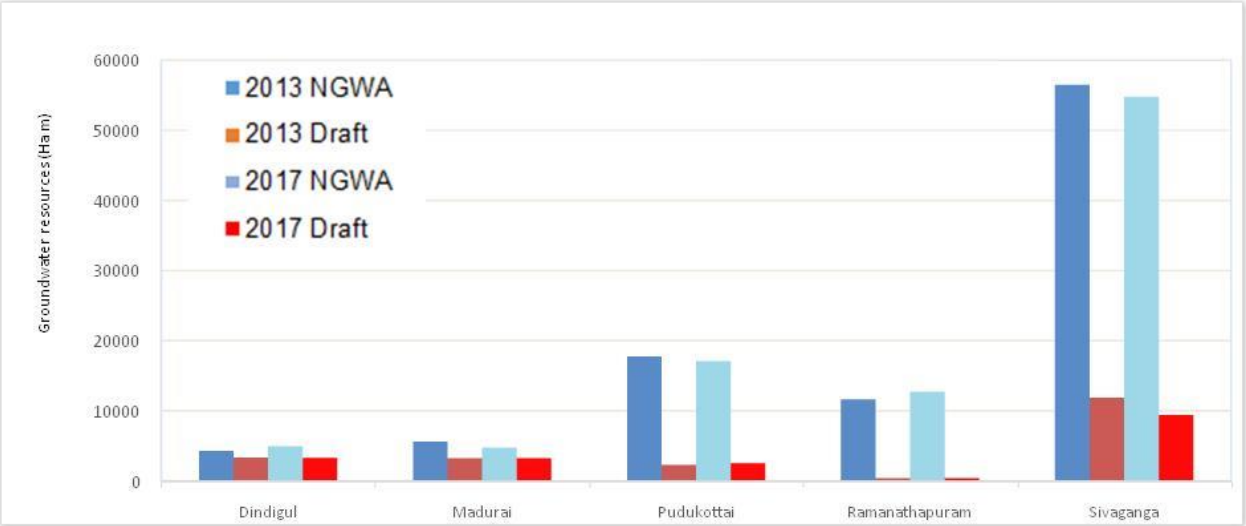


Figure 4.1. Groundwater resources of Pambar - Kottakaraiyar aquifer system

4.2. Stage of Development and Categorization

The stage of development is defined by stage of groundwater development (%) = (Existing groundwater draft/ Net Groundwater availability) x 100

The stage of groundwater development is calculated for all the 113 firkas of the basin The Categorization has been done by considering the two factors as suggested by GEC 97, viz.,

Stage of Development and long-term trend of pre and post monsoon water levels.

The following FOUR categories have been suggested by GEC-97 based on the above two factors.

a) Safe b) Semi-critical c) Critical and d) Over-exploited

Out of 42 firkas in the basin, 1 firkas of the Pambar - Kottakaraiyar aquifer system falls under over exploited category, which lies in Madurai District. There are 36 safe firksa, 22 safe firkas falling in Sivaganga district, 5 safe firkas each in Pudukottai and Ramanathapuram districts and 2 safe firkas each in Dandigul and Madurai districts. There are 3 Semi-Critical firkas falling in the basin, falling in Sivaganga Pudukottai and Dindigul distrcts. The total stage of development of Pambar - Kottakaraiyar aquifer system is 37%. The District wise categorisation firkas are tabulated below.

Sl. No	District	Safe	Semi Critical	Saline	OE
1	**Sivaganga**	**22**	**1**	**-**	**-**
2	**Ramanathapuram**	**5**	**-**	**2**	**-**
3	**Pudukottai**	**5**	**1**	**-**	**-**
4	**Dindigul**	**2**	**1**	-	-
5	**Madurai**	**2**	**-**	-	1
	Total	**36**	**3**	2	1

The management plan for Kottampatti OE firka is worked out in details in terms of supply and demand side management. Artificial recharge structures were proposed in Kottampatti fika by utilising overlay analysis.

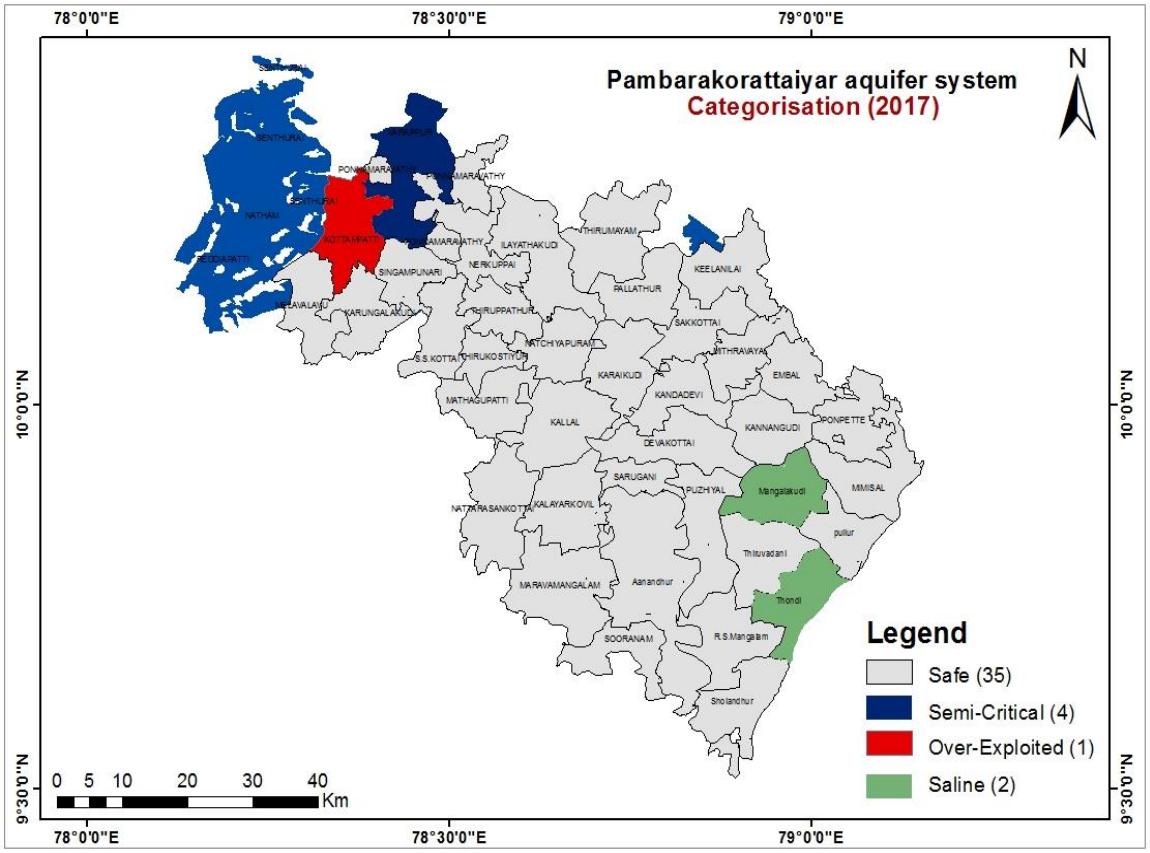


Figure 4.2 Categorisation of Firka in Pambar - Kottakaraiyar aquifer system

5.0. GROUND WATER RELATED ISSUES

Groundwater is extensively utilized for irrigation in the entire basin area for the past two decades, especially in the 42 over-exploited firkas out of the 1 firkas of the basin. There is no anthropogenic contamination in the basin as there is much urbanization.

5.1. Groundwater quality issues

Sea water has intruded the coastal area between Devipattinam village of Ramanathapuram district to Palangulam village of Pudukottai district, covering a coastal length of 69.73 km and width of 10 km from the coast is considered for this study. The study area is 657.569 sq.km.

Following measures can be taken up in the coastal region.

- Stopping of heavy pumping of GW in the seawater intruded area.
- Construction of percolation tanks in the affected area to make fresh water ridge.
- Coconut and saline resistance crops are grown in areas having TDS 1500– 2500 mg/l)
- Mounds on the upstream side of ponds shows groundwater with low EC even in pre-monsoon period there are positive indications of recharge. More ponds can be constructed parallel to the coast and this can create huge mounds of freshwater.
- Artificial recharge structure in the Pambar - Kottakaraiyar River shows improvement in GW Level and GW quality.

5.2. Future Demand Scenario and Stress on Aquifer system

For agriculture, the surface water potential of this basin is being utilized in addition to the supplemental irrigation by ground water. Since the maximum quantity of surface water is consumed for irrigation, the following short term measures are suggested for effective consumption of water in irrigation sector: 1. Improving the performance of the existing irrigation system by suitable structural measures. 2. Lining of canals to improve the efficiency by reducing conveyance loss of water. 3. Renovating old tanks and ponds, desilting of tanks and supply channels and constructing recharge structures to improve irrigation potential. 4. Equitable distribution of irrigation water by better water management. 5. Conjunctive use of surface and ground water wherever possible. 6. Introducing modern irrigation techniques like, drip and sprinkler irrigation. 7. There is no Gauging site installed in this basin. Hence automatic flow measuring devices may be installed in anicuts, so as to quantify the flow.

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 water resources are used extensively both for irrigation and industrial needs. In addition, to meet the domestic requirements of the fast growing urban agglomerations the administrators are compelled to allocate a considerable quantum of resource which otherwise is being used for irrigation purpose. So, the urbanization has a negative impact on the food production as well as grabbing the employment of the agricultural laborers. 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 Pambar - Kottakaraiyar 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. The study area is characterized by weathered and fractured system with very heavy abstraction of groundwater for irrigation practices.

6.1. Augmentation Plan

Augmentation of groundwater can be achieved through construction of percolation ponds with 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 eastern and southern 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 & Critical firkas of the basin through utilizing the uncommitted surface runoff of 119 MCM.

6.1.1. 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 basin has been estimated as 14.50 MCM. The annual uncommitted runoff is only 14.20 MCM which is less than 100% of required water to fill the

available void space of aquifer unit - I. Artificial recharge and water conservation plan is prepared for the over exploited firkas of the basin area through harnessing just less than 40% of the annual uncommitted runoff of 2.03 MCM only with a total out lay of 3.8775 Crore rupees.

The suggested artificial recharge structures are mainly Nala bunds, Check Dams 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. Particularly geomorphological and drainage aspects are being given more weightage in selection of the Artificial Recharge structures.

A total number of 7 check dams, 21 nala bunds and 5 recharge shafts are proposed in the OE firka of the basin. A total number of 361 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 2.03 MCM.

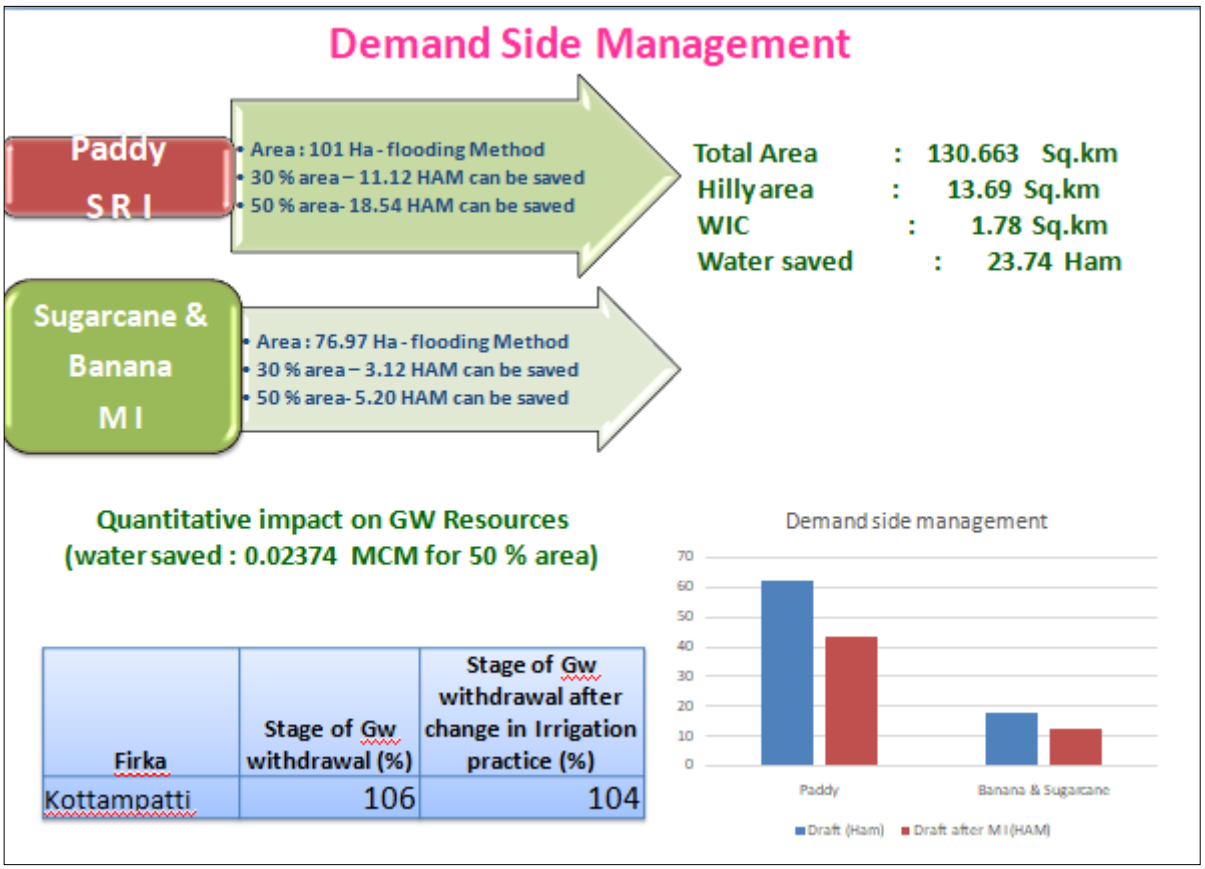
The expected benefit by the recharge structures in the 1 OE firka area will be creation of additional crop area of Paddy of 7438 ha or Sugarcane of 5950 ha (or) Banana of 11900 ha (or) Irrigated Dry crops of 23800 ha.

6.1.2. Water Conservation Plan

Low pressure water distribution system is being proposed in 1775.3 sq.km of cropped area which otherwise is under irrigation through earth channels. The expected savings of water through this method is expected to be 23.74 ham/ yr. A total number of 775 Farm ponds are proposed which will act as storage tanks in farm as well as augment groundwater recharge and the expected annual groundwater recharge through these ponds is in the order of 23.74 ham..

6.2. Demand side Management Plan

Demand side management can be accomplished through change in irrigation pattern. 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 1.01 sq.km and similarly for sugarcane and banana crops shift from flooding to drip irrigation would save 79.40 and 31.37 MCM respectively. The total water saved is 23.74.

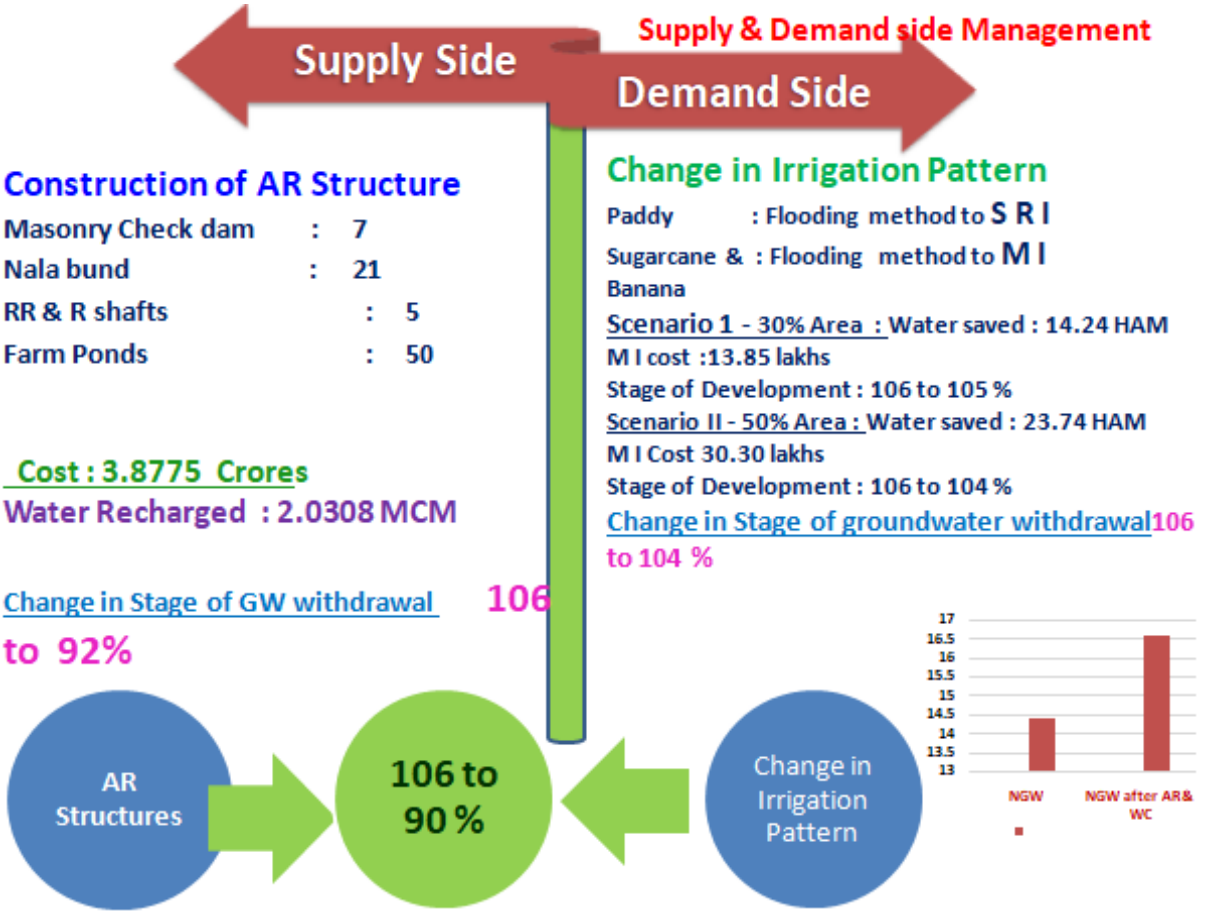


Firka	Stage of Gw withdrawal (%)	Stage of Gw withdrawal after change in Irrigation practice (%)
Kottampatti	106	104

6.2.1. 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.



6.3. 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.

The demand side strategies to overcome future stresses are mainly

Promoting irrigation pattern change

Agronomic Water Conservation

Reducing water use, reduction in urban areas

6.4 Groundwater management plan for Pambar Kottakaraiyar basin

Net groundwater availability: 943.11 MCM

Total groundwater draft : 189.65 MCM

For safe firkas,

A. Groundwater development up to 70 % can be carried out by

1. Second crop of vegetables, pulses and millets with micro irrigation, in addition to paddy crop.
2. Cultivable waste land can be utilized and new crop area added

B. De siltation of tanks and ponds

Solution for Groundwater depleted area of Kottampatti firka

- Maintenance of Existing Water bodies/Recharge sources (Tanks and Ponds).
- Construction of additional Artificial Recharge & Water Conservation structures.
- Nala bunds and Check Dams, Percolation ponds
- Desilting of the tanks along with construction of recharge shaft or recharge bore wells.
- Construction of farm ponds & recharge Ponds.
- Rainwater harvesting through dug wells.
- Less water intensive crops like vegetables, flowers, pulses may be encouraged

Over-Exploited Firka: Kottampatti firka

Supply side interventions:

Existing- 52 Check dams

Ariticial recharge structures proposed

Check dam - 7

Nala bund - 21

RR and Recharge shafts in tanks - 5

Farm ponds - 50

Artificial recharge/ conservation measures		Nos
Artificial recharge structures proposed	Check dam Nala bund Recharge shafts in tanks	5 21 5
Water conservation measures	Farm ponds	50
Tentative cost (including O & M)		3.8775 Cr
Vol. of unsaturated zone available for Recharge (up to 3m bgl)		14.50359 MCM
Uncommitted Surplus runoff		14.20960 MCM
Harnessable runoff		11.36768 MCM

Expected recharge from all AR structures and conservation measures	2.0308 MCM
Improving water efficiency through micro irrigation (MI)	0.15 MCM
Water available after AR and water conservation measures	2.1808 MCM
Additional crop area created for 2.1808 MCM water with MI	560 ha Groundnut or 1113 ha Pulses or 808 ha Vegetables or 974 ha Sesame
or	Raise in water level Sustainability of wells and increase in pumping hours
or	Change in Stage of groundwater withdrawal : 106 to 92 %

Demand side intervention:

Wet crops area

Paddy: 102.9988 ha, Sugarcane and Banana : 76.9663 ha

crop	**Change in irrigation type**	**Water saved in 30 % of the crop area (Ham)**	**Water saved in 50 % of the crop area (Ham)**
Paddy	SRI	11.1239	18.5398
Sugarcane & Banana	MI	3.1171	5.1952
	Total	14.2410	23.7350
	MCM	0.01424	0.02374
	Change in SGW	106 to 105	106 to 104
	Cost	13.85 lakhs	23.09 lakhs

System of Rice Intensification (SRI) and Micro irrigation (MI)

After implementation of artificial recharge schemes and water conservation measures and change in

Net Groundwater Availability : 16.5522 MCM

Irrigation draft after change in irrigation type : 14.4826 MCM

Stage of groundwater withdrawal: 106 to 91 %, from O**ver-Exploited to Critical**

Proposed artificial recahrge structures in Kottampatti Firka.

Sl.No.	Structure	Lattidue	Longitude	Remarks
1	Nala bund	10.2645	78.3454	
2	Nala bund	10.2681	78.3438	
3	Nala bund	10.2879	78.3526	
4	Nala bund	10.2848	78.3611	
5	Nala bund	10.2867	78.3424	
6	Nala bund	10.2538	78.3591	
7	Nala bund	10.244	78.3564	
8	Nala bund	10.2413	78.3588	
9	Nala bund	10.2358	78.3584	
10	Nala bund	10.2385	78.3387	
11	Nala bund	10.2508	78.3326	
12	Nala bund	10.2486	78.3806	
13	Nala bund	10.2847	78.3725	
14	Nala bund	10.2635	78.3886	
15	Nala bund	10.2648	78.3737	
16	Nala bund	10.255	78.3838	
17	Nala bund	10.2511	78.3826	
18	Nala bund	10.2345	78.3793	
19	Nala bund	10.235	78.3817	
20	Nala bund	10.2642	78.4035	
21	Nala bund	10.2655	78.4166	
22	Check Dam	10.2838	78.3519	
23	Check Dam	10.2679	78.347	
24	Check Dam	10.2795	78.3504	
25	Check Dam	10.2807	78.3746	
26	Check Dam	10.26	78.3915	
27	Check Dam	10.2618	78.4065	
28	Check Dam	10.2578	78.3996	
29	Recharge Shaft	10.1574	78.3427	
30	Recharge Shaft	10.1882	78.3508	
31	Recharge Shaft	10.2261	78.3896	
32	Recharge Shaft	10.1942	78.3226	
33	Recharge Shaft	10.2077	78.3953	