केंद्रीय भूमि जल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण मंत्रालय

भारत सरकार

Central Ground Water Board

Ministry of Water Resources, River Development and Ganga Rejuvenation

Government of India

Report

on

AQUIFER MAPPING AND GROUND WATER MANAGEMENT

Amaravathi Basin, Tamil Nadu

दक्षिण पूर्वी तटीय क्षेत्र, चेन्नई

South Eastern Coastal Region, Chennai

सरकारी उपयोग के लिए

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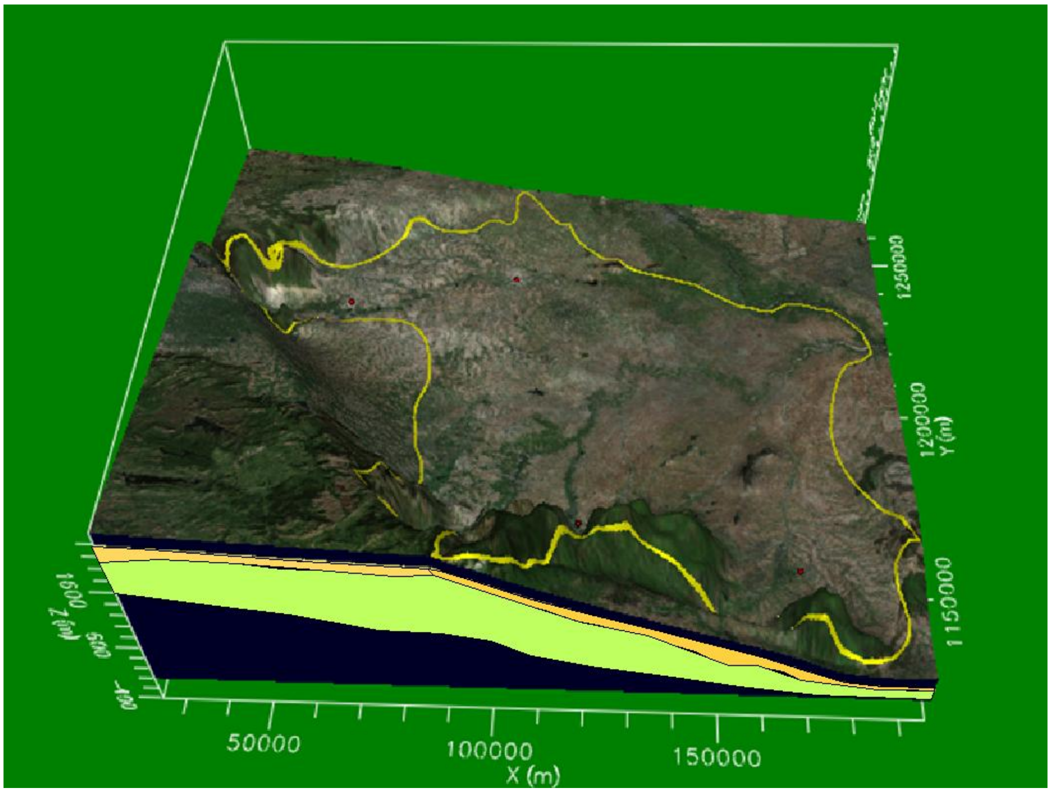
AQUIFER MAPPING AND MANAGEMENT PLAN FOR AMARAVATHI BASIN, TAMIL NADU



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Government of India
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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. Out of 6607 ground water assessment units (Blocks/ mandals / taluks etc.), 1071 units are over-exploited and 914 units are critical. These units have withdrawal of ground water 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 mapable area of country ~ 23.25 lakh sq. km with an vertical extent of 300 m in alluvial area and 200 m in hard rock area. The extent of aquifer, their potential, resource availability, chemical quality, its sustainable management options will be addressed. The NAQUIM programme will also facilitate participatory management of ground water to provide long-term sustainability for the benefit of farmers. Currently focus is on ground water stressed areas of eight states comprising 5.25 lakh sq.km viz. Haryana, Punjab, Rajasthan, Gujarat, Andhra Pradesh, Telangana, Karnataka and Tamil Nadu and also covers Bundelkhand region.

South Eastern Coastal Region, Central Ground Water Board, Chennai Under NAQUIM has been envisaged with the Mapping of an area of 70,102 sq.km during the XII five year plan in Tamil Nadu and UT of Puducherry. This report deals with the Aquifer mapping studies carried out in water stressed Amaravathi and Noyyil Basin covering an basin area of 12285 sq .km having 10489 sq.km as mappable area. The basin comprising of drought prone district of Coimbatore, Tiruppur, Dindigul and Erode and Karur in parts with 107 firkas (74 OE and critical) and is mainly dependant on groundwater (80%) for its agricultural needs. The major issues in the region include the declining water levels, sustainability of wells contamination of groundwater due to textile and tanneries in parts of Tiruppur and Dindigul districts. Two aquifer units were deciphered with aquifer Unit -I being the weathered, occurs from ground level to 45 m bgl and Aquifer Unit –II is the fractured/Jointed zone existing from 11 to 199.75 m bgl (3-4 fractures are encountered). In order to arrest the decling groundwater levels and increase the sustainability of wells management plans were formulated firka wise. Construction of AR structure (CD-166, NB- 155, RS-716 & Revival of Ponds with RS -220) and water conservation structures (Recharge ponds 25,240) at a cost of 424. 93 cr would create additional resource of 197.45 mcm/yr and would help in arresting groundwater level decline and reduce the stage of groundwater withdrawal from 111 to 98 %.

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

A.Subburaj
Head of Office

AQUIFER MAPPING REPORT FOR SUSTAINABLE MANAGEMENT OF GROUNDWATER RESOURCES IN AMRAVATHI BASIN, TAMILNADU STATE

AT A GLANCE

S. No.	Item		Particulars
1.	Geographical area Hilly area	: :	12285 Km^2 1796 km2
2.	Districts		Coimbatore, Tiruppur, Erode, Dindigul, Karur
3.	Firkas (Assessment Units)	:	Total :107 (Fully: 80 Partially: 27),
4.	Locations	:	North Latitude ; 10°07´14"-11°22´57" East Longitude 76°39’28"-78°12´40”.
5.	River Basin	:	Major Basin: Amravathi River and Noyil River
6.	Sub-basins	:	Chinnar, Kodavanar, Nanganji, Kuduraiyar & Shanmuganadi
7.	Geomorphology	:	▪ Dissected / Undissected landforms, ▪ Shallow and medium pediments
8.	Land use		▪ Agricultural land - 78% ▪ Forest land - 11%
9.	Major crops	:	Paddy, Sugarcane ,Banana and Dry crops etc.
10.	Soils	:	Red soil, Black cotton soil, sandy loam,
11.	Geology	:	▪ Granite gneisses, ▪ Charnockites & ▪ Granite
12.	Rainfall	:	720 mm (100 years) Min : 530.6 mm Max :1720.50 mm
13.	Depth to water Table Elevations (m amsl)	:	150-450. The flow gradient is 2.6 m/km
14.	Depth to water levels (2015-16) (mbgl)	:	Pre-monsoon : (I Aquifer): 1.10-42.25 (II aquifer) : 0.45 -113.35 Most frequent range: (I Aquifer): 2-10 m bgl (II aquifer): 20 - 40 m bgl

S. No.	Item		Particulars	
			Post monsoon : (I aquifer) 0.98-41.53 (II aquifer) 0.78 - 49.81 Most frequent range: (I Aquifer): 2 - 5 m bgl (II aquifer): 10 - 20 m bgl	
15.	Water Level Fluctuations (m)	:	55 % wells shows rise in water levels in the first Aquifer 80 % shows rise in water levels in II Aquifer	
16.	Long term water level trends	:	Western Part: 0.20 to 0.35 m/year Eastern Part: : 0.30 to 0.45 m/year	
17.	Ground water yield	:	0.2 to 3.5 lps	
18.	Number of ground water structures (as on 2013 March)	:	268801 (Dug wells:235776; Bore wells:28873 DCB:4152)	
19.	Conceptualization		**Weathered zone**	**Fractured zone**
20.	Depth (m bgl)	:	Up to 45	Up to 199.75
21.	Dynamic GW Resources-2013 **(MCM)**	:		
22.	Net dynamic groundwater availability	:	1475.11	
23.	In-storage groundwater availability	:	553.3	616.42
24.	Gross GW Draft	:	1640.35	342.19
25.	Provision for D & Ind (2038)	:	118.82	
26.	Stage of Groundwater development (%)	:	111	
27.	Hydraulic Properties	:	Weathered Zone	Fractured Zone
28.	Transmissivity (m^2/day)	:	5-80	10-110
29.	Specific yield (%)		1.5 - 2.0	
30.	Storativity	:	-	0.00002 to 0.001
31.	**Groundwater Quality 2015**			
32.	EC (Ω Siemen's/cm)-Pre-monsoon	:	50-5750	410-3600

EXECUTIVE SUMMARY

Detailed hydrogeological studies were conducted in the study basin of the Upper Cauvery and huge existing data pertinent to geology, geophysics, hydrology, hydrochemistry were collected, synthesized and analyzed to bring out this report. This report mainly comprises the Aquifer geometry and 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.

Area experiences semi-arid climate with 720 mm annual normal rainfall covering 12285 km^2 areas in Coimbatore, Tiruppur, Erode, Dindigul and Karur districts of Tamil Nadu. About 253130 hectares of area is under groundwater irrigation in the basin and accounts for 20.6% of the geographical area. The main crops irrigated are paddy, sugarcane, banana, groundnut, maize, cotton, ragi and other minor crops are turmeric, vegetables and flowers.

Weathered and fractured Granitic Gneiss and Charnockite form main aquifer system in the area. Groundwater occurs under unconfined condition in the weathered zone and unconfined to semi-confined conditions in the fractured/fissured zone and flows downward from the weathered zone into the fracture zone. The predominant water levels are in the range of 10 to 20 m bgl during pre-monsoon season and 2 to10 mbgl during post-monsoon season of 2015-2016. The net annual groundwater availability is 1475.11 MCM and the gross groundwater draft is 1640.35MCM and the average stage of groundwater development is of 111%.

Aquifer systems from the area can be conceptualized as weathered zone down to ~42m and fractured zone between ~42 and 199.75 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 5 and 80 m^2/day and specific yield 1.5 -2.0 %. High yield is, associated sometime with Pegmatite vein. The average transmissivity of this zone varies between 5 and 80 m^2/day and storativity varies from 0.00002 to 0.001.

Groundwater is extensively utilized for irrigation in the entire basin area for the past two decades, especially in the 74 over-exploited and critical firkas out of the 107 firkas of the sub-basins. Groundwater contamination due to Textile Industry in Coimbatore, Thiruppur, and Karur districts on the banks of Noyil and Amravathi river courses have a created a major problem. Groundwater monitoring wells (89 Nos.), which were monitored regularly shows decline trend of 0.20 to 0.35 m/year in Coimbatore and Tiruppur districts and 0.30 to 0.45 m in Dindgul district.

The annual uncommitted runoff is 899 MCM. As both the source of excess water and place to store is available, Artificial recharge and Water conservation plan is prepared for the over exploited firkas of the sub basins. Using all the scientific approach an artificial recharge Plan has been prepared to harness 197.45 MCM of water from the uncommitted runoff at the cost of 424.93 Crores.

A total number of 166 check dams, 155 nala bunds and 716 recharge shafts in the existing 575 tanks are proposed in the OE firkas of the basin. A total number of 220 ponds out of 1851 have been recommended for de-siltation. Apart from these structures 25240 Nos. of Recharge ponds have also been planned to construct. The expected recharge through these artificial recharge structures is in the order of 197.45 MCM.

The expected Potential through ID crops for 197.45 MCM of recharge is 33912 ha. Through this supply side management it is expected to bring down the current stage of development from 111 to 98%.

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 of may be incorporated in the regulatory acts.

AQUIFER MAPPING REPORT FOR SUSTAINABLE MANAGEMENT OF GROUNDWATER RESOURCES IN AMRAVATHI BASIN, TAMILNADU STATE

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AQUIFER MAPPING REPORT FOR SUSTAINABLE MANAGEMENT OF GROUNDWATER RESOURCES IN AMRAVATHI BASIN, TAMILNADU

1. INTRODUCTION

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. As India is largest user of groundwater in the world, there is urgent need for an accurate and comprehensive picture of groundwater resources in different hydrogeological settings through aquifer mapping, which will enable robust groundwater management plans.

Aquifer Mapping has been taken up in **Amravathi basin** of Cauvery basin **i**n Tamil Nadu in a view to formulate strategies for sustainable management of the dynamic groundwater resource which help in drinking water security and improved irrigation facility.

1.1.Objective:

National Project on Aquifer Mapping (NAQUIM) initiated by Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India with a vision to identity 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.

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 TWAD Board, PWD, Agricultural Engineering. Groundwater monitoring regime has been strengthened by establishing additional monitoring wells. 2D and 3D sections have been prepared.

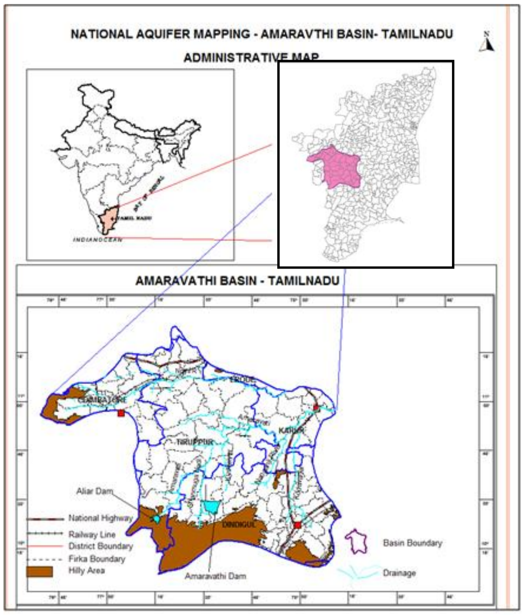
1.3. Approach& Methodology:

Multi-disciplinary approach has been adopted involving geological, geophysical, hydrological and hydrogeological and hydrogeochemical components of study on toposheet scale of 1:50000 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 geo-electrical layers with different resistivities have been interpreted in corroboration with the litho stratigraphy of the observation wells and exploratory wells down to depths of 200m bgl. Hydrological and hydrometerological_data have been collected from state PWD and IMD departments. Drainage, Soil and Geomorphology of the sub-basins were complied based on the maps collected from Water Resources Department, Anna University, Chennai. Based on the data gap analysis data generation process has been scheduled through establishing key observation wells, pinpointing exploratory sites, collecting geochemical samples in order to study groundwater regime, geometry of the aquifer and aquifer parameters, and quality of the groundwater. Groundwater recharge and draft have been computed through different methods and resources of the basin estimated through groundwater balance method. A three-dimensional mathematical model of regional groundwater flow was used to provide a mechanistic description of groundwater flow in the aquifer system of Amravathi basin. The model was simulated using the finite-difference approximation of three-dimensional partial differential equation of regional groundwater flow and was calibrated for steady and transient conditions to forecast the dynamic groundwater flow under different recharge and stress conditions. Based on the above studies management strategies have been evolved for augmentation of groundwater through artificial recharge and water conservation and formulated plans for sustainable management of the resource.

1.4. Area Details:

The study area trending NNW-SSE covering 12285 km^2, lies between North Latitude 10°07´14"-11°22´57"and East 76°39’28"-78°12´40”. It forms part of the Cauvery mid basin of Amravathi sub-basin (Area: 8654 km^2 , 70 %) covering 7 major watersheds and Noyil river sub-basin (Area: 3631 km^2, 30%) covering 3 major watersheds of the Cauvery river basin falling in Coimbatore, Tiruppur, Erode, Dindigul and Karur districts and administratively governed by 107 firkas. Administrative details of Amaravathi basin is given in Figure –1. 1.

Administrative Details of Amaravathi Basin,Tamil Nadu



Total Area of the Basin	:	12,285 Sq.Km.
Hilly Area	:	1,796 Sq.Km.
Mappable area	:	1,0489 sq.km.
Total Districts (Covered)	:	5 Nos
Total Firkas in Study Area	:	107 Nos
Average Normal Rainfall	:	720 mm (100 years)

Sl. No	District	Area Sq. Km.	No. of Firkas	No. of OE and Critical Firkas
1	COIMBATORE	1,543	21	16
2	DINDIGUL	4,381	36	21
3	ERODE	260	8	5
4	KARUR	1,425	12	8
5	TIRUPPUR	4,676	30	24
	Total	12,285	107	74

Figure – 1. 1. Administrative Details of Amaravathi basin

1.5. Data availability

During the Aquifer mapping period, existing data of 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, Bore well data, Water quality & Water level data have been collected from Tamil Nadu water Supply and Drainage Board. Cropping pattern and Soil data has 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, land use/land cover, geomorphology, etc., from various State Government agencies were collected, complied and used in this study.

1.6. Data adequacy

Exploratory well data is available for 248 wells drilled by CGWB and State Departments. Water level and Water Quality monitoring data for 66 Observation wells is available for a period of more than ten years. Land use, Cropping and irrigation data has been collected from Statistical 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 complete the Aquifer map on the desired resolution of 1:50,000 scale.

1.7. Data Gap Analysis & Data Generation:

The study area is having 89 monitoring wells of CGWB, 172 wells of State department, to monitor the regime of the first aquifer and 15 piezometers for the second aquifer to know aquifer parameters. Dug wells (139 Nos.) have been established to monitor the first phreatic aquifer and 17 bore wells drilled down to a depth of 200m bgl to know the aquifer characters of semi-confined aquifer system, which is extensively developed in recent years, during micro level study. Quality monitoring was carried out through 66 existing dug wells and from all the 139 wells established during study for first phreatic aquifer and are analyzed in order to assess the groundwater quality for drinking and irrigation purposes. Similarly as per the proposed data gap analysis of aquifer mapping, 21 new VES have been taken up down to the depth of 200 m bgl, in addition to the existing 279 VES points, to know the vertical characteristics of the aquifer down to 200mbgl.

1.8. Climate and Rainfall

The basin area experiences tropical climate being hot and dry for the greater part of the year. The period from March to June is generally hot. The temperature ranges from 20° to 38°C. The area receives rainfall through both south-west and north-east monsoons. About 40 percent of the precipitation is contributed by south-west monsoon and north-east monsoon accounts for 50 to 60 percent. The average annual rainfall for the basin area is 720 mm.

1.9. Physiography:

The Amaravathi basin has two distinct topographical features. The hilly terrain occupies the southern, southwestern and western parts of the basin between the elevation 2300 metere above mean sea level (mamsl) and 500 mamsl and the undulating plains with stray hillocks lie between 500 mamsl and 40 mamsl. The basin is more or less fan shaped and has a length of about 174 km from west to east and maximum length of 137 km from south to north.

1.10 Geomorphology:

The southern part of the basin is covered with series of hill ranges of Kodaikanal and form upland (Figure –1. 2). Many lower order streams flowing from this upland region join in Chinnar River. Pediments form on northern and eastern parts of the basin. More than 90% of the area is occupied by upland and pediment zones. Structural and residual hills, pediplains are the other geomorphic features manifested in the basin in lower proportion.

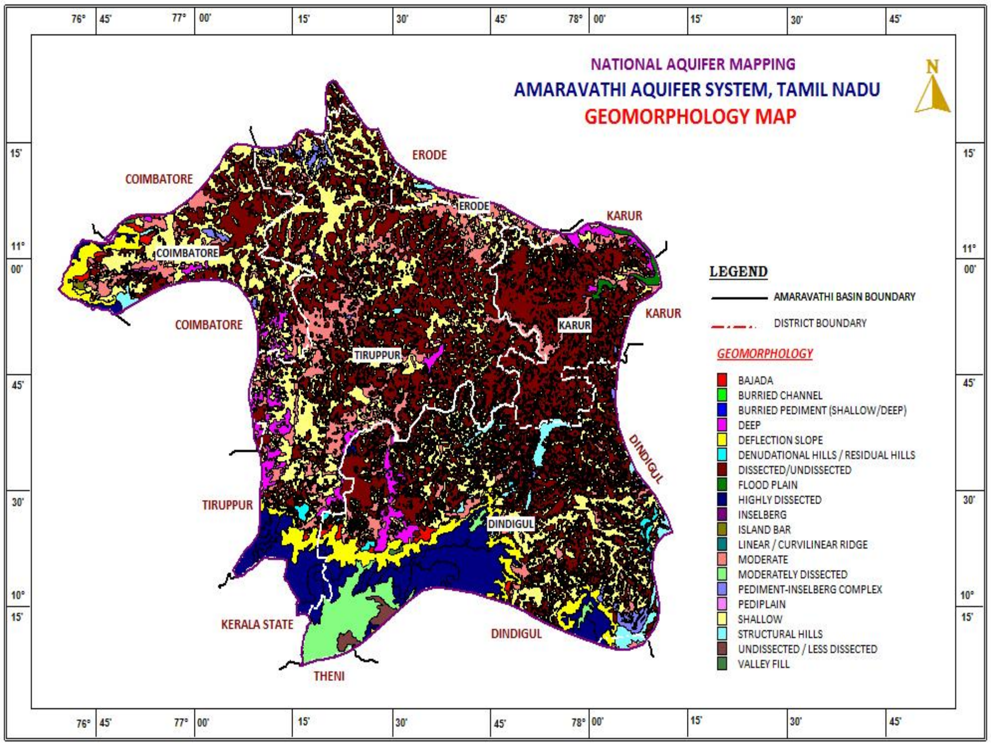


Figure –1. 2. Geomorphoology, Amaravathi basin

1.11. Land use:

Seventy-eight percent of the study area falls under agriculture, Forests occupy mainly on western and southern parts of the basin (11%), of the mapping area. Fallow land accounts for 4% and Urban and rural settlements confined to 5% of the total geographical area. Water bodies including Amaravathi reservoir and Aliyar reservoirs and irrigation tanks etc., spread over 0.11 % of the geographical area. The remaining part of the basin is occupied by scrubs and stony waste, Figure –1. 3.

1.12 Soils:

The soils of the basin mainly consist of red soil, black cotton soil, sandy loam and forest loam. The black or regular loam is very fertile due to its moisture absorbing character. On the other hand the red ferruginous soil is good for plant productivity. The soils in the basin are generally deep, loose and friable with its colour varying from red to dark reddish brown. The soils of the basin have low nitrogen and phosphate content. The highly undulating terrain in the basin especially in the upper reaches accelerates run-off causing soil erosion. Agricultural soils types are given in Figure – 1.4.

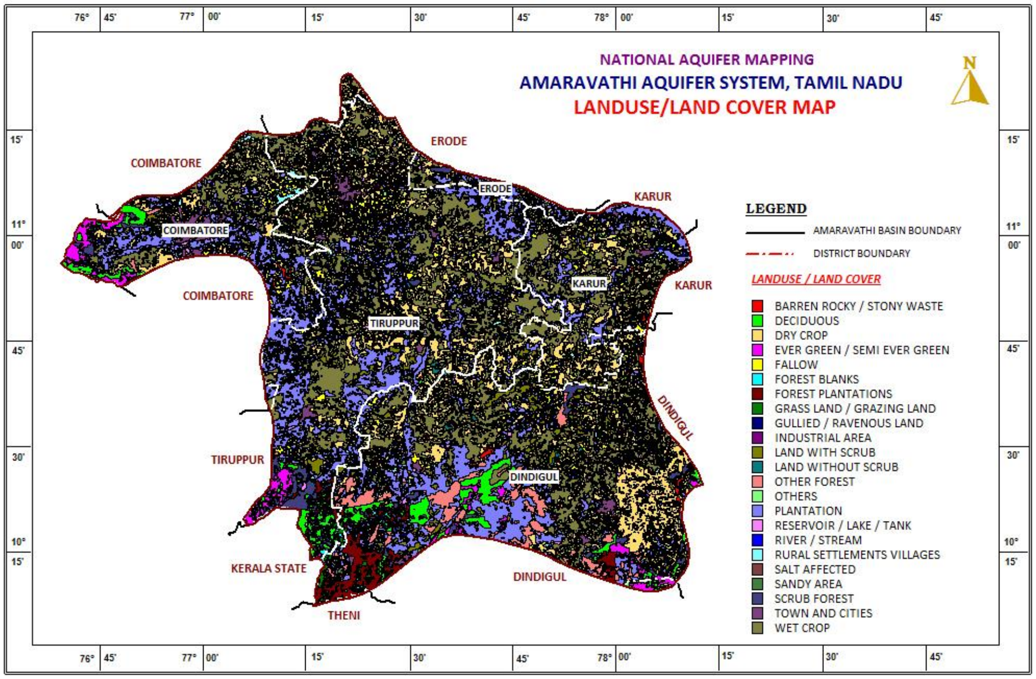


Figure –1.3. Landuse / Land Cover, Amaravathi basin

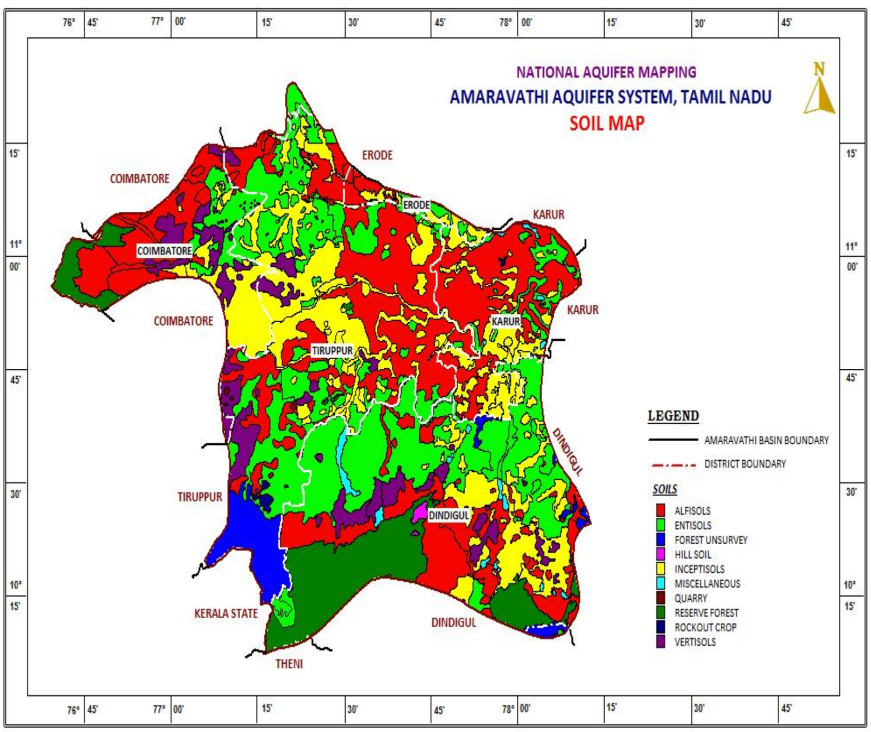


Figure – 4. Soils, Amaravathi basin

1.13: Geology

Geologically the entire area is covered with crystalline rocks of Granitic Gneiss, Granites and charnockites (Figure – 1.5). The weathered and fractured Granitic gneiss is the principle aquifer system, followed by Charnockites. Quartz vein intrusions are observed as out crops in porphyritic granites. Un-consolidated deposits comprising alluvial sands, clay, occur in isolated narrow patches along the Amravathi and Noyil rivers and major streams.

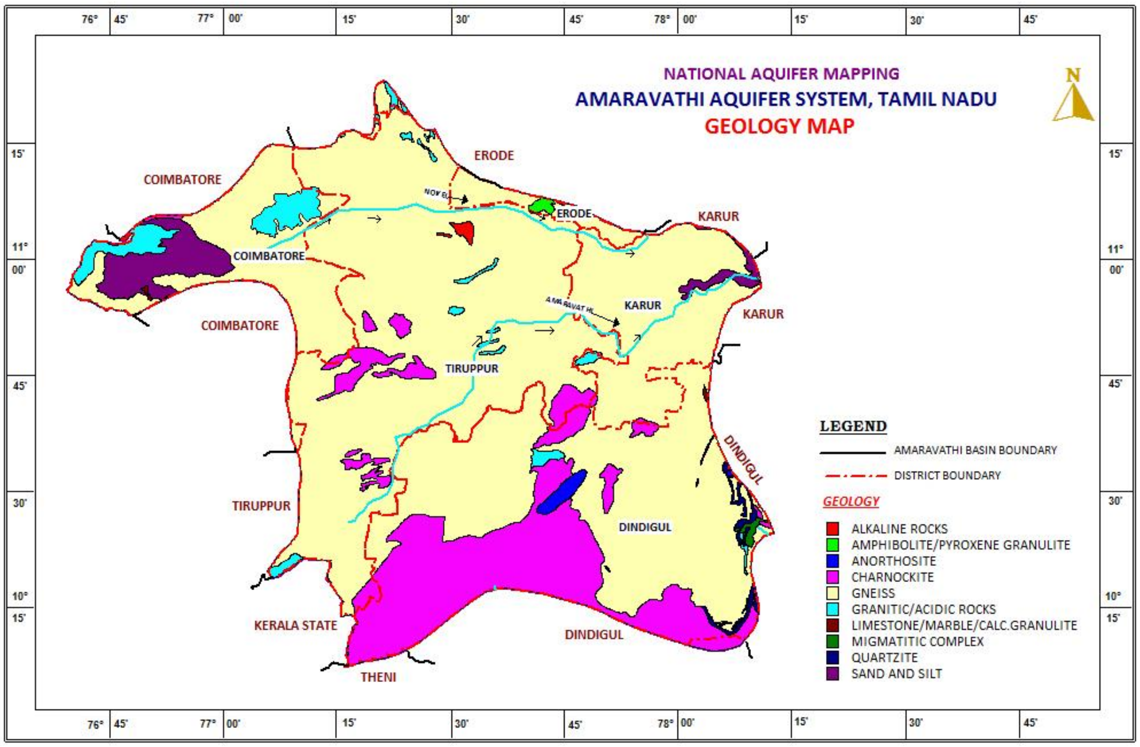
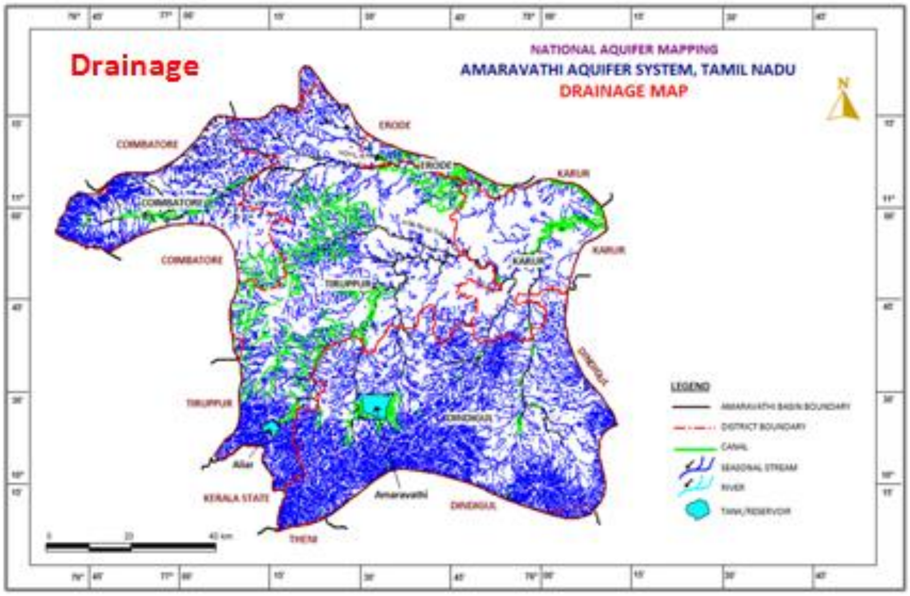


Figure –1. 5. Geology, Amaravathi basin

1.14. Hydrology and Drainage:

The Amaravathi rises in the Anjanad Valley in the Kerala State between the Anaimalai and the Palanis hills. The Chinnar river originates from Anamalai hills joins with another river called Tenar of Palani hills, and form a Amaravathi river. It descends in a northerly direction and debouches into the plains near Kallapuram at the mouth of the Anjanad Valley in the Udumalpet Taluk. It then runs north-east and receives the Kudiriyar from the Dindigul district on the right at Kumaragam. Thereafter, it flows into the Dindigul district to emerge again into the Dharapuram taluk. Here, after passing the town of Dharapuram and receiving the Uppar on its left, it goes along a winding course, fed by a few small streams, and finally leaves the district and enters the Karur district and falls into the Cauvery at Kattalai in the Kulitalai taluk. Fed by the south-west monsoon, it flows with some regularity from June to the end of August; then-it-falls to some extent in September, but rises again with the north-east monsoon till November, when it begins to fall once more until March at the end of which it is practically dry. Its banks are low and its water is fully utilized for irrigation of good quality along its entire course as a dam named Amaravathi Reservoir (Figure – 1. 6) was constructed near Kallapuram on the mouth of Anjanad Valley in Udumalai taluk of district.



Major river	: Amaravathi & Noyil
Flow Direction	: Noyil- W to E & Amaravathi- SW-NE
Major tributary	: Chinnar, Kodavanar, Nanganji, Kuduraiyar & Shanmuganadi
Pattern	: Dentritic
Reservoir	: Aliyar & Amaravathi

Figure – 1. 6. Drainage, Amaravathi basin

1.15. Agriculture:

Agriculture is the main stay of the rural population in the entire study area. The main crops irrigated are paddy, sugarcane, banana, groundnut, maize, cotton, ragi etc., and other minor crops are turmeric, flowers and vegetables. Total area cultivated in the study area is 490426 ha., which is about 40% of the geographical area of the basin.

1.16. Irrigation:

The total area irrigated under different crops is 338088 Ha out of the total geographical area of 12,28,500 Ha, which accounts for 27.52%. Out of the 107 firkas of the basin the highest area under irrigation is in Pethampatti of Tiruppur district (68.13% of firka area) followed by Kurichikottai of Tirupur district (59.36%), Arachalur of Erode district (65.43%), while the lowest area irrigated in Thandikudi firka of Dindigul district (<0.3% of the respective geographical area, as it is a hilly area). The irrigated area within the basin is relatively more in Tiruppur district part followed by parts of Dindigul and Coimbatore districts. The least area irrigated is in Karur district.

1.17. Recharge Practices:

Groundwater is being augmented through the recharge structures by departments/ agencies of State such as, Agricultural Engineering Department, Agricultural Department, PWD, TWAD Board and Forest Department. In addition, recently PWD is taking up Repair, Renovation and Restoration (RRR) of surface water bodies with central fund, which will be of immense use in groundwater augmentation in addition to the increase in storage capacity of the tanks.

2. DATA COLLECTION AND GENERATION

Collection, compilation and generation for aquifer mapping studies are carried out in conformity with EFC document of XII plan of CGWB encompassing various activities **(Table - 2.1)**.

Table - 2.1. Brief activities showing data compilation and generations.

S. No.	Activity	Sub-activity	Task
1	Compilation of existing data/ Identification of Principal Aquifer Units and Data Gap	Compilation of Existing data on groundwater	Preparation of base map and various thematic layers, compilation of information on Hydrology, Geology, Geophysics, Hydrogeology, Geochemical etc. Creation of data base of Exploration Wells, delineation of Principal aquifers (vertical and lateral) and compilation of Aquifer wise water level and draft data etc.
		Identification of Data Gap	Data gap in thematic layers, sub-surface information and aquifer parameters, information on hydrology, geology, geophysics, hydrogeology, geochemical, in aquifer delineation (vertical and lateral) and gap in aquifer wise water level and draft data etc.
2.	Generation of Data	Generation of geological layers (1:50,000)	Preparation of sub-surface geology, geomorphologic analysis, analysis of land use pattern.
		Surface and sub-surface geo-electrical and gravity data generation	Vertical Electrical Sounding (VES), bore-hole logging, 2-D imaging etc.
		Hydrological Parameterson ground water recharge	Soil infiltration studies, rainfall data analysis, canal flow and recharge structures.

S. No.	Activity	Sub-activity	Task
		Preparation of Hydrogeological map (1:50, 000 scale)	Water level monitoring, exploratory drilling, pumping tests, preparation of sub-surface hydrogeological sections.
		Generation of additional water quality parameters	Analysis of groundwater for general parameters including fluoride.
3.	Aquifer Map Preparation (1:50,000 scale)	Analysis of data and preparation of GIS layers and preparation of aquifer maps	Integration of Hydrogeological, Geophysical, Geological and Hydro-chemical data.
4.	Aquifer Management Plan	Preparation of aquifer management plan	Information on aquifer through training to administrators, NGO's, progressive farmers and stakeholders etc. and putting in public domain.

Periodical data pertaining to water levels, 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 implies the groundwater recharge and discharge (natural and manmade) occurring in the aquifer systems. There were 89 (Nos.) of groundwater monitoring wells existed earlier to the present studies, which were monitored periodically. To fill data gap in the basin, 139 Nos. of additional wells (Figure – 2.1)were established and monitored periodically during the aquifer mapping study period, in order to record the temporal and special changes in aquifer system. The details of monitoring wells are presented as Annexure - I. The groundwater level monitoring was carried out four times in a year since May 2012 to Jan 2015.

2.2. Hydrochemical data:

The groundwater quality of the basin was studied by collecting water samples from dug wells and bore wells. The sample locations were plotted on the map and identified data gap (Figure – 2.1). In the basin, groundwater quality of 66 wells was monitored periodically. To fill data gap in the basin, 139 Nos. of water samples were collected during micro level study. Water samples were collected from the study area in different aquifers (Aquifer - I & Aquifers - II) to assess the groundwater quality for drinking and irrigation purpose. The analytical results are given as (Annexure - 1I) & (Annexure - III) for aquifers - I & II respectively. Groundwater quality data has also been collected from TWAD, Govt. of Tamil Nadu.

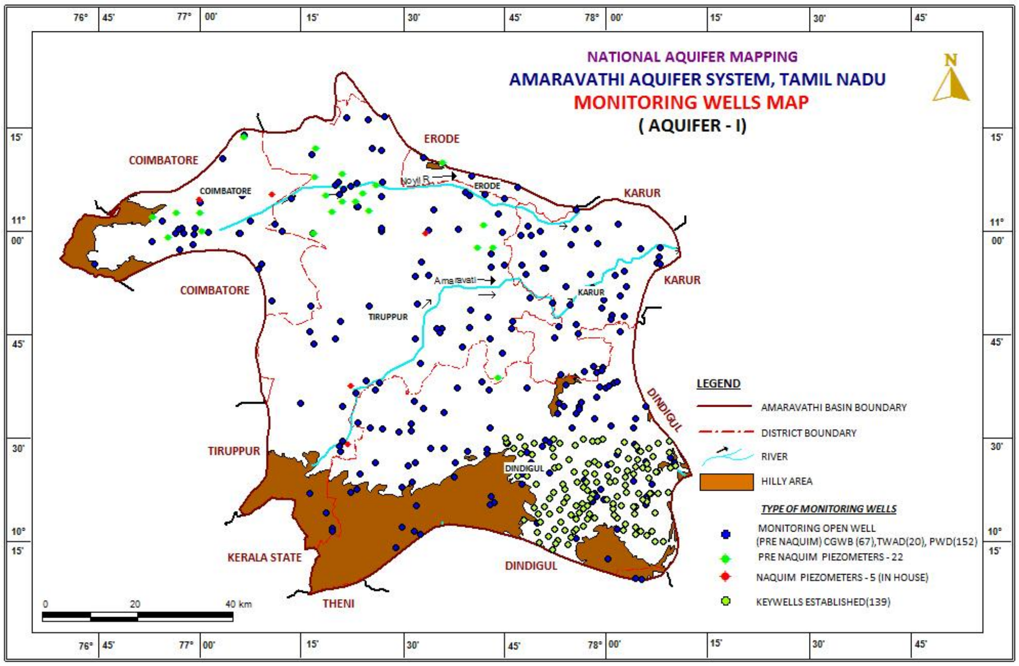


Figure – 2. 1. Water Quality Monitoring Wells in Amaravathi basin

2.3. Geophysical data:

The geophysical survey was conducted in the study area consisting of Vertical Electrical Soundings (VESs) by employing Schlumberger configuration with maximum half current electrode separation of 400m. The objective of the study was to decipher the sub-surface conditions such as; weathered and fractured layer resistivity and thicknesses, and massive formations, down to the depth of 200 mbgl. In all VESs were available in the survey area. The data was acquired by deploying the CRM 500 Aquameter and WDDS-2/2B Digital Resistivity meter by adopting the Schlumberger electrode configuration with a maximum current electrode separation (AB) of 400m. The data was processed and interpreted by IPI2Win software developed by Moscow State University, after marginally modifying the manually interpreted results keeping in view the local geology and hydrogeology. A total number of 21 VES were carried out during micro level survey and geo-electric layers inferred through interpretation of the results obtained. The locations of the VES are presented in the Figure – 2.2.

Figure – 2. 2. Locations of VESs conducted in Amaravathi basin

2.4 Groundwater Exploration data:

A total of 248 Nos. of exploratory wells were drilled in the basin under Groundwater exploration activity of the CGWB, SECR, Chennai prior to National Aquifer Mapping project (Figure – 2. 3). . These wells were plotted on the 1:50,000 scale topographical map. As per the National Aquifer Mapping guidelines for the hard rock, data requirements were identified on the plotted topographical map. Based on the data requirements, 17 Nos. of exploratory wells were drilled in the micro level aquifer mapping area of the basin as part of the data generation. The data such as lithology, fracture depth, yield, water level, aquifer properties were generated and utilized to depict the prevailing aquifer systems of the basin (**Annexure - 1Va**). Similarly data of wells drilled by state department has also been collected.

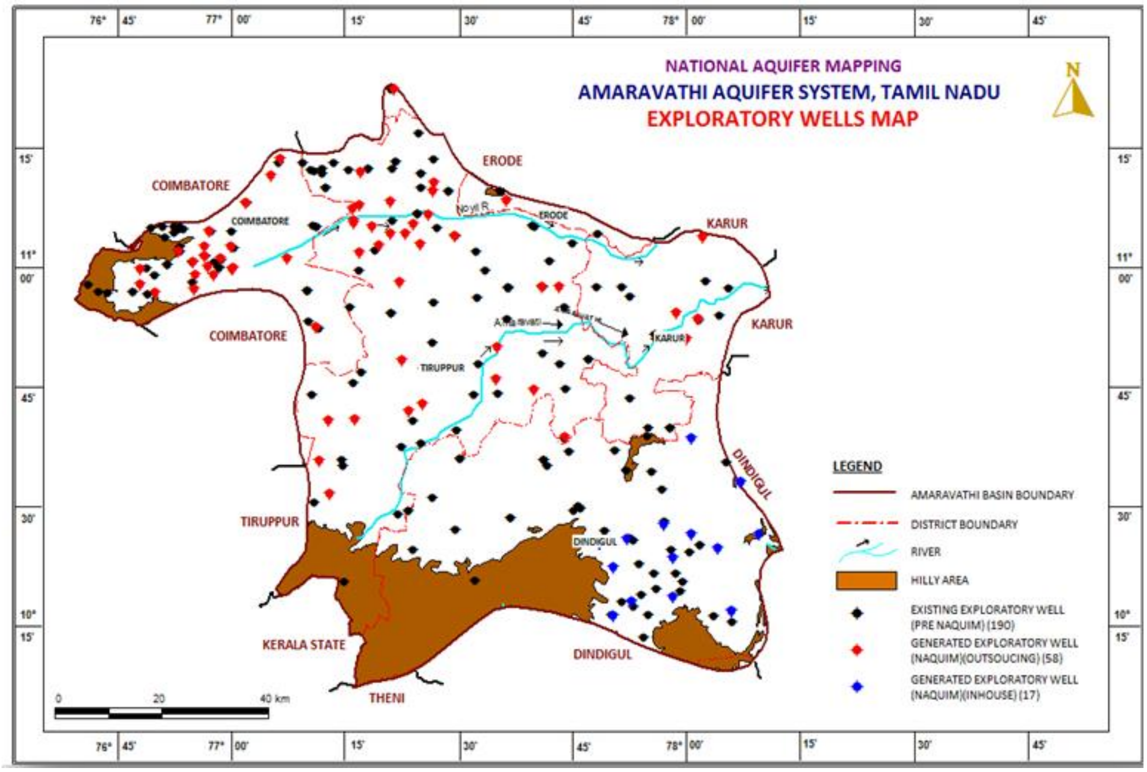


Figure – 2. 3. Locations of Exploratory wells drilled in Amaravathi basin

3.0 DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

3.1. Hydrogeological Data Interpretation

3.1.1 Groundwater Level

During Aquifer Mapping studies in Amravathi basin, 89 Groundwater monitoring wells which were monitored regularly were used along with 139 key wells established in different formations in order to know the behaviour of the groundwater regime. Out of total 139 wells, 30 wells were established in Charnockite, 85 in Gneiss, 14 in Granite, 5 each in Biotite gneiss and Migmatite formations respectively. The water levels were monitored from May 2012 to January 2016 (four times in a year). The depth of key wells ranged from 5.00 to 30.5 mbgl.

3.1.1 Pre Monsoon Depth to Water levels of aquifer - I (May 2015)

The water level data, pertaining to the period of May 2015 (pre monsoon), of key wells inventoried and national groundwater monitoring wells, was used for the preparation of depth to water level map (Figure – 3.1) of the basin The depth to water level during May 2015 is varied from 1.10 mbgl (Sulur, Sulur firka, Coimbatore district) to 42.25 mbgl (Vadavalli, Thondamuthur Firka, Coimbatore district.) Water levels ranging from 0 to

2 mbgl is seen in 28 wells (12%), whereas >2 to 5 mbgl range is seen in 53 wells (23%). Water levels ranging from >5 to 10 mbgl is observed in 78 wells (33%) Water levels ranging from >10 to 20 mbgl is observed in 55 wells (24%), Water levels ranging from >20 to 40 mbgl is shown in 13wells (6%). water level of > 40 mbgl is observed only in 4 wells (2%). Major part of the basin shows water level in the range of 5 to 10 mbgl. Water level in the range of >2 to 5 mbgl is found in central portion of basin. Water levels ranging >5 to 10 mbgl are observed in NW and SE parts of the basin. Water levels of >10 to 20 mbgl are observed in Dindigul and Ottanchatram, in the SE of the basin and Sulur and Pongalur firkas in NW part of the basin. Water levels in the range of >20 to 40 mbgl are observed in North –western fringes of the area i.e., in Gopichettipalayam and Perinackinayanpalyam and Gujiliamparai firkas of the basin.

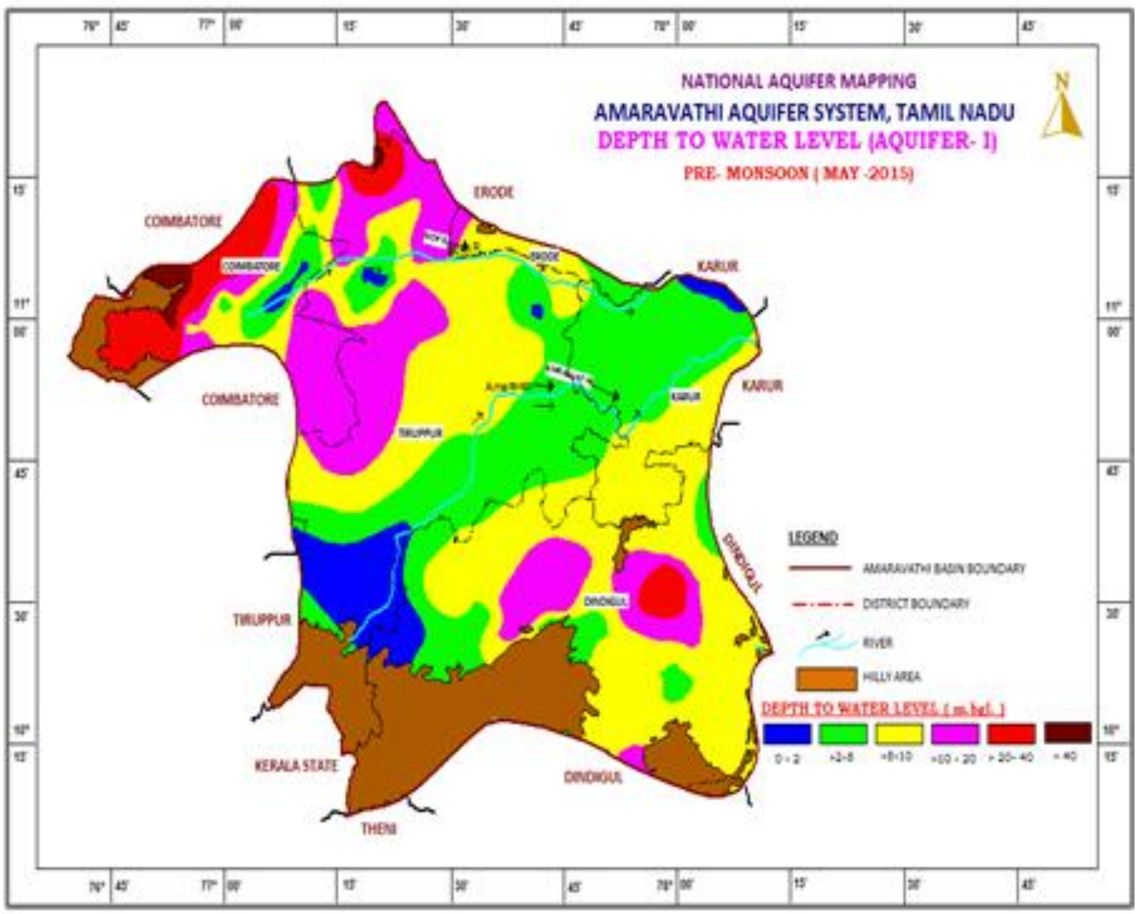


Figure – 3.1. Pre Monsoon Depth to Water levels of aquifer - I (May 2015)

3.1.2. Pre monsoon Depth to piezometric surface of aquifer - II (May 2015)

During May 2015, the depth to piezometric surface in the deeper aquifer in the basin ranged from 0.45 mbgl (Udumalpet PZ, Coimbatore district) to 113.35 mbgl (Ponnapuram pz, Erode district). Depth to piezometric surface of < 2 mbgl observed in 4 piezometers (PZs) (5%), >2 to 5 mbgl range was observed in 16 PZs wells (19%), >5 to

10 mbgl range was observed in 21 PZs (26%) >10 to 20 mbgl range was observed in 19 PZs (23%). >20 to 40 mbgl was observed in 17 PZs (23%) and > 40 mbgl was observed in 5 PZs (6%).

3.1.3. Post monsoon Depth to Water levels of aquifer - I (January 2016)

The depth to water level map for the post monsoon period (January 2016), is prepared based on the key wells and national groundwater monitoring wells data of the basin area is presented as (Figure – 3.2). The depth to water levels during this period is varied from 0.98 mbgl (Paramathi, Paramathi firka, Karur district) to 41.53 mbgl (Vadavalli, Thondamuthur Firka, Coimbatore district). Depth to water levels ranging from 0 to 2 mbgl was observed in 44 wells (19%). Water levels ranging from >2 to 5 mbgl is observed in 74 wells (32%), water levels ranging from >5 to 10 mbgl shows in 84 wells (37%), water level ranging from >10 to 20 mbgl is observed in 19 wells (8%), water levels ranging from >2 to 40 mbgl is observed in 8 wells (3%) and 2 wells (1%) show water levels >40 mbgl.

More than one third area of the basin (37%), shows water levels in the range of >5 to 10 mbgl, covering Northwest and south east of Amravathi river. Next major range is 0 to 2 mbgl (32%) observed infringe areas of central portion of the basin. Water levels ranging >2 to 5 mbgl is observed in central part of basin in Dharapuram and Mullanur firkas. Water levels >10 to 20 is observed in Pongalur and Avinashi firkas. More than 20 to 40 mbgl is observed in Thondamuthur and Thudiliyur firkas.

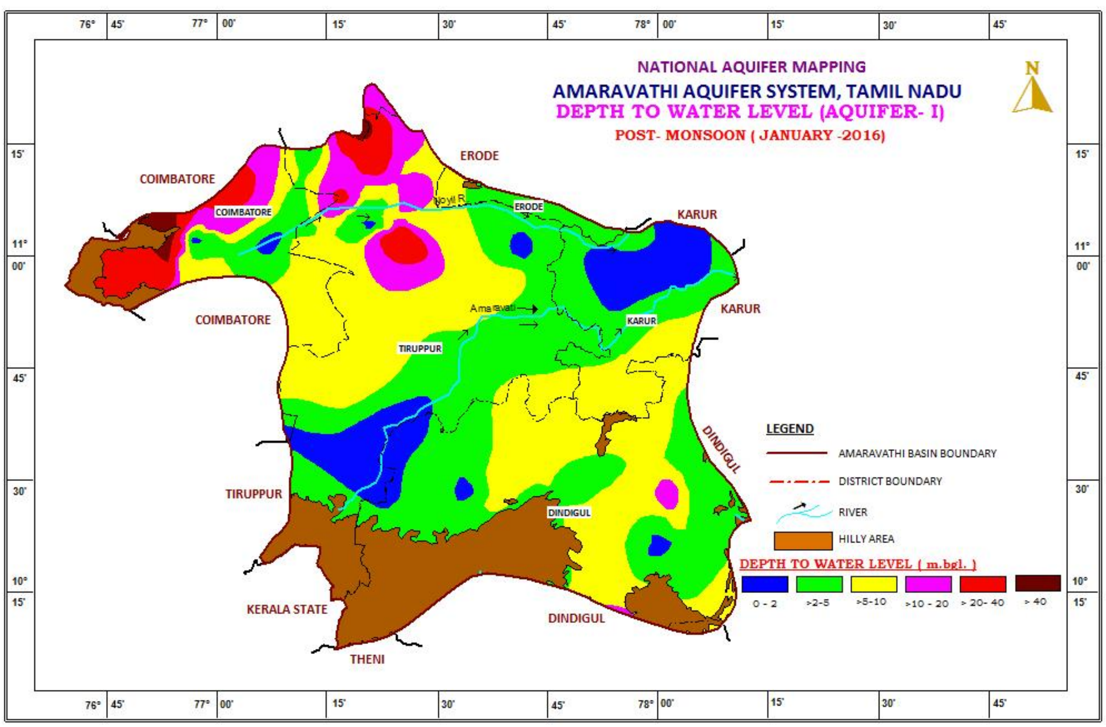


Figure – 3.2. Post monsoon Depth to Water levels of aquifer - I (January 2016)

3.1.4 Post monsoon Depth to Piezometric surfaces of aquifer II (January 2016)

During January 2016, the depth to piezometric surface of the deeper aquifer in the basin area ranges from 0.78 m bgl (Udumalpet Pz, Udumalpet firka, Coimbatore district) to 49.81mbgl (Kalvirampalayam Pz, Thudiyalur firka, Coimbatore district). Depth to piezometric surface <2 mbgl was observed in 9 PZs (11%) the basin. Piezometric surface ranging from >2 to 5 mbgl is observed in 22 PZs (27%), >5 to 10 mbgl is observed in 21 PZs (26%). piezometric surface in the range of >10 to 20 mbgl recorded in 14 PZs (17%) and >20 to 40 mbgl is recorded in 11 PZs (13%) and >40 mbgl observed in 5 wells (6%). In about 50% of the basin the depth to the piezometric surface is within the range of 2 to 5 and >5 to 10 mbgl.

3.1.5 Water Level Fluctuation:

Water level fluctuation in the observation wells 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 for sustainable groundwater development. The seasonal water level fluctuation in the area has been analyzed using the water level data of May 2015 and January 2016. As both southwest and northeast monsoons are active in the area the fluctuation recorded in groundwater levels of January 2016 in comparison to the water levels of May 2015 indicate the extent of replenishment of the shallow aquifer due to the monsoon rainfall.

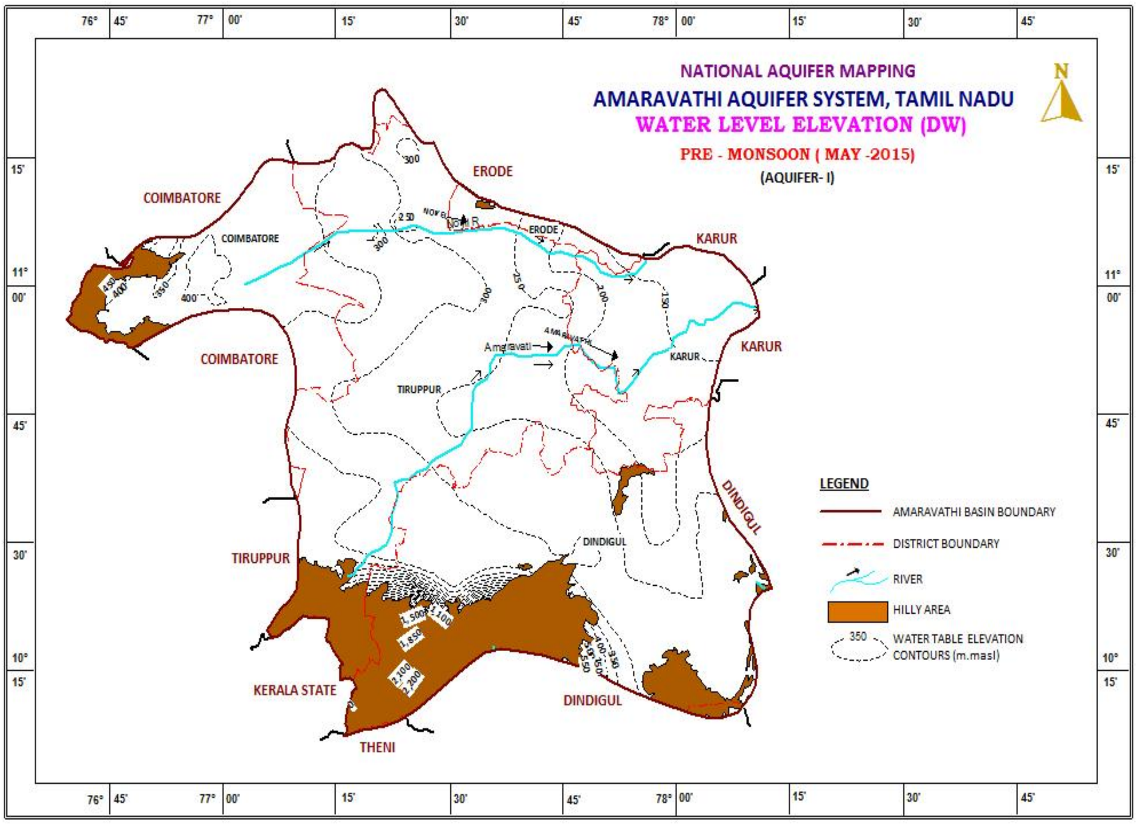
The water level fluctuation in the basin ranged from a decline of 3.50 m. (Palladam, Palladam firka, Coimbatore) to a rise of 25.20. m (Vedasundur, Vedasundur firka, Dindigul district) in phreatic aquifer (Aquifer - I) and decline of 21.55 m (Govindapuram pz, Ponnapuram firka, Tiruppur district to a rise of 22.12 m (Choladasanpatti Pz, Aravakurichi firka, Karur district) in deeper aquifer (Aquifer - II) during the period of study. The analysis indicates that water levels have risen during post-monsoon period in comparison to pre-monsoon in the major part of the basin, indicating replenishment of phreatic aquifer due to rainfall recharge. Rise in water levels in the phreratic aquifer during the period have been observed in more than 76% of the wells considered. The rise in water levels is in the range of 0.13 to 25.20 m and fall in the range of 0.01 to 3.50m. In Aquifer - II the rise in water levels is in the range of 0.10 to 22.12 m and fall in the range of 0.02 to 21.25m.

In Aquifer – I, rise in the water levels in the range of 0 to 2 m is observed in 86 wells (37%); >2 to 4 m rise observed in 26 wells (11%); and > 4 m rise observed in 64 wells (28%). Fall in the water levels in the range of 0 to 2 m is recorded in 43 wells (19%); of >2 to 4 m fall observed in 7 wells (3%); and > 4 m fall is observed in 5 wells (2%).

In aquifer – II, rise in piezometric surface in the range of 0 to 2 m is observed in about 40% of PZs, rise in piezometric surface in the range of >2 to 4 m observed in 16% of PZs, and > 4% is observed in 24 % of PZs. In the same aquifer - II fall is in the range of 0 to 2 m observed in 13% of PZs, > 4 m observed in 3% of the of PZs.

3.1.6. Water Table Elevation:

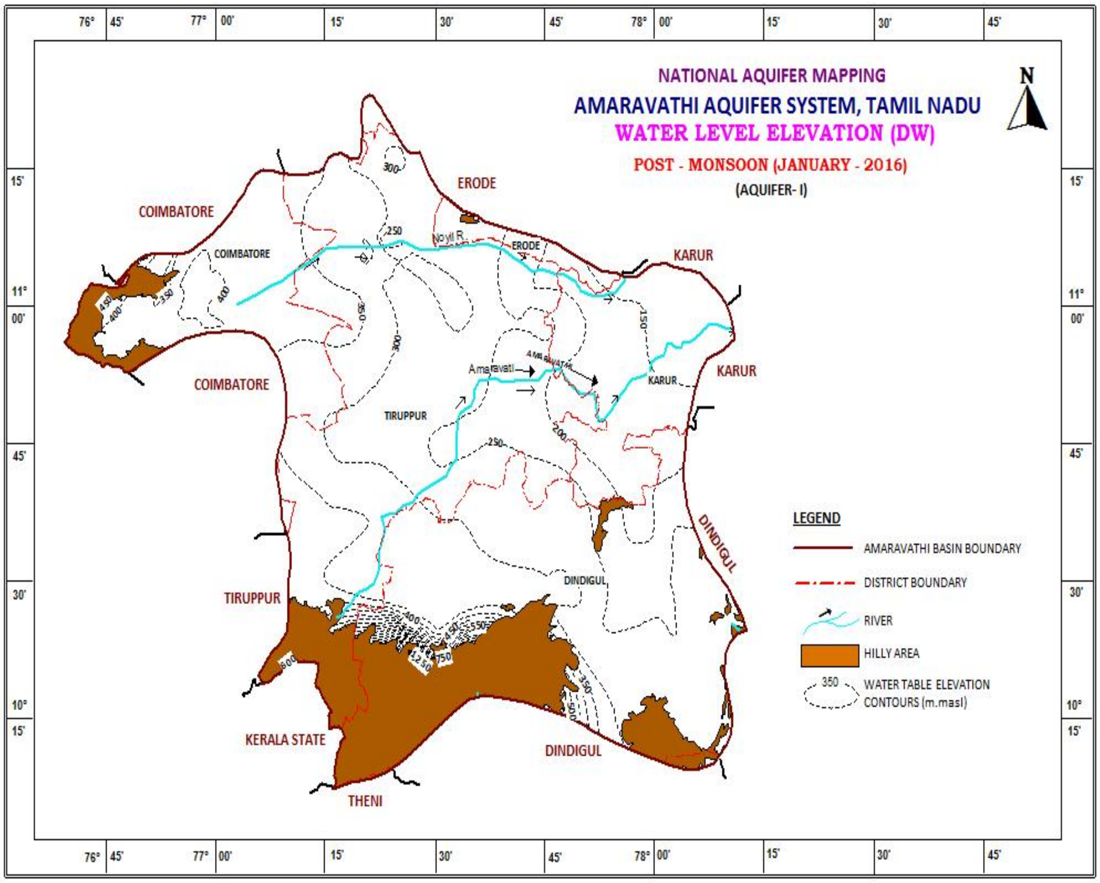
Water table elevation maps of aquifer - I of the basin during May 2015 and January 2016, along with flow lines showing the direction of groundwater movement are prepared and as & 3.4 respectively . The water table elevation ranges from 150 mamsl (Karur, Vangal - firkas) to 450 mamsl (Alandhurai and Thondamuthur firkas) in the basin. The groundwater movement of the basin is from west to east and from south to north and again towards east, where the Amravathi River takes a flow of east direction. Figures - 3.3



Figures - 3.3 Pre monsoon Water Table Elevations

3.1.2 Pumping Tests

Many of dug wells in the area have less than one meter water column during most of the years and about 50% of wells get dry during summers. Most of the time dug wells are used as storage tanks to collect water from a number of bore wells and to distribute the collected water for irrigation as the yield of each bore well is much less to support irrigation. The wells located in favorable hydrogeological settings like shear zones, topographic lows, river alluvium, etc., are able to sustain at a rate of 240 lpm for 3 to 4 hrs of pumping. The yield of large diameter wells tapping the weathered mantle of crystalline rocks ranges from 20 to 260 m^3/day 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 180 lpm/m/dd. The Transmissivity values of the weathered formation computed from pumping tests ranges from 5 to 80 m^2 /day and storativity ranges from 4.37×10^{-4} to 7.89×10^{-3}. At a very few places the weathered mantle extends down to 35 mbgl.



Figures - 3.4 Post monsoon Water Table Elevations

Due to drilling technology bore wells for Irrigation and drinking water purpose has increased. The depths of bore wells generally vary from 150 to 350 mbgl with yields varying from 0.01 to 4 lps, in general. Occasional high yielding wells of 7.69 lps has also occurred at some places. The duration of pumping tests vary from 500 to 1000 minutes. The maximum drawdowns of the wells ranging 2.5 to 60.10 m. The specific capacity value varies from 5.18 to 10.42 lpm/m. The Transmissivity value of these aquifer system ranges from 9 to 24.56 m2/day. The computed storativity value ranges between 0.0378 and 0.00026. Permeability value ranges from 0.015 to 3.54 m/day. Slug tests were conducted on the bore wells drilled by the CGWB. The computed Transmissivity value ranges from 0.42 to 4.5 m^2/day.

3.2. Hydro chemical Data Interpretatin

Chemical composition of Groundwater in aquifer is influenced by various factors such as the chemical composition of litho units, composition and permeability of soils, degree and pattern of weathering etc. It is also influenced by agricultural, drainage and irrigation practices prevalent in the area. The chemical characteristics of ground water in the phreatic zone in Upper Cauvery basin has been studied using the analytical data of groundwater samples collected from key wells, Network stations of Central Ground Water Board and observation wells of State Groundwater Department, Government of Tamil Nadu

Table4. Ground water quality of Amaravathi basin during May-2015 Dindugal , Coimbatore, Karur & Thirupur

S.No	Parameters	Range	No. Of sample	Percentage
1	Electrical Coductivity µs/cm at 25^{o}c	< 750	8	11
		75 1- 2250	43	60
		2251- 3000	11	15
		> 3000	10	14
2	Chloride mg/l	< 250	42	58
		251-1000	26	36
		> 1000	4	6
3	Fluoride mg/l	< 1.0	58	80
		1.1- 1.5	12	17
		>1.5	2	3
4	Nitrate mg/l	<4 5	58	80
		45-100	13	18
		> 100	01	2

3.2.1. Quality of Groundwater in phreatic aquifer:

The analytical data of groundwater samples collected from key wells during May 2015 have been used for detailed study of various aspects of water quality in the basin. Groundwater in phreatic aquifers in Amaravathi basin, in general is colourless, odourless, and slightly alkaline in nature. The range of concentration of the various chemical constituents and the degree of mineralization in groundwater samples of phreatic aquifers in the area are presented in

Table4.1 **Chemical Constituent**

Chemical Constituent	Range of Chemical constituent	
	From	**To**
pH	7.0	8.2
EC(µS /cm at 25° C)	20	5750
Total hardness	20	1800
Ca	6	510
Mg	1	340
Na	2	718
K	1	32
HCO3	18	732
Cl	04	1602
SO^4	02	1085
NO^3	1	124
F	0.29	1.6
As	0.045	9.35

The waters are generally alkaline with pH varying from 7.0 (P.N.Palayam,P.N.palayam block) to 8. 2 (Perumal malai, Kodaikanal /block).

The Specific electrical conductance of groundwater in phreatic aquifer is in the range of 50((Perumal malai, Kodaikanal /block to 5750 (Myanur , Krishnarayapuram block) in the basin. In the major part of the basin Electrical Conductivity is in the range of 750 to 2250 µS/cm.(60 %). Conductance exceeding 3000µS/cm have been observed in parts of Palani, Vedasandur , Krishnarayapuram, Thogamalai , Pollachi north, Pongalur, and Thiruppur blck.

Chloride in phreatic groundwater varies from 04 to 1602 mg/l in the basin and is below 500 mg/l in major part of basin. Value 1000 mg/l, more than permissible limit only found in Thiruppur , Vedasandur ,Krishnarayapuram block. This may be due to human activities in and around the area.

Nitrate is one of the major indicators of anthropogenic sources of pollution. The negative charge and high mobility favours its persistence in nature and transport along the ground water flow path. Nitrate is the ultimate oxidized product of all nitrogen containing matter and its occurrence in ground water can be fairly attributed to infiltration of water through soils containing domestic, vegetable and animal waste, fertilizer and industrial pollution. As the lithogenic sources of nitrogen are very rare, its presence in ground water is almost due to anthropogenic activity.The concentration of Nitrate in the phreatic groundwater ranged between 01(Perumal malai, Kodaikanal block) and 124 (Thoppampatti , Thoppampatti block) mg/L. About 80% of the samples showed the drinking desirable limit of nitrate below 45 mg/L, 18% of the samples showed nitrate between 46-100 mg/L and about 2% of the samples showed nitrate 100 mg/L, which are above permissible limit of BIS. These wells are located in Thoppampatti block.

Fluoride exists naturally in all waters derived from the dissolution of fluoride containing minerals. Surface water generally has low fluoride while ground water may have high concentrations of fluoride as has been found in many parts of the world. The formation of high fluoride ground waters is principally governed by climate, composition of bedrock and hydrogeology. Areas with semi-arid climate, crystalline, igneous bedrock, and alkaline soils are the most affected. Fluoride is an impurity commonly found in phosphate fertilizers used in the agriculture. Accumulation of fluoride in the soils eventually results in leaching by percolation into the groundwater aquifer and thereby increases the concentration of fluoride level. In the shallow groundwater, the concentration of fluoride ranged between 0.29(Saravanapatti/Sarkarsamakulam block) to 1.6mg/L(Mayanur , Krishnarayapuram block). About 80 % of samples showed fluoride < 1mg/L, which is the desirable limit for drinking. About 17 % of samples showed fluoride in the range of 1 to 1.5mg/L, the maximum permissible limit in the absence of alternate sources. About 03 % of samples showed fluoride > 1.5mg/L. These wells are located predominantly in the Krishnaroyapuram and Thathane blocks in the study area.

3.2.2. Quality of Groundwater in the Fractured Aquifers:

Quality of Groundwater in the fractured zones at depth has been studied using the analytical data of water samples collected from Irrigation wells, Hand pumps during well inventory and exploratory bore wells drilled by CGWB. However these samples have been collected represent the cumulative quality of all water yielding fractures in the well, they have been used only to get an idea about the water quality of the deeper aquifer as a whole.

The range of concentration of the various chemical constituents and the degree of mineralization in groundwater samples of fractured aquifers in the area are presented in **Table5**.

Table 5:

Chemical Constituent	**Range of Chemical constituent**	
	From	**To**
pH	7.0	8.6
EC(µS /cm at 25° C)	841	8690
Total hardness	45	1364
Ca	10	280
Mg	05	423
Na	09	1035
K	4	74
HCO3	31	732
Cl	25	2446
SO^4	02	936
NO^3	1	87
F	0.1	1.8

The Chemical analysis result indicates that there is considerable variation in the chemistry of groundwater from the deeper aquifer as well.

The Specific Electrical Conductance of ground water in the fracture aquifers ranges from 150(µS /cm at 25° C) (Karumbapatti , Karur Dt) to 8690(µS /cm at 25° C) (Velvarkottai, Dindugal). Chloride ranges from 25mg/l((Karumbapatti , Karur Dt)) to 2446mg/l (Velvarkottai, Dindugal),Nitrate ranges from 01mg/l (Sivalasaragu, Dindugal DT) to 87 mg/L(Karumansirai, Thiruppur Dt) and Fluoride ranges from 0.1mg/l (Noyyal/Karur Dt) to 1.8 mg/L(Sittapatti/Karur Dt). As the occurrence of groundwater in the deeper zone is restricted to fractures which may or may not have continuity on a regional basis, preparation of maps showing the distribution of groundwater quality has not been attempted. Suitability of Groundwater for domestic uses has been analyzed with reference to various constituents and the results are given in **Table -6.**

Table - 6: Ground water quality in different aquifers in Amaravathy basin, Tamil Nadu

S.No	Parameters	Range	Classification	% of samples	
				Aquifer-I	Aquifer-II
1	Electrical Conductivity µs/cm at 25°c	< 750	Fresh	11	5.4
		75 1- 2250	Moderately Fresh	60	60
		2251- 3000	Slightly mineralized	15	17.8
		> 3000	**Highly mineralized**	14	**13.6**
2	Chloride mg/l	< 250	Desirable limit	58	60.2
		251-1000	Permissible limit	36	38.4
		> 1000	**Above permissible limit**	6	**1.4**
3	Fluoride mg/l	< 1.0	Desirable limit	80	63.1
		1.1- 1.5	Permissible limit	17	27.4
		>1.5	**Above permissible limit**	**3**	**9.5**
4	Nitrate mg/l	<45	Desirable limit	80	72.6
		46-100	Permissible limit	18	27.4
		> 100	**Above permissible limit**	2	Nil

In the study area the pH ranged from 7.0 to 8.2 and 7.0 to 8.6 for aquifer- I and aquifer-II respectively. Most of the samples have pH ranging between neutral to slightly alkaline in nature and are within the limits of drinking water standard of BIS 10500:2012.

3.2.3. 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 distributions of EC in different aquifers are in Fig. 3.5.

The phreatic aquifer ground water quality is fresh in about 11% , as indicated by the EC value less than 750 µs/cm at 25^{o}C. In about 60% of the Ground Water indicating the moderately fresh showing the EC varies between 751 -2250µs/cm at 25^{o} C, 15% of Ground Water showing EC between 2251-3000 µs/cm at 25^{o} C indicating that the ground water is slightly mineralized and about 14% of groundwater wells the EC is more than 3000 µs/cm at 25^{o}C indicating that the ground water is highly mineralized.

The fractured zone ground water quality is fresh in about 5.4%, as indicated by the EC value less than 750 µs/cm at 25^{o}C. In about 60% of the Ground Water, the EC varies between 751 -2250µs/cm at 25^{o} C indicating that groundwater is moderately fresh and 17.8% of groundwater are between 2251-3000 µs/cm at 25^{o} C indicating that the ground water is slightly mineralized and about 13.6% of groundwater wells the EC is more than 3000 µs/cm at 25^{o}C indicating that the ground water is highly mineralized

3.2.4. Chloride:

The classification of concentration of chloride in phreatic aquifer groundwater is that about 58% shows with in desirable limit, where as in fractured aquifer 60.2%shows with in desirable limit., 36% of samples in phreatic aquifer and 38.4% of samples in fractured aquifer are within permissible limit respectively and about 6% of groundwater wells in phreatic aquifer and 1.4 % of the samples in fractured aquifer are above permissible limit.

3.2.5 Nitrate:

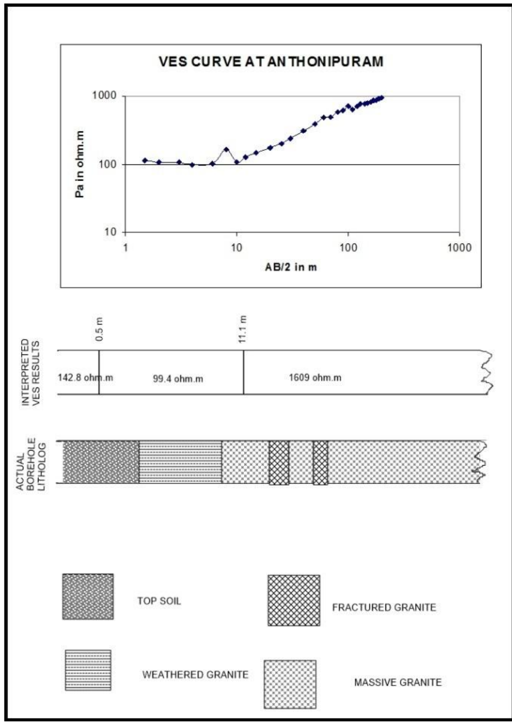
The concentration of Nitrate in the phreatic groundwater shows that about 80% of the samples nitrate below 45 mg/L, the desirable limit , 18 % of the samples showed nitrate between 46-100 mg/L and 2 % of the samples showed nitrate more than 100 mg/L, which are above permissible limit. Nitrate concentration in the fractured aquifer shows that about 72.6% of the samples nitrate below 45 mg/L, the desirable limit for drinking and 27.4% of the samples showed nitrate between 46-100 mg/L and there is no samples showed nitrate more than 100 mg/L, which are above permissible limit of Burea of Indian standard (IS 10500:2012).

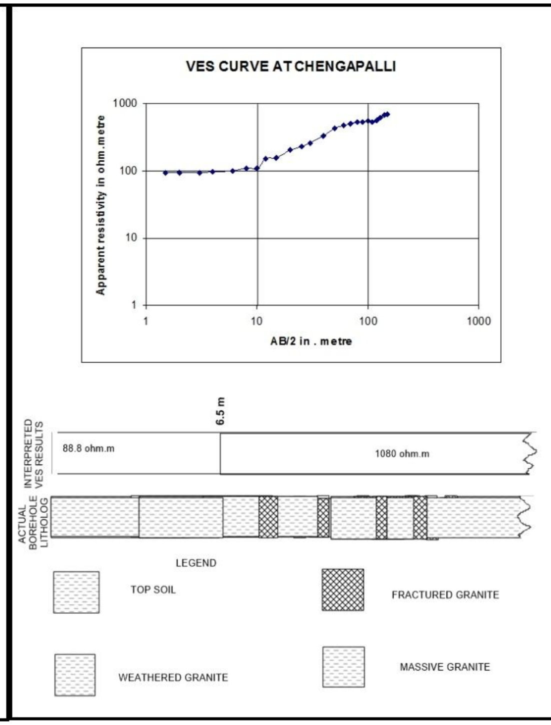
3.2.6 Fluoride:

In the Phreatic groundwater, the concentration of fluoride shows that about 80% of samples fluoride is < 1mg/L, which is the desirable limit for drinking. About 17% of samples showed fluoride in the range of 1 to 1.5mg/L, the maximum permissible limit in the absence of alternate sources. About 3% of samples showed fluoride > 1.5mg/L. In fractured aquifer the groundwater shows that about 63.1% of wells fluoride is in the range of 0 to 1.0mg/L, about 27.4% in the range of 1.1 to 1.5mg/L and about 9.5% more than 1.5mg/L. It clearly indicates that more number of wells in deeper aquifers have fluoride more than 1.5mg/L compare to phreatic aquifer water. High concentration (>1.5 mg/l) of fluoride in fractured aquifer.

3.3 Geophysical Data Interpretation

As discussed in section in 2.3 the VES data generated were interpreted in both qualitative and quantitative manner. Based on the interpreted results of VESs conducted in the area, three to five subsurface geo-electrical layers are revealed by A, H, AA, HA, KH and QHA types of curves. The VES results were standardized based on the local geology & hydrogeology and existing borehole data that the first layer resistivity is varying in the range of 11.2 to 255 ohm. m, which is top soil. The thickness of this layer is varying in the range of 0.5 to 3 m. The second layer resistivity, which is varying in the range of 12.2 to 250 ohm. m is considered as weathered formation. In this range, the lower order of resistivity indicates higher weathered content and higher order of resistivity indicates dryness. The thickness of this formation is varying in the range of 2.5 to 30 m. The resistivity in the range of 34 to 999 ohm.m was recorded as third and (or) fourth and (or) fifth layer, which was considered as massive formation with fractures at different depths.In general, the thickness of this formation is varying in the range of 20 to 185 m. Based on the VES results, 2 numbers of geo-electric cross sections AA' and BB' were prepared through ROCKWORKS software and some of the VES curves are correlated with actual lithology shown in **Figure – 3.5 to 3.7.**





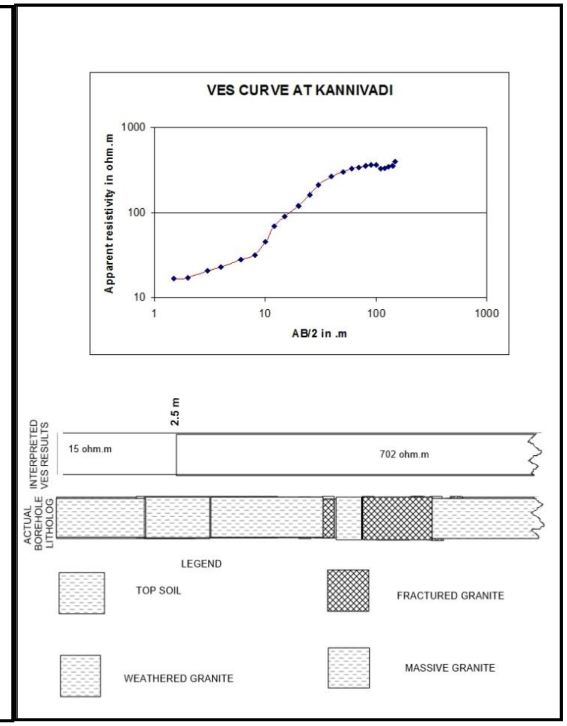


Figure – 3.5. Comparison of VES Results with Actual Bore well litholog at Anthonipuram	**Figure – 3.6. Comparison of VES Results with Actual Bore well litholog at Chengapalli**	**Figure - 3.7. Comparison of VES Results with Actual Bore well litholog at Kannivadi**

3.4 Groundwater exploration data results

The data generated, as discussed in section 2.4, such as lithology, fracture depth, yield, water level, aquifer properties were and utilized to depict the prevailing aquifer systems of the basin. Depth of Exploratory wells drilled in the basin ranging from 25.16 mbgl (SiruvaniAdivaram, Coimbatore district) to 304.10 m.bgl (Kumarapalayam, Coimbatore district). Drilling data of the exploratory wells has revealed the presence of productive fractures in the area underlain by granitic gneiss, granites and charnockites. Over all productive fracture zones have been encountered in crystalline rocks at the depth range of 11 to 199.75 m.bgl at (Sriramapuram, Athur Firka, Dindigul district) in the basin. Discharge of the bore wells in the basin varies from 0.035 to 4.0 lps. Wells drilled in Granitic gneiss, yield more than the wells drilled in Chornockites. Wherever the pegmatite and quartz veins intrude the granitic gneiss have yielded exceptionally high discharge (12 lps, Somandhuraichittur of Coimbatore). The fractures encountered in Granitic gneissic rock formations are more than that of other formations. A few of the wells have been abandoned due to poor yield.

Total 265 bore wells data have been analyzed for fracture analysis in the study area. It shows that 1^{st} fracture encountered in 20 wells with depth vary from 7.00 to 35.00 mbgl. 2^{nd} fracture encountered in 80 bore wells with depth varying from 35.00 to 103.21 mbgl. Similarly, 3^{rd} fractured encountered in 38 bore wells with depth vary from 80 to 110 mbgl. The fourth fractures were also encountered in 27 bore wells with depth vary from 90.50 to 140.0 mbgl. Data clearly indicates that generally two fractures are available in the study area with depth of 20.12 to 213 mbgl.

The aquifer mapping studies reveal that the presence of two distinct aquifers in the hard rock formations. They are;

3.4.1. **Aquifer - I**: It comprises of weathered, partially weathered and first fracture to some extent in Granitic gneisses, Charnockites and Granitic formations. The depth of occurrence of first aquifer ranges from 0 to 3 mbgl. The aquifer with a thickness of 7 to 35 m is noticed in the study area. The maximum thickness is observed in eastern part of basin in and around Ullappukudi of Dindigul district. The wells located in this aquifer zone yield groundwater of 20 to 260 m^3/day and sustain 2 to 3 hrs. of pumping. Specific Capacity and Transmissivity values of this aquifer across the basin ranges from 7 to 180 lpm per meter drawdown and 5 to 80 m^2/day respectively.

3.4.2. Aquifer - II: It comprises of mainly of fractures (secondary porosity) developed during tectonic disturbances**,** occurs at depth generally ranges from 20.12 to 199.75 mbgl. The maximum yield of wells tapping this aquifer varies from 3 to 345 m^3 /day and sustain for 3 to 5 hrs. of pumping. The Transmissivity value of the aquifer ranges between 0.1 and110 m^2/day while the Specific capacity values vary from 0.016 to 15.97 lpm/m drawdown. Storativity of the aquifer ranges from 0.00001 to 0.0214 in the basin.

3.5. Aquifer Maps

3.5.1. 2D models showing Aquifer Dispossition:

Based on the lithologs of the exploratory wells and the well sections observed during field studies as part of Aquifer Mapping studies, 2D models of the aquifer system of the basin has been deciphered by using ROCKWORKS software. The data input for ROCKWORKS is prepared in following format as shown in **Table** – **3.5.1** to generate 2D models of the basin along different selected sections.

Table – 3. 5. 1 Database prepared for generation of aquifer models

Data - 1

Bore	District	Longitude	Latitude	Elevation (mamsl)	Total Depth (mbgl)
SRIRAMAPURAM	Dindigul	77.81	10.42	305.49	200.00

Data - 2

Bore	$Depth_1$	$Depth_2$	Lithology
SRIRAMAPURAM EW	0	24.15	Weathered
SRIRAMAPURAM EW	24.15	199.75	Fractured Zone
SRIRAMAPURAM EW	199.75	200.00	Massive

Data - 3

Bore	$Depth_1$	$Depth_2$	Yielding Fracture
SRIRAMAPURAM EW	36.00	36.75	1st Fracture
SRIRAMAPURAM EW	198.00	199.75	2nd Fracture

Data - 4

Bore	Type	$Depth_1$	$Depth_2$	Value (lps)
SRIRAMAPURAM EW	Discharge	36.00	36.75	0.20
SRIRAMAPURAM EW	Discharge	198.00	199.75	5.40

Data - 5

Bore	$Depth_1$	$Depth_2$	Stratigraphy
SRIRAMAPURAM	0	1	Top soil
SRIRAMAPURAM	1	24.15	Weathered
SRIRAMAPURAM	24.15	199.75	Fractured
SRIRAMAPURAM	199.75	200.00	Massive

3.5.1.1. Section along SW-SE direction (A-A')

Section along Southwest – Southeast (Figure – 3.5.1) direction in the basin indicates that the 1st Aquifer exists above 280 to 360 mamsl with thickness varying from 3.46 to 30.00 m in between. Second Aquifer exists 160 to 280 mamsl with 6.5 to 162 m thickness and 2 to 3 sets of fractures.

3.5.1.2. Section along SSW- NNE direction: (B-B')

Section (Figure – 3.5.2) shows that weathered aquifer spreads about 6 to 25.74 m thickness and it thins out at Ponnapuram of Coimbatore district, where the thickness is minimum of 6 m. Fractured aquifer has attained its maximum thickness about 110 m at Talakarai of Tiruppur district. Rest of the stretch of section the fractured aquifer thickness varies from 10 to 80 m with 2 to 3 sets of fractures.

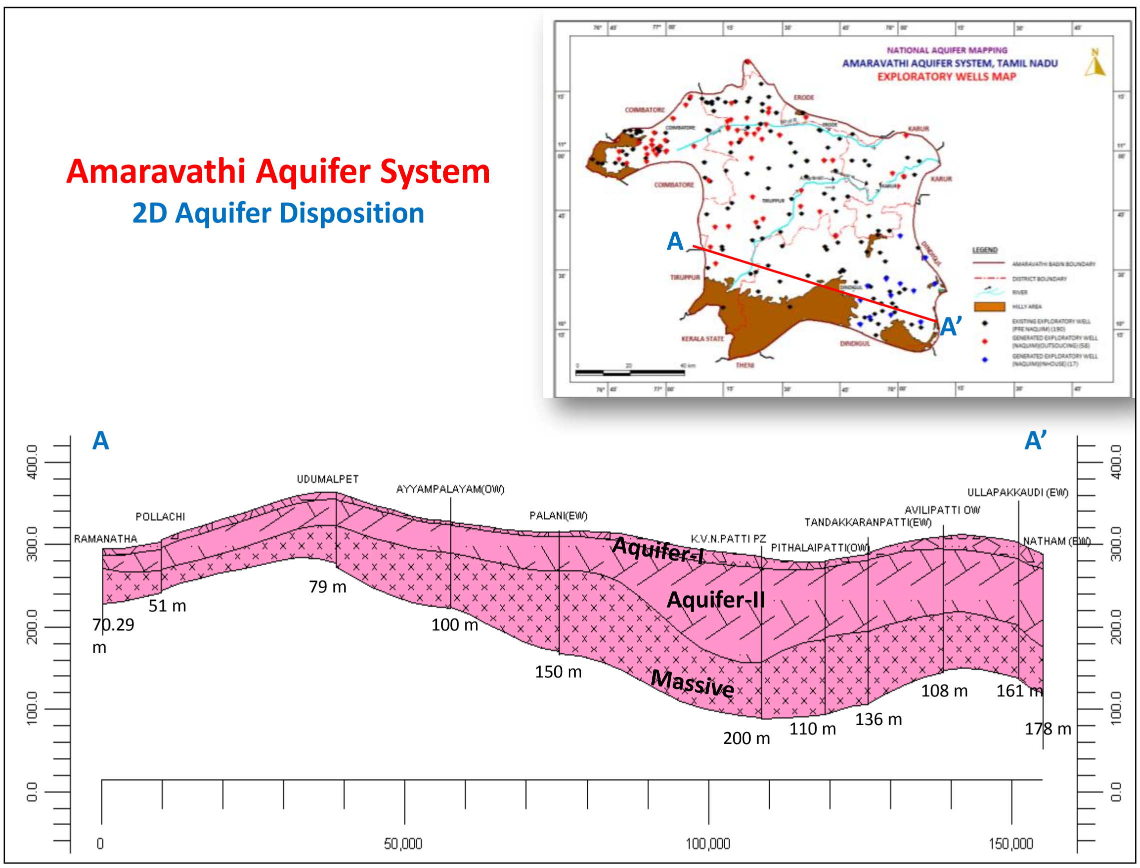


Figure – 3.5.1. Section along A – A'

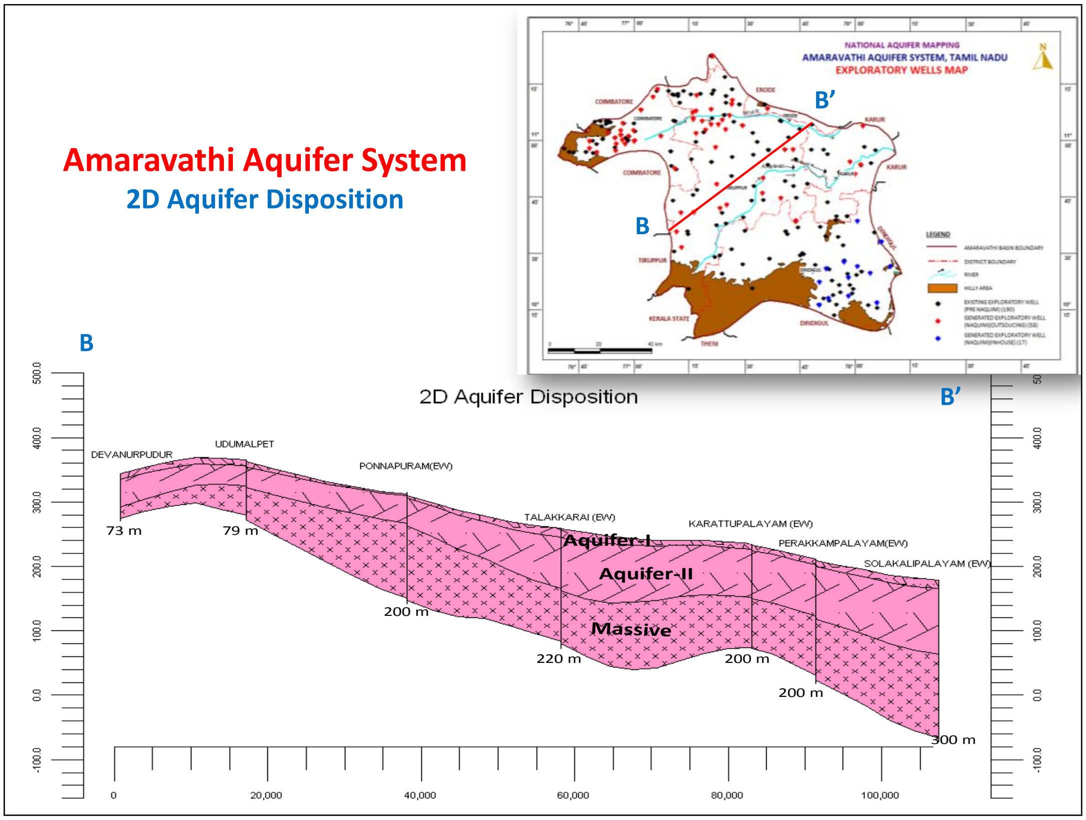
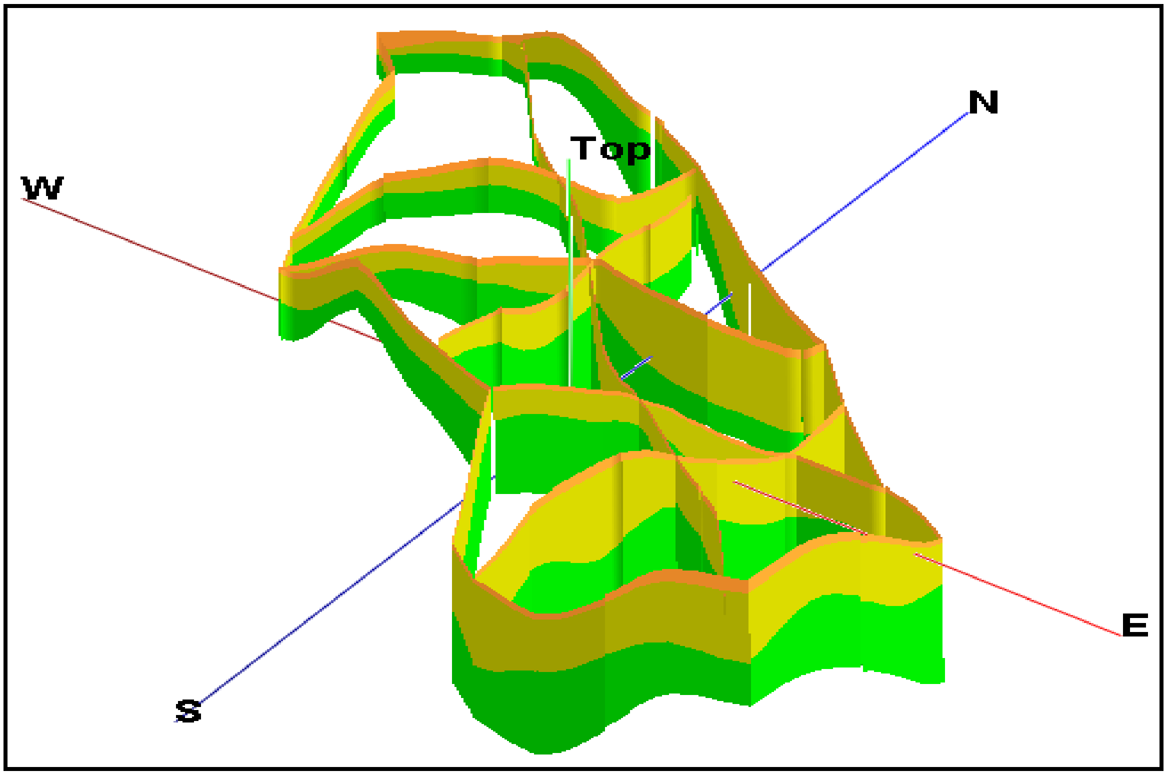


Figure – 3.5.2. Section along B – B'

3.5.2. 3D Models

3D (Figure - 3.5.2.1) view shows that spreading of two aquifers throughout the basin with 1st aquifer thickness vary from 7 to 35 m and Fracture aquifer spread with thickness vary from 11 to 199.75 m. 3D section indicates that thickness of weathered aquifer is considerably high in north portion compared to south. Thickness of fractured aquifer is considerably high in North & East compare to, West and South of the basin.



(Figure - 3.5.2.1) 3D Aquifer Disposition

4.0. GROUNDWATER RESOURCES:

The dynamic groundwater resourcesis estimated as on 2012-13 based on the methodology suggested by Ground Water Estimation Committee (GEC) 1997.

The groundwater recharge is calculated both by groundwater fluctuation-specific yield method and by rainfall infiltration method. The annual replenishable groundwater 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 2013, jointly by State PWD of Tamil Nadu and CGWB, to arrive at the total resources available in the study basin. Out of the 107 Firkas of the Amravathi and Noyil sub-basins 80 firkas are falling totally in the basin and the rest 27 are falling partly. The resources have been apportioned to as per the ratio of the firka area within the basin and total firka area for the 16 firkas, which are falling partly in the basin.

4.1. Net Groundwater Availability:

The net groundwater 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 groundwater potential 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 ground water recharge may be taken as net groundwater availability.

District	Resources (in Ham)							
	2004		2009		2011		2013	
	NGWA	Draft	NGWA	Draft	NGWA	Draft	NGWA	Draft
Coimbatore	14536.00	17084.49	16623.51	16882.42	18934.56	25790.55	21145.83	23531.30
Dindigul	45012.48	54252.87	43580.02	52647.15	48029.02	58208.57	51409.50	56458.48
Erode	15602.01	13084.95	15963.53	14256.44	17097.30	19099.77	16231.89	18396.74
Karur	12656.62	7512.54	11111.55	11200.41	14466.77	15351.37	15723.64	16628.67
Tiruppur	44355.33	31276.62	50297.95	37445.18	42437.14	54684.54	43000.15	49006.11
Total	**122162.44**	**113211.46**	**127576.56**	**122431.60**	**140964.80**	**173134.80**	**147511.03**	**164021.33**

The net groundwater availability (NGWA) of the basin for the year 2013 is arrived at - 140965 Ham . The NGWA is maximum in Madathukulam Firka of Tiruppur district (5198 ham) followed by Kurichikottai firka of Tiruppur district (2857.80 ham) and Vellakoil firka of Tiruppur district (2728.97 ham) etc.

4.2. 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 draft of the basin is 173134 Ham.

The existing groundwater draft for irrigation is maximum in Madathukulam Firka of Tiruppur district (4321.88 ham) followed by Mulanur of Tiruppur district (3680.65 ham), Thoppampatti firka of Dindigul district (3502 ham) etc. The gross groundwater draft for domestic and industrial uses is maximum at in Madathukulam Firka of Tiruppur district (4464.89 ham) followed by Mulanur of Tiruppur district (3759.90 ham), Thoppampatti firka of Dindigul district (3576 ham). The existing gross groundwater draft in Coimbatore, Dindigul, Erode, Thiruppur, Karur districts 25791 ham, 58208 ham, 19100 ham, 15351 ham, and 54685 ham respectively. The total gross groundwater draft of the basin is 173135 ham against the availability of 140965 ham.

4.3. Stage of Development and Categorization:

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

The stage of groundwater development is calculated for all the 80 firkas of the basin and it varies from 1.09% (Kodaikanal Firka of Dindigul district) to 283.70 % (Nambiyur firka of Erode district) (Figure – 4.1). The Categorization has been done by considering the two factors as suggested by GEC 97, viz.

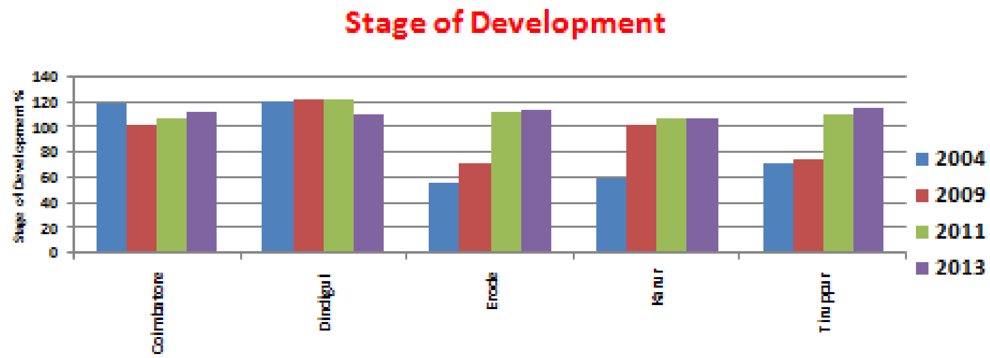
i) Stage of Development
ii) Long term trend of pre and post monsoon water levels.

The following FOUR categories have been suggested by GEC-97 based on the above two factors.
a) Safe b) Semi-critical c) Critical d) Over-exploited

Based on the above categorization, out of 80 firkas (major area falling) of the basin, 53 are Over Exploited, one is Critical, 18 Semi-critical and rest are in Safe categories (Figure – 4.2). Eight out of the 11 firkas of Coimbatore district and 16 out of 29 firkas of Dindigul district, 2 out of 2 firkas of Erode district, 6 out of 10 Karur district and 21 out of 28 firkas in Tiruppur district falls under Over-exploited (Figure – 4.3).

Comparison of stage of development of basin shows that there is a continuous increase from 84.60% (2004) to 111% (2013). Although Coimbatore and Dindigul districts maintain their stage of development, there is a steep increase in the stage of development in Erode, Karur and Tiruppur districts.

4.4. Static Ground Water Resource:
The ground water available below the zone of water level fluctuation is called Static Ground Water Resource. But in the present study basin static resource is developed in all the 53 Over-exploited firkas and a total quantity of 165 MCM is being extracted from static resource as the available dynamic groundwater resource is only 1566 MCM against the gross draft of 1731 MCM. The calculated in-storage available in the Aquifer-I is 533.30 MCM and that of Aquifer –II is 1230.20 MCM.



District	Stage of Development (%)			
	2004	2009	2011	2013
Coimbatore	117.53	101.56	106.21	111
Dindigul	120.53	120.81	121.19	110
Erode	55.07	71.37	111.71	113
Karur	59.36	100.80	106.11	106
Tiruppur	70.51	74.45	108.86	114
Total	84.60	93.80	109.82	111

Figure – 4.1. Stage of Development

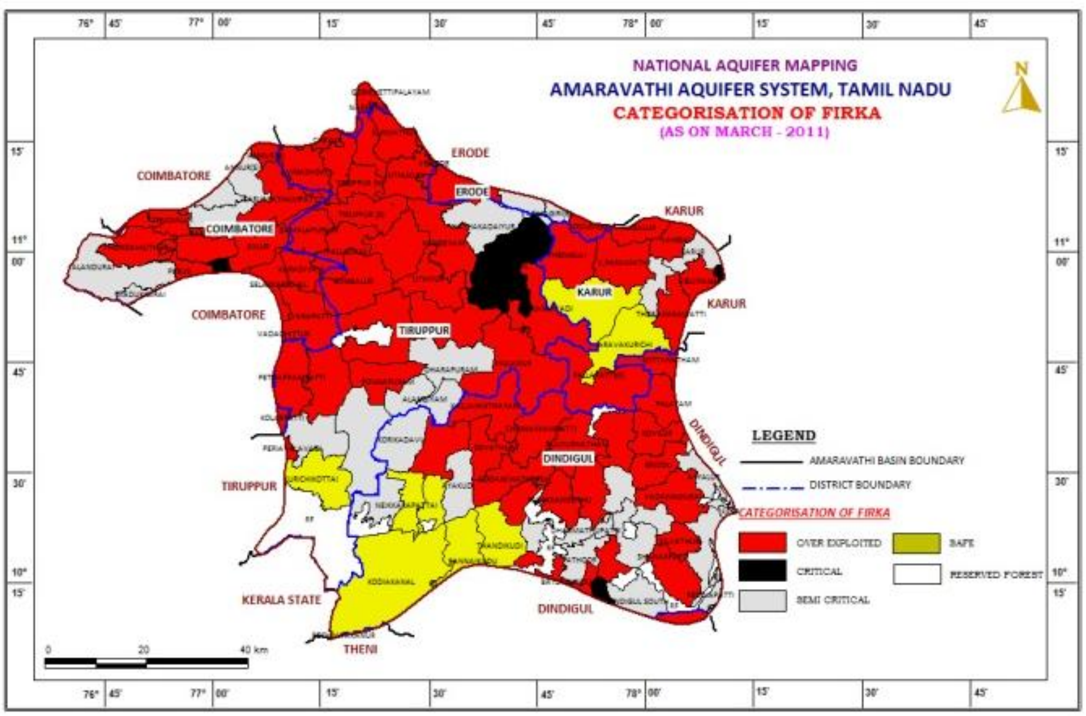


Figure – 4.2. Categorization of Firkas

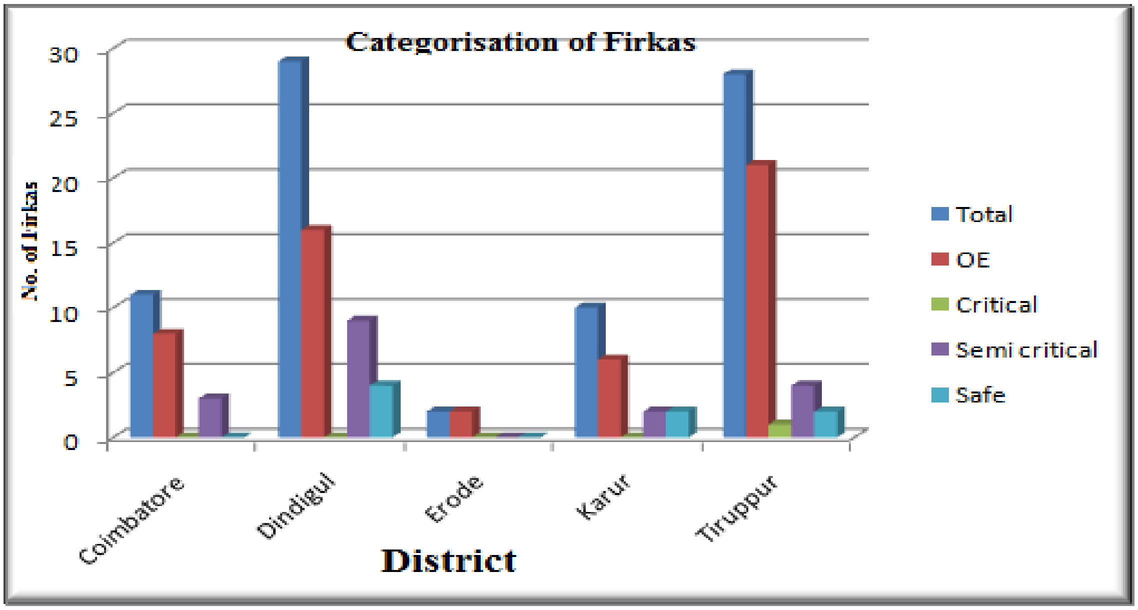


Figure – 4.3. District-wise Categorization of Firkas

5.0 GROUNDWATER RELATED ISSUES

Groundwater is extensively utilized for irrigation in the entire basin area for the past two decades, especially in the 74 over-exploited and critical firkas, out of the 107 firkas of the basin. There is no anthropogenic contamination in the basin as there is no much urbanization. Groundwater contamination due to Textile Industry in Coimbatore, Thiruppur, and Karur districts on the banks of the Noyil and Amravathi river courses have a created a major problem.

5.1 : Geographical Distribution and Rsource Availability

a) Over-exploitation

About 8000 Km^2 area covering 54 firkas can be categorized as over-exploited, in the Amravathi basin. Over all stage of development is 111 %. Comparision of stage of development of basin shows that there is a continuous increase from 84.60% (2004) to 111% (2013). Although Coimbatore and Dindigul districts maintain their stage of development, there is an increase in the stage of development in Erode, Karur and Tiruppur districts.

b) Decline in groundwater level:

1. During Aquifer Mapping studies in Amravathi and Noyil sub-basins, 89 Groundwater monitoring wells, which were monitored regularly show decline

trend of 0.20 to 0.35 m/year in Coimbatore and Tiruppur districts and 0.30 to 0.45 m/year in Dindgul district (Figure – 5.1).

2. The shallow aquifer wherever the depth of weathering is less gone dry due to over-exploitation and many dug wells, which were in existence having become defunct and are abandoned.
3. Deep water levels (> 20 m bgl) are observed during pre and post-monsoon seasons in 8 % and 4% of the area respectively.
4. Low yield (<1 lps) occurs in ~40 % area and yields of bore wells have reduced over a period of time and some bore wells which used to yield sufficient quantity of water have gone dry and rich farmers are acquiring water from nearby places (if available) or transporting water from far off places (2 to 3 km) and saving the commercial crops thereby incurring lot of financial expenses.

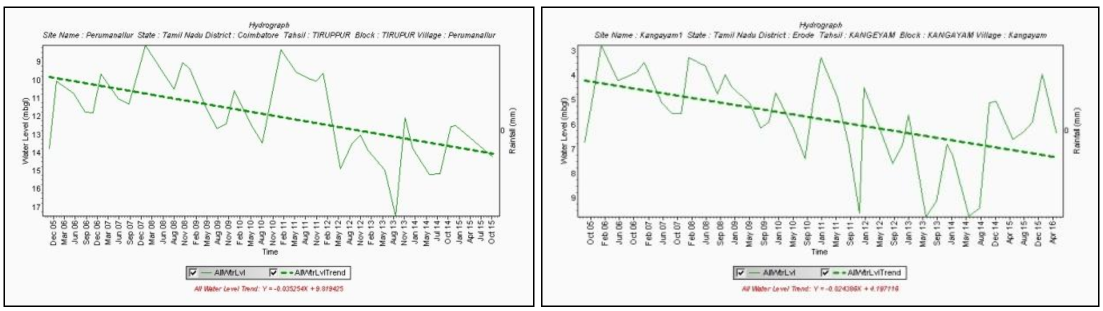


Figure – 5.1. Hydrographs showing declining trends

C) **Sustainability**

Moderate Drought” conditions are experienced in the range of 2 years in Dindigul, Palani and Avinashi, to 6 years in Nilakottai, Dharapuram, Kangeyam, Sulur and K. Paramathi and 50% of the dug wells are going dry and sustainability of 2 to 4 hrs pumping in dug wells is reduced to 1 hour in summer and bore wells tapping deeper fractures also dwindling in yield. Many bore wells are abandoned due to poor yield and it causes great concern to farmers in Dindigul and Tiruppur districts. The saturated thickness of phreatic aquifer exists 5 to 12 during monsoon is reduced to 0 to 3 m during non monsoon.

5.2 Ground water quality issue :

The sample locations were plotted on the map and identified data gap. In the basin, groundwater quality of 66 nos wells were monitored periodically. To fill data gap in the basin, 139 nos of water samples were collected during micro level study. Water samples have been collected from the study area in different aquifers (Aquifer-I & Aquifers-II, **Fig- 2.2**) to assess the groundwater quality for drinking and irrigation purpose. The analytical results are given as (Annexure-1I) & (Annexure-III) for aquifer- I & II respectively. Aquifer - I water samples show electrical conductivity 270 to 8000 µMhos at 25°C and aquifer- II show EC 410 to 3600 µMhos at 25°C and generally major part of the basin suitable for drinking.

1) Groundwater Contamination

Groundwater having high TDS of 6000 is noticed in Coimbatore, Tiruppur and Dindigul districts (Figure – 5.2) due to high industrial developments. Coimbatore and Tiruppur are major textile centers of the country and high concentration of Pb ranging from 0.07 to 0.093 are noticed where as permissible limits are 0.01 and also due to Tannery industries. Dindigul district are also having more total dissolved solids. Manganese is also observed above the permissible limit of 0.03 mg/l .in Tiruppur district.

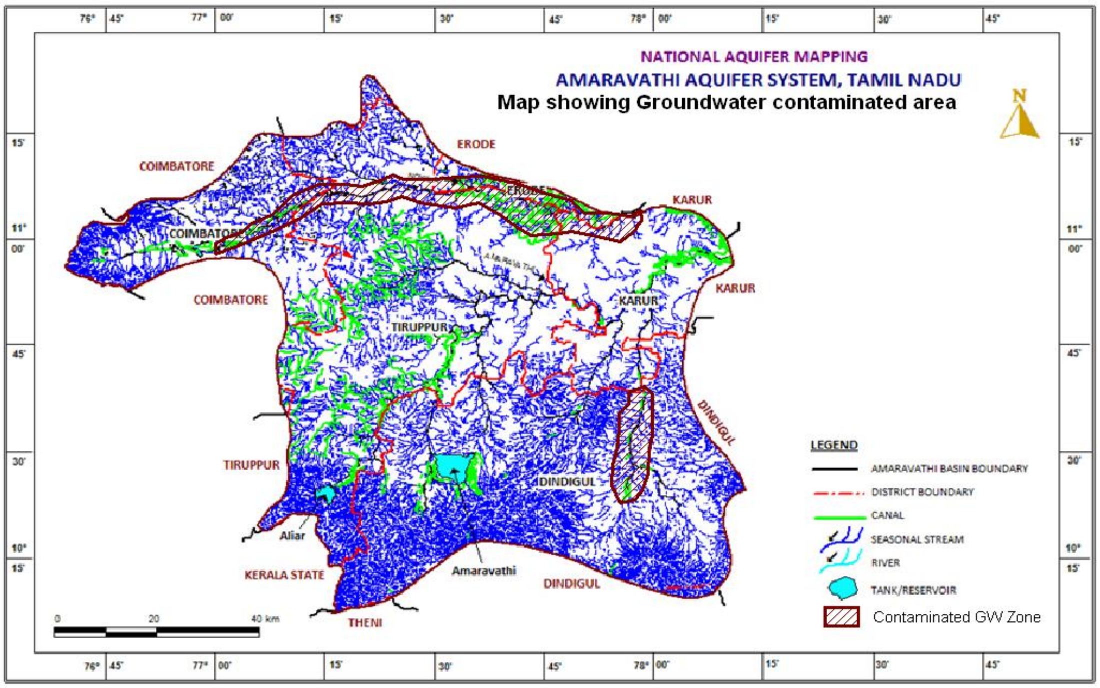


Figure – 5.2. Groundwater contaminated area

2) High concentration of Fluoride :

High fluoride content (>1.5 mg/l) in groundwater is the major concern in some isolated pockets of the basin falling in Sankaradampalayam firka of Tiruppur and Chennimalai firka of Erode district. Highest fluoride levels are recorded in the water samples of bore wells collected from aquifer II at Rudhrapalayam and Kumarapalayam of Erode district (Figure – 5.3).

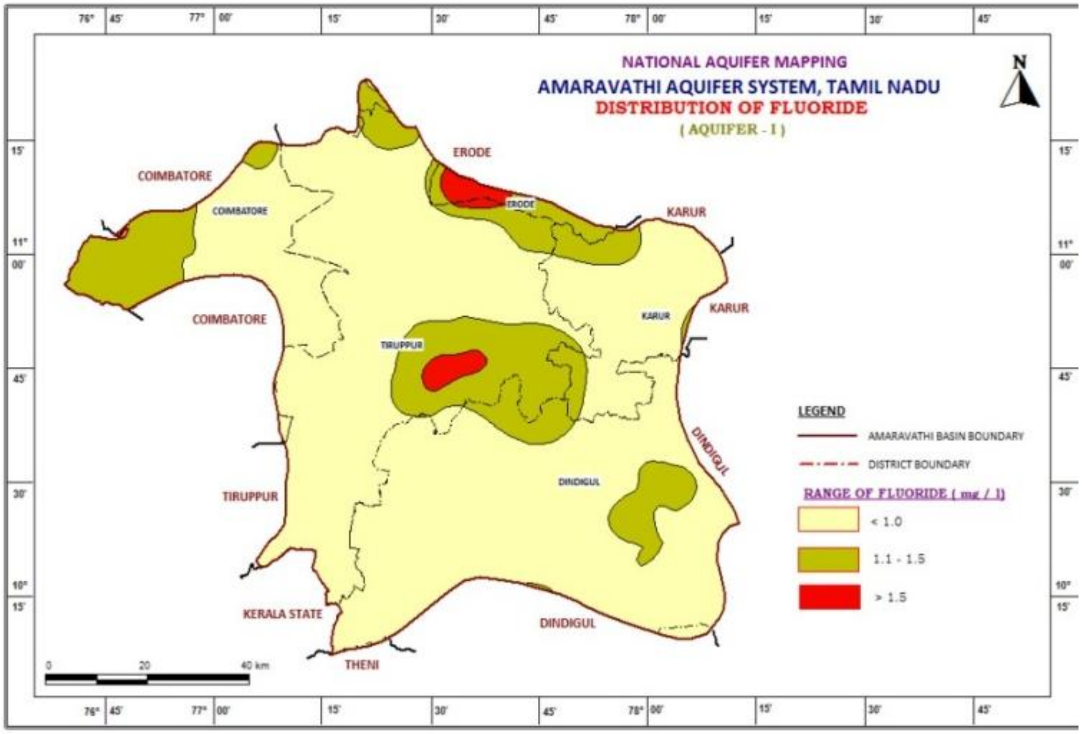


Figure – 5.3. High concentration of Fluoride

6. 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 Amravathi and Noyil sub basins of Cauvery major basin, the sustainable management plan for groundwater is being proposed after a thorough understanding of the aquifer disposition down to a depth of 200 m bgl. The study area is characterized by weathered and fractured system with very heavy abstraction of groundwater for irrigation practices.

6.1 Sustainable Management Plan

The groundwater resource is over-exploited in 74 firkas of the basin comprising an area of 8658 Sq.km. out of the 12285 sq.km area of the basin. Gross draft of 1640.21 MCM is estimated as per the GEC 2013 against the Net availability of the resource of 1475.11 MCM. A total of 165 MCM in excess was drawn from the groundwater system of the 74 OE firkas. Therefore, the usage of groundwater has to be reduced by 11 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.

6.2 Augmentation Plan

Augmentation of groundwater can be achieved through de-siltation of existing ponds / tanks along with the construction of 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 uplands, wherever first order second order streams occur we may construct Checkdams and Nallah Bunds to augument the groundwater recharge.

In the study area except south west and west remaining area is subjected to Over-exploitation. Groundwater levels are getting depleted gradually due to over exploitation. The natural rainfall recharge is insufficient to recoup the extracted groundwater. Artificial Recharge and Water Conservation Plans are proposed in the OE firkas of the basin through utilizing the uncommitted surface runoff of 899 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, to bring the deepest water level to the level of 3.0 m bgl, of the basin has been estimated as 917.75 MCM. The annual uncommitted runoff is 899 MCM. As both the source of excess water and place to store is available, Artificial recharge and Water conservation plan is prepared for the over exploited firkas of the basin. Using all the scientific approach an artificial recharge plan has been prepared to harness 197.45 MCM of water from the uncommitted runoff at the cost of 424.93 Crores.

The suggested Artificial recharge structures are mainly Check Dams, Nala bunds, and Recharge Shafts in addition to de-siltation of 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 166 check dams, 155 nala bunds and 716 recharge shafts in the existing 575 tanks are proposed in the OE and critical firkas of the basin. A total number of 220 ponds out of 1851 have been recommended for de-siltation. Apart from these structures 25,240 Nos. of recharge ponds have also been planned to construct. The expected recharge through these artificial recharge structures is in the order of 197.45 MCM. The expected Potential through ID crops for 197.45 MCM of recharge is 33912 ha. Through this supply side management it is expected to bring down the current stage of development from 111% to 98%.

6.2.2 Water Conservation Plan

Low pressure water distribution system is being proposed in 3384 Sq.km of cropped area which otherwise is under irrigation through flooding channels. Ditch and furrow method is recommended for the Paddy and the drip irrigation is recommended for the Sugarcane and Banana. The expected savings of water through these method is expected to be 81.2 MCM/yr for paddy, 54 and 57 MCM/Yr for Sugarcane and Banana respectively (Figure – 6.1.).

6.3.Demand side Management Plan

Demand side management can be accomplished through irrigation water scheduling, soil moisture management and practicing agronomic measures such as deep ploughing, straw mulching, and the use of improved strains/ seeds and drought resistant agents. Change in crop type and land use i.e., practicing higher-value crops under green house cultivation or returning a proportion of the wet crop area to dry land cultivation of drought-resistant crops, will lead to a considerable savings of groundwater extraction. It is essential that the savings in groundwater are not spared to expand the irrigated area or to divert to other industrial uses but to leave it to restore the depleted water levels to rise and to build the aquifer storage. This can be achieved through clear incentives for farmers to act in the collective interest of resource conservation.

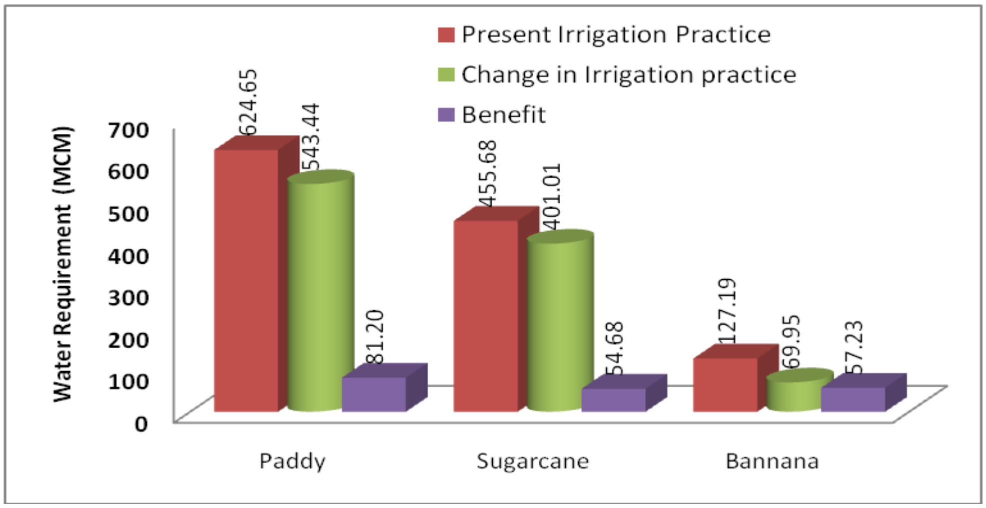


Figure – 6.1.Benefits of change in irrigation practice

If applied the recommended changes in the demand side the expected change in the stage of development of groundwater resources is expected to reduce from the current 111% to 99%, thus releasing the category from Over Exploited. The district wise impact is shown in the following table and Bar Diagram (Figure – 6.2)

District	Present Stage of GW Development	Stage of GW development after change in Irrigation practice
Coimbatore	111	99
Dindigul	110	100
Erode	113	90
Karur	106	93
Tiruppur	114	103
Total Basin	**111**	**99**

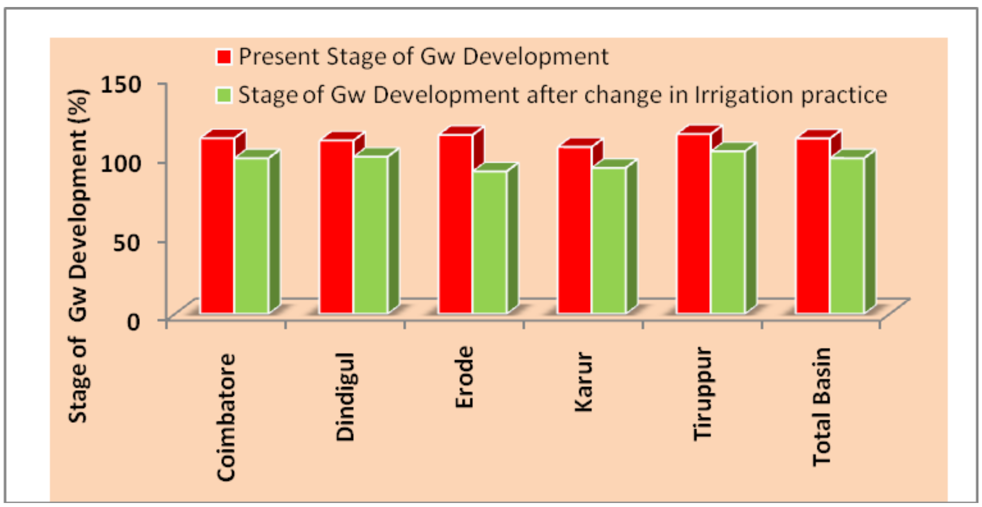


Figure – 6.2. Bar Diagram

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 and following up of old unscientific methods. Hence, the policy makers at higher administrative level and rural development authorities at Firka level should educate the farmers in their jurisdiction in such a way that they should switch over from the old methods to the new technology based methods. 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.