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

Upper Ponnaiyar River Basin, Tamil Nadu

दक्षिण पूर्वी तटीय क्षेत्र, चेन्नई

South Eastern Coastal Region, Chennai

REPORT ON

AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUNDWATER RESOURCES IN UPPER PONNAIYAR RIVER BASIN AQUIFER SYSTEM, TAMIL NADU

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AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUNDWATER RESOURCES IN UPPER PONNAIYAR AQUIFER SYSTEM, TAMIL NADU

1 INTRODUCTION

India is the largest user of ground water in the world and development activities over the years have adversely affected the ground water regime in many parts of the country. Hence, there is an urgent need for an accurate and comprehensive picture of ground water resources available, through aquifer mapping in different hydro-geological settings, to enable the preparation of robust groundwater management plans for this natural resource. Aquifer mapping at the appropriate scale has to be devised for a sustainable management plan of this precious resource.

The **'National Aquifer Mapping Studies'** envisages integration of information available on soil types, agro-climatic conditions, geomorphology, geology, hydrogeology, hydrochemistry, cropping pattern, irrigation statistics, forest cover, etc., on a GIS platform and formulation of a **Ground Water Management Plan** for individual units of optimal size in accordance with the nature of the aquifer, its quality of water, sustainability and stress on the resource.

Aquifer mapping at an appropriate scale and formulation of sustainable management plan will help in achieving drinking water security, improving irrigation facility and sustainability of water resources will also result in better management of vulnerable areas.

With these aims, Aquifer Mapping was carried out in Upper Ponnaiyar Aquifer system which includes areas of Dharmapuri, Krishnagiri district, Tamil Nadu under the Annual Action Programme of 2012 – 2013, 2013 – 2014 and 2014 - 15. However, with the view of doing Mathematical modelling of the aquifers, which warrants definite inflow and out flow boundaries, the basin wise approach is adopted and thus the upper Ponnaiyar Basin covering **7130 sq.km** area has been selected for aquifer mapping in the Phase-I.

1.1. Objective

The objectives of the aquifer mapping in Upper Ponnaiyar Aquifer system can broadly stated as;

a. To define the aquifer geometry, type of aquifers and ground water regime behaviors,
b. To decipher hydraulic characteristics and geochemistry of two-layered aquifer systems on 1:50,00 on a 3-D section
c. To develop an Aquifer Information and Management System for sustainable management of ground water resources based on the aquifer maps prepared and
d. To involve the local community for self governance so that the user community will be aware of the available resource and shoulder responsiblity in proper optimal utilisation.

1.2. Scope of the Study

The important aspect of the aquifer mapping is the synthesis of the large volume of data already generated during specific studies carried out by Central Ground Water Board (CGWB) and various Government organizations with a new data set generated that broadly describe the aquifer system. The available generated data are assembled, analysed, examined, synthesized and interpreted from available sources. These sources are predominantly non-computerized data, which are 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), Publics Works Department (PWD), 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 has been carried out in different segments of the basin and aquifer parameters have been estimated. Groundwater regime monitoring has been strengthened by establishing additional monitoring wells. 2D and 3D sections have been prepared twice. The first one, prior to the generation of data based on the data collected, assembled and synthesized through different sources and the second one, after generation of data at identified gaps. The latter prepared maps are of more realistic as the data points are more closure.

1.3. Approach and Working Methodology

Multi-disciplinary approach involving geological, geophysical, hydrological, hydrogeological and hydro-geochemical surveys would be carried out in 1:50000 scale toposheets to meet the aim and objectives listed above. Geographic Information Systems (GIS) would be used to prepare the maps.

Compilation of Existing data and identification of Data gaps:

Preliminary work will consist of the collection and review of all existing data, which relate to the area. This usually includes the results of any previous hydrogeological studies. Also, Exploration data which have been carried out by CGWB and State agencies and by local administrations shall be collected and compiled to identify the data gaps in the study area. After the data compilation all the data will be integrated and analyzed.

Hydrogeological Investigations

A review of background information will lead the study teams to the further studies in the field, where they will employ various techniques to determine the three-dimensional extent and aquifer characteristics of the significant water-bearing formations.

Key Observation wells representing the different aquifers will be established and monitoring will be carried out. Village-wise well inventory and data collection are to be carried out to strengthen the data base. Exploratory wells and Observation wells will be constructed; litholog samples of aquifer materials and ground waters sample will be collected. Aquifer Performance tests will be carried out to determine the aquifer parameters. The analysis of the data will be carried out to prepare maps.

Geo -hydro chemical Investigations

Water Samples will be collected, analyzed and interpreted to bring out ground water quality scenario of the study area.

Hydrological Investigations

Hydrological studies to be carried out are

- Determination of Aquifer parameters
- Infiltration Test

Geophysical Investigations

Geophysical studies would be carried to assist the hydrogeological survey in aquifer mapping/geometry.

Generation of relevant thematic layers using GIS:

- Drainage
- Soil
- Land use and land cover
- Geomorphology
- Lineament Pattern
- Geology
- Aquifer disposition – two dimensional
- Hydrogeological map in 1: 50000 scale.
- Fluoride concentration map

Development of aquifer-wise management plan

To develop an aquifer management plan geologic, hydrogeological, hydrological, geochemical and geophysical information are to be integrated. Determining aquifer potential for effective, development and management are catered on for long-term sustainable development of aquifers.

1.4. Area

Upper Ponnaiyar Aquifer system is located in the North western region of Tamilnadu State and is covering an area of 7130 Sq. Km. The study area is located between North latitude 11°44’46” and 12°53’ & East longitude 77°46’& 78°53’ and is covered in parts of Survey of India Degree sheet Nos. **57H, 57L and 58I**. The Upper Ponnaiyar basin comprises parts of Dharmapuri, Krishnagiri, Tiruvannamalai, Vellore, Villupuram and Salem districts of Tamil Nadu. It is bounded by Karnataka state in North, West and North west and by Andhra state in the North East in other words it is bounded by Cauvery basin in the south and south west and by Palar basin in the north east. Administrative map of Upper Ponnaiyar Basin is presented in **Figure 1.1**.

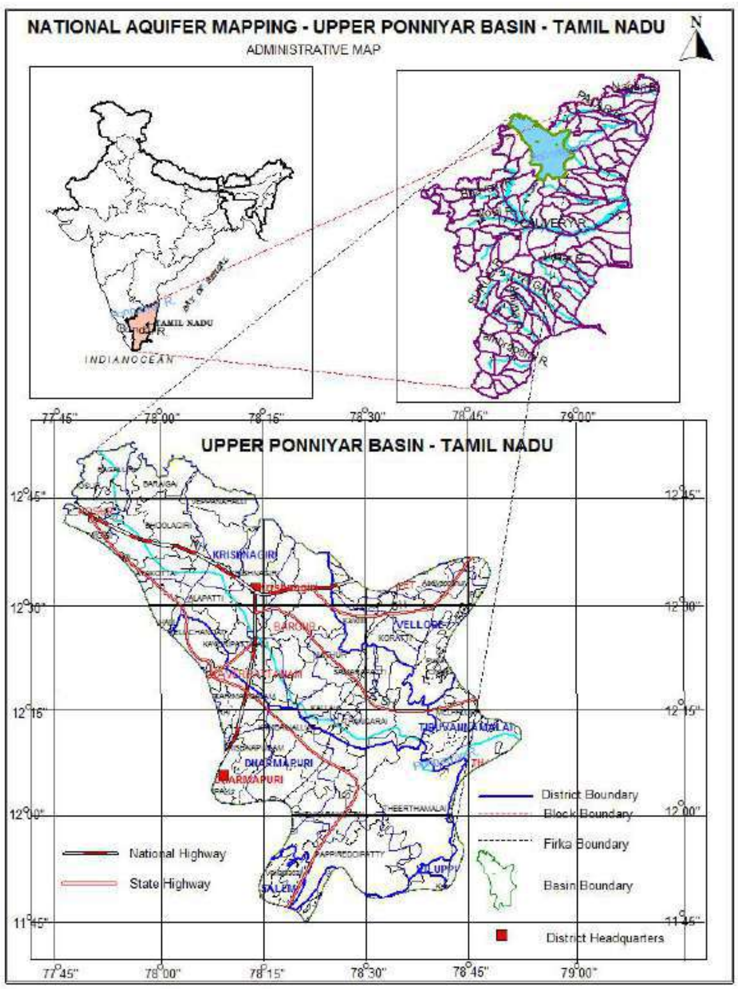


Figure 1.1: Administrative Map of Upper Ponnaiyar Aquifer system

1.5. Accessibility

The two important district Head quarters lie within this basin boundary viz., Dharmapuri and Krishnagiri. It also contains about 20 block headquarters within the boundary. All these blocks and District head quarters have well connected roads. The district headquarters are well connected with other towns in the neighboring districts, as well as with the towns in the neighboring States of Andhra Pradesh & Karnataka. Bengaluru to Chennai and Bengaluru to Salem National Highways passes through the study area. More than four State highways pass through the study area. All the villages are mostly connected by roads and occasionally by all-weather roads. The Chennai – Cochin Railway passes through the study area.

1.6. Administrative divisions

The study area covers 1077 villages. District-wise administrative divisions lying inside the study area are presented in **Table 1.1**. Village map of study area is shown in **Figure 1.2.**

Table 1.1: Administrative divisions falling in the study area

Sl.No.	District Name	No. of Firkas	No. of Villages	Area (Sq.Km.)
1	DHARMAPURI	16	340	2273
2	KRISHNAGIRI	25	565	3293
3	SALEM	6	41	230
4	TIRUVANNAMALAI	5	36	390
5	VELLORE	12	88	877
6	VILUPPURAM	1	7	67
	Total	**65**	**1077**	**7130**

1.7. Demography

According to 2011 census, the proportionate population of study area is 31,42,109 out of which the population living in urban area is 8,43,854 and the rest 21,97,143 are living in the villages. The population density of the district is 407/sq. km (**Table 1.2**).

Table 1.2: Proportionate Population of districts falling in the study area (Census - 2011)

District	Total Area (Sq. Km.)	Total Population	Area in study (Sq. Km.)	Proportionate			
				Population	Rural population	Urban population	Population Density (Per Km^2)
Dharmapuri	4498	1502900	2273	705006	482241	122144	334
Krishnagiri	5143	1883731	3293	1284146	992049	292096	366
Salem	5245	3480008	230	170517	83479	86548	663
Tiruvannamalai	6190	2468965	390	319889	255580	64308	399
Velore	6077	3928106	877	637986	362845	275141	646
Villupuram	7190	3463284	67	24566	20949	3617	482
Area Total			**7130**	**3142109**	**2197143**	**843854**	**407**

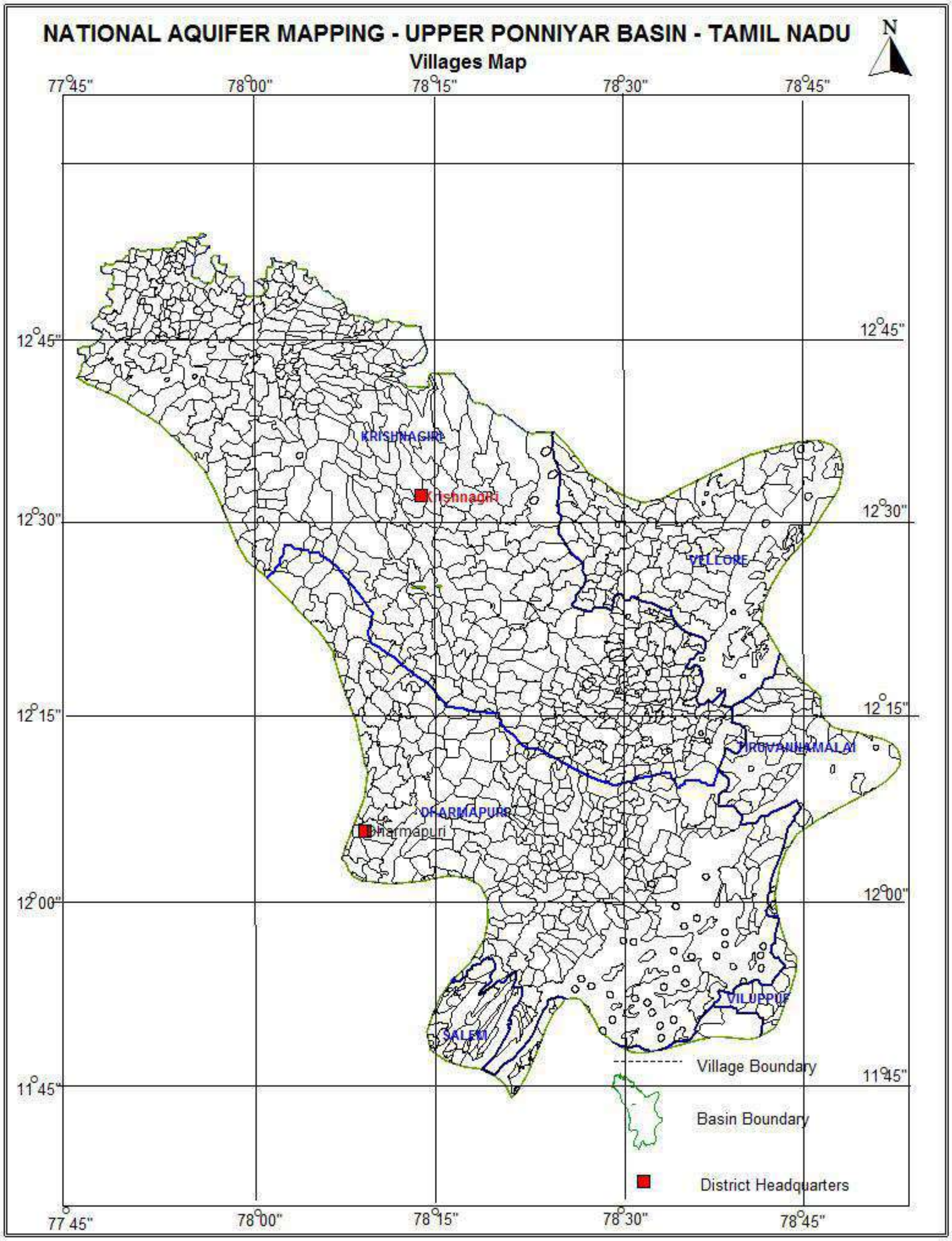


Figure 1.2: Village Map of Upper Ponnaiyar River Basin

1.8. Land use

As per the statistical figures of the Upper Ponnaiyar River Basin for the year 2012-13, nearly 2,59,930 hectares form the net area sown. Forests occupy an area of 95,166 hectares. The details of land use particulars for the year are given in **Table 1.3**

The proportionate nine-fold land use classification for the districts falling within the study area is given below (2012-13).

Table 1.3. Nine Fold Classifications

S. No.	Classification	Extent (Ha)						
		Dharmapuri	**Krishnagiri**	**Salem**	**Vellore**	**Villupuram**	**Tiruvannamalai**	**Total**
1	Forests	26926	66258	535	917	399	131	**95166**
2	Barren & Uncultivable Lands	7413	16318	1906	3321	402	2673	**32032**
3	Land put to non-agricultural uses	24148	28528	3003	12982	965	12494	**82119**
4	Cultivable Waste	1771	3032	239	937	69	1138	**7185**
5	Permanent Pastures & other grazing lands	2913	5354	206	656	30	380	**9537**
6	Groves not included in the area sown	1367	5895	142	497	45	240	**8186**
7	Current Fallows	20036	23870	2122	11255	596	14559	**72438**
8	Other Fallow Lands	1646	12493	784	11255	106	3198	**29481**
9	Net Area sown	74681	116085	10945	28514	2403	27303	**259930**
	Total	**160900**	**233823**	**16807**	**55708**	**5013**	**62114**	**534365**

(Source: Department of Economics & Statistics, Govt. of Tamil Nadu)

1.9. Agriculture

Agriculture is the main occupation of the people in the basin. The amount of rainfall and its distribution throughout the season contributes to the cropping pattern in the area. Climate, type and characteristics of soils and irrigation facilities available are the major other factors affecting the cropping pattern of the area. There are two agricultural seasons namely Kharif and Rabi season. The Kharif season starts in the month of June/July and terminates in Sep/October, whereas the Rabi season starts from middle of October and terminates in the middle of February.

The major Kharif crops in the area are paddy, maize, ragi, tur and vegetables. Similarly, in the Rabi season the main crops grown are ragi, maize, horse gram, groundnut, sunflower. sugercane, fruits, are perennial crops grown in the area. It is observed that cereals are the major crops grown in the entire area (104860 ha.). Among oil seeds, groundnut, and sunflower constitute a major portion. Total pulses are grown over an area of 34365 ha. The district wise details of various crops grown in the area, for the year 2012-2013 are presented in the **Table 1.4 below**.

Table 1.4. Cropping pattern in the study area. (All figures in Hectares)

Sl.No.	Name of the crop	Districts						Total
		Dharmapuri	Krishnagiri	Salem	Vellore	Villupuram	Tiruvannamalai	
1	Paddy	10725	11137	1631	7020	1063	16259	47835
2	Cholam	7363	3488	1014	1119	12	83	13079
3	Cumbu	646	302	95	301	76	431	1851
4	Samai	3740	802	38	449	12	566	5607
5	Ragi	5867	27471	399	746	4	159	34646
6	Maize	303	159	1183	55	21	29	1750
7	Cereals	28662	43362	4410	9704	1194	17528	104860
8	Pulses	9415	18482	2066	2987	157	1258	34365
9	Sugarcane	8627	1654	605	2285	457	4073	17701
10	Oil seeds	8736	21758	2030	10753	321	8327	47835
11	Cotton	3491	1086	702	928	39	154	13079
12	Fruits	6759	24403	405	3346	68	532	1851
13	Vegetables	16119	6178	1291	513	90	610	5607

(Source: Department of Economics & Statistics, Govt. of Tamil Nadu)

1.10 Irrigation facilities

Area irrigated under different resources of irrigation facilities viz., canal, open wells, bore wells and tanks are available in the study area which are presented in the **Table 1.5** . Groundwater through open wells is the major source of irrigation which irrigates about 1,02,322 ha.

Table 1.5. Sources-wise and District-wise area irrigated under different of irrigation facilities in the study area. (Hectares)

Sl.No.	Sources of Irrigation	Districts						Total
		Dharmapuri	Krishnagiri	Salem	Vellore	Villupuram	Tiruvannamalai	
1	Area under canal irrigation	256	641	65	13	14	131	1120
2	Area under wells	39252	22650	6157	14139	1052	19972	103222
3	Area under borewells	174	9423	760	2635	354	221	13567
4	Area under Irrig.Tanks	1462	5881	6	434	422	5051	13256

(Source: Department of Economics & Statistics, Govt. of Tamil Nadu)

1.11 Industries

The major Hosur industrial area falls in the study area. Automobile industry is major in the study area.

2 RAINFALL & CLIMATE

As like the State, the Upper Ponnaiyar Aquifer system is also bestowed with two monsoon seasons, namely north-east monsoon (October-December) and south-west monsoon (June-September). The intensity of rainfall is generally high during north-east monsoon, moderate during south-west monsoon and low during transitional period.

2.1.1 Distribution of Normal Rainfall

The normal rainfall of the area is 850.7 mm. The season-wise distribution of normal rainfall is that South-west monsoon contributes about 399 mm (47%), North-east monsoon is 289.4 mm (34%), winter rainfall is 10.7 mm (1%) and hot-weather rainfall is 151.6 mm (18%). The distribution of normal rainfall and average annual rainfall of the area is given in the **Figure 2.**

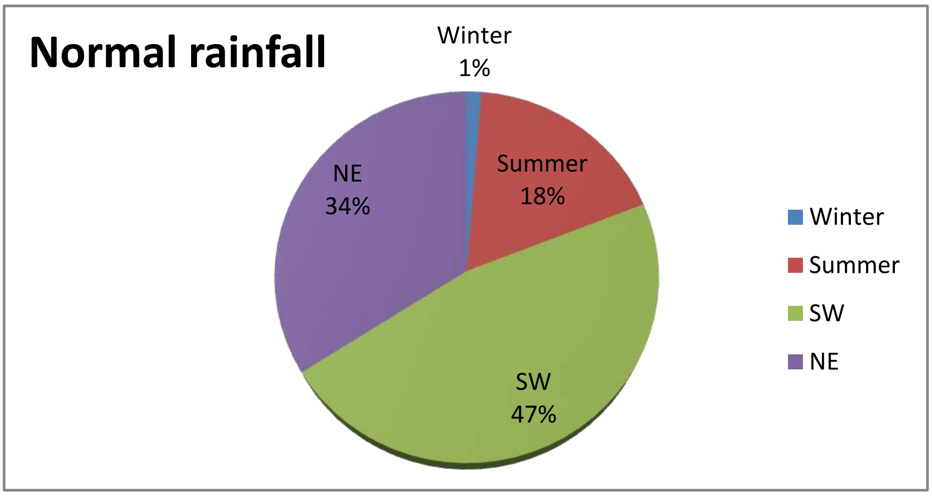


Figure. 2.1. Distribution of Normal Rainfall

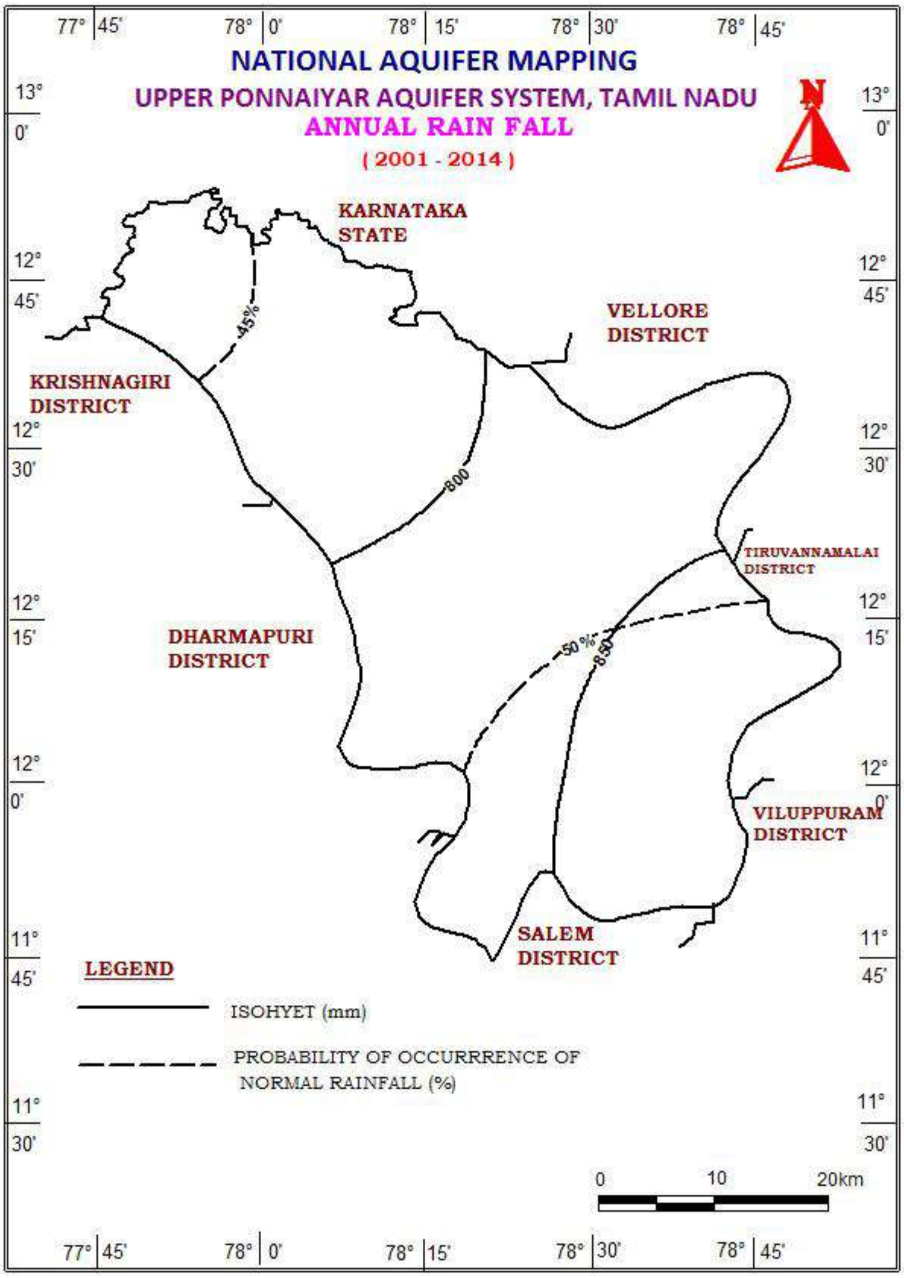


Figure. 2.2. Distribution of Avearage Annual Rainfall 201-2014

2.1.2 Actual Rainfall Distribution (2014)

Based on the IMD, during the year 2014, the study area received an average annual rainfall of about 766 mm. The contribution from south-west monsoon is about 378.2 mm (49%), north-east monsoon is 235.2 mm (31.0%), winter rainfall is 7.2 mm (1.0%) and hot-weather rainfall is 145.4 mm (19%). The distribution of actual annual rainfall of 2014 is given in the **Figure 2.3**.

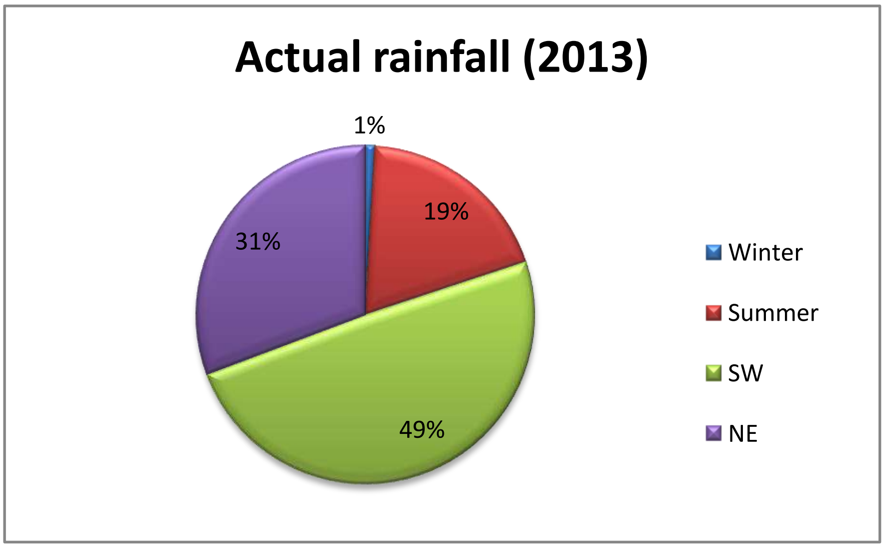


Figure 2.3. Distribution Actual Annual Rainfall

(i) South-West monsoon (June'14 to September'14)

The SW monsoon contributes about 50% of the annual rainfall of the study area. The total rainfall received during the south-west monsoon period was 378.2 mm, which is 49% of the total actual annual rainfall. However, it is less than normal SW monsoonal rainfall of 399 mm.

(ii) North-East Monsoon (October'14 to December'14)

The rainfall during the north-east monsoon season is greatly influenced by the formation and movements of cyclones and depressions. The study area received 235.2 mm rainfall during NE monsoon season, which is 31% of the actual annual rainfall. However, the actual rainfall received was much lesser than the normal rainfall of 289.4 mm.

(iii) Winter Period (January'14 and February'14)

The seasonal rainfall received during this period is 7.2 mm against normal seasonal rainfall of 10.70 mm. The actual rainfall received is about 1.0% of the actual annual rainfall. The seasonal rainfall received is higher than the normal rainfall of the season.

(iv) Hot-weather Period (March'14 to May'14)

The rainfall received during this season is 145.40 mm, which is about 19 % of the actual annual rainfall. Further, the actual rainfall received is much lower than the normal rainfall of 151.40 mm.

2.1.3 Temperature

The temperature slowly rises to its maximum in summer upto the month of May and afterwards show a general decline. The monthly average temperature in degree celcious of the area is given as figure 2.4.

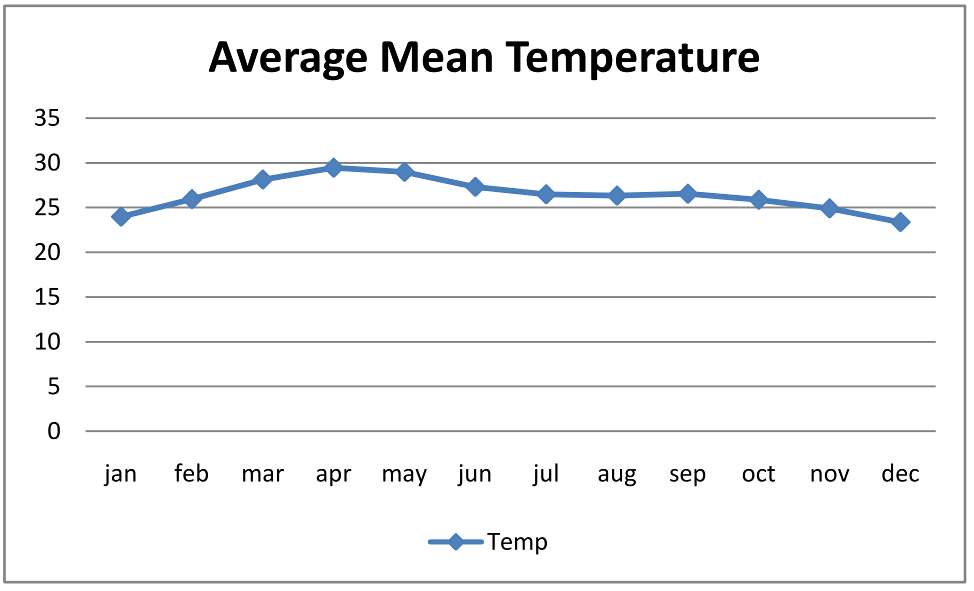


Figure 2.4 Monthly average temperatures

2.1.4 Humidity

During January, the relative humidity is about 60% in the morning and varies from 40 to 70% in the evening increasing towards the coast while during April the humidity is about 70% in the morning and varies from 40 to 70% in the evening. During July, the relative humidity varies from 60 to 80% in the morning and is about 60% in the evening while during October, it is 80% in the morning and varies from 65 to 75% in the evening.

2.1.5 Evaporation

The mean daily evaporation varies from 5.17 to 7.50 mm increasing from east to west during January. The mean maximum daily evaporation in April is about 7.5 mm.

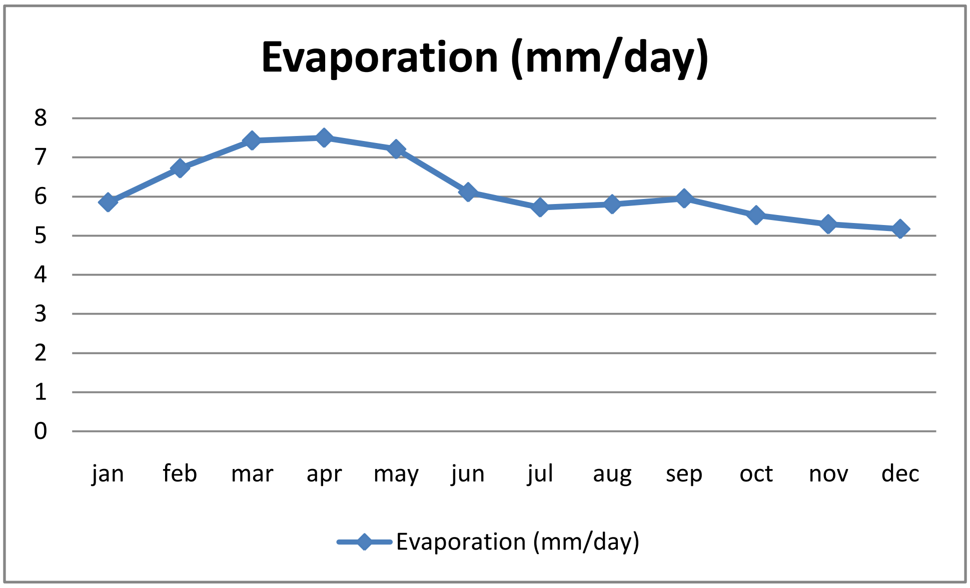


Figure 2.5 Mean maximum daily evaporation

2.2 Probability of Occurrence of Normal Rainfall

The probability of occurrence of normal annual rainfall over the study area has been studied. It is observed that the chances of receiving normal annual rainfall vary from 42% at Thalli to 51% at Uthangarai. These chances are the minimum (40 to 45%) in an area around Denkanikottai in the western part. The chances are the maximum (50 to 55%) in a southern part of the study area including Uthangarai. In the remaining part of the study area these chances are in the range of 45 to 50%.

2.3 Variability of Annual Rainfall

The coefficient of variation, of annual rainfall from the normal, ranges from 24% to 36%. It is the minimum (20-25%) in the northwestern part of the area around Thalli. It is the maximum (30% and above) in the central part around Rayakottai and Hosur. In the remaining parts it is in the range of 25-30% .

2.4 DROUGHTS – Incidence, Intensity & Periodicity

A study of the negative departures of the annual rainfall from the normal, reveals that the probability of occurrence of moderate drought ranges from 12% at Krishnagiri to 18% at Rayakottai. Severe drought conditions were experienced at all the stations for 1 to 8% of the years studied. Acute drought conditions were not experienced at any station. Overall, the total drought years over the area ranged from 14% at Krishnagiri to 25% at Rayakottai.

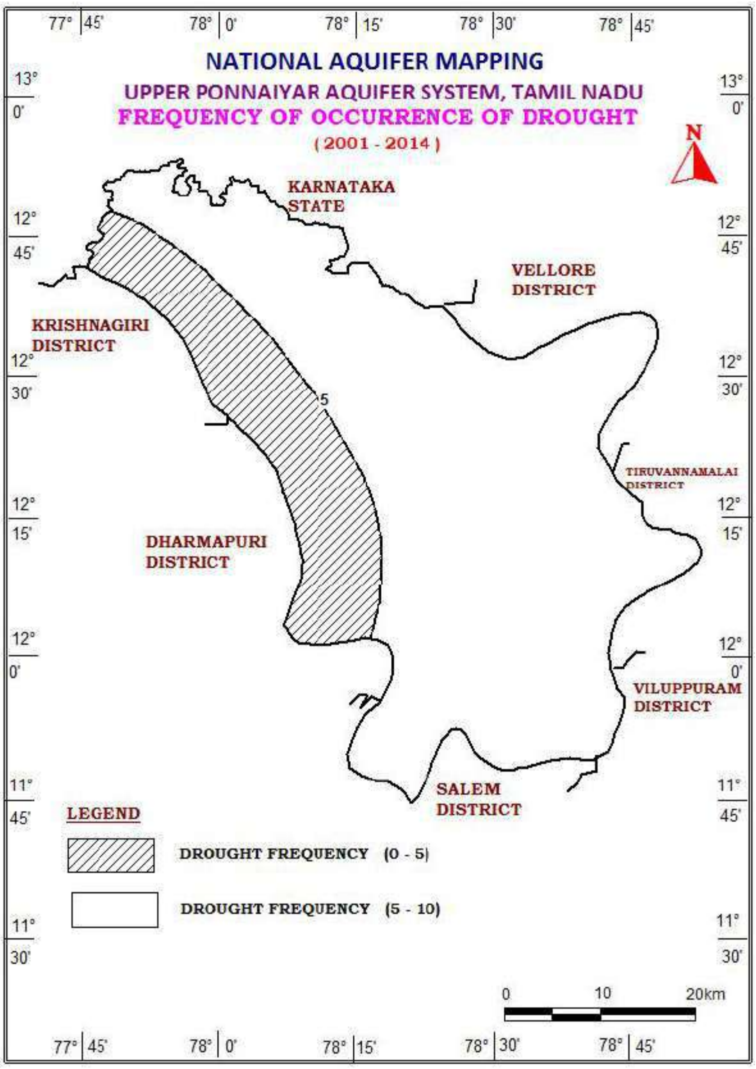


Figure 2.6. Frequency of occurrence of drought

It is observed that the central and northern parts of the district around Hosur and Rayakottai experienced drought conditions for more than 20% of the study period. Hence, this area of the study area comes under the category **"drought area"**. The frequency of occurrence of various kinds of drought at each station has been studied on the basis of number of years per one drought. It varies from 4 years per drought at Rayakottai to 7 years per drought at Krishnagiri. It has been observed that the frequency of occurrence of drought is high (less than 5 years per drought) over an area around Rayakottai & Hosur in central part of the study area. Over remaining portion it is in the range of 5 to10 years per drought presented in figure 2.6.

3 PHYSIOGRAPHY & DRAINAGE

3.1 Physiography

The study area forms part of the upland plateau region of Tamil Nadu with many hill ranges and undulating plains. The western part of the district between Pennagaram and Denkanikottai has hill ranges of Mysore Plateau with a chain of undulating hills and deep valleys extending in NNE – SSW direction. The plateau region along the western boundary and the north western part of the study area has an average elevation of 914 m. above Mean Sea Level (mamsl). The Guttirayan Durg (12º 16’ 00’’, 77 º 52’ 00”), with an elevation of 1395 m. amsl is the highest peak in the area.

Various geomorphic units have been identified through interpretation of Satellite imageries of the study area. These include Structural hills along the southern and southeastern parts of the study area, denudational landforms like buried pediments in the plains and inselbergs and plateaus represented by conical hills aligned with major lineaments. Major lineaments have been identified in Hosur, Pennagaram, Uttangarai and Krishnagiri areas of the study area. A map showing the distribution of various geomorphic units in the study area is shown as **Figure 3.1**

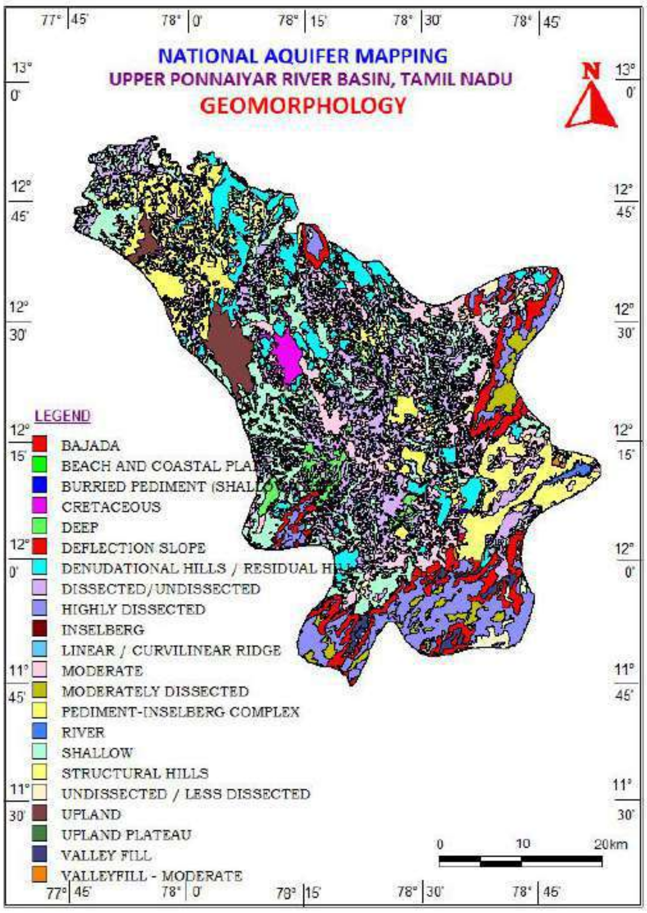


Figure 3.1 Geomorphology of Upper Ponnaiyar River Basin

3.2 Drainage

The Ponnaiyar is the major river draining the area and is ephemeral in nature. It originates from the Nandhi hills in Karnataka, enters into Tamil Nadu west of Bagalur and flows almost in a southeasterly direction till it reaches Daddampatti from where it takes an easterly course. The *Pambar, Vaniyar* and *Kallar* are important tributaries of the Ponnaiyar draining the eastern part of the study area whereas the *Chinnar* and the *Markandeya Nadhi* drain the northern part of the study area. Map showing the drainage pattern of the study area is given as figure 3.2.

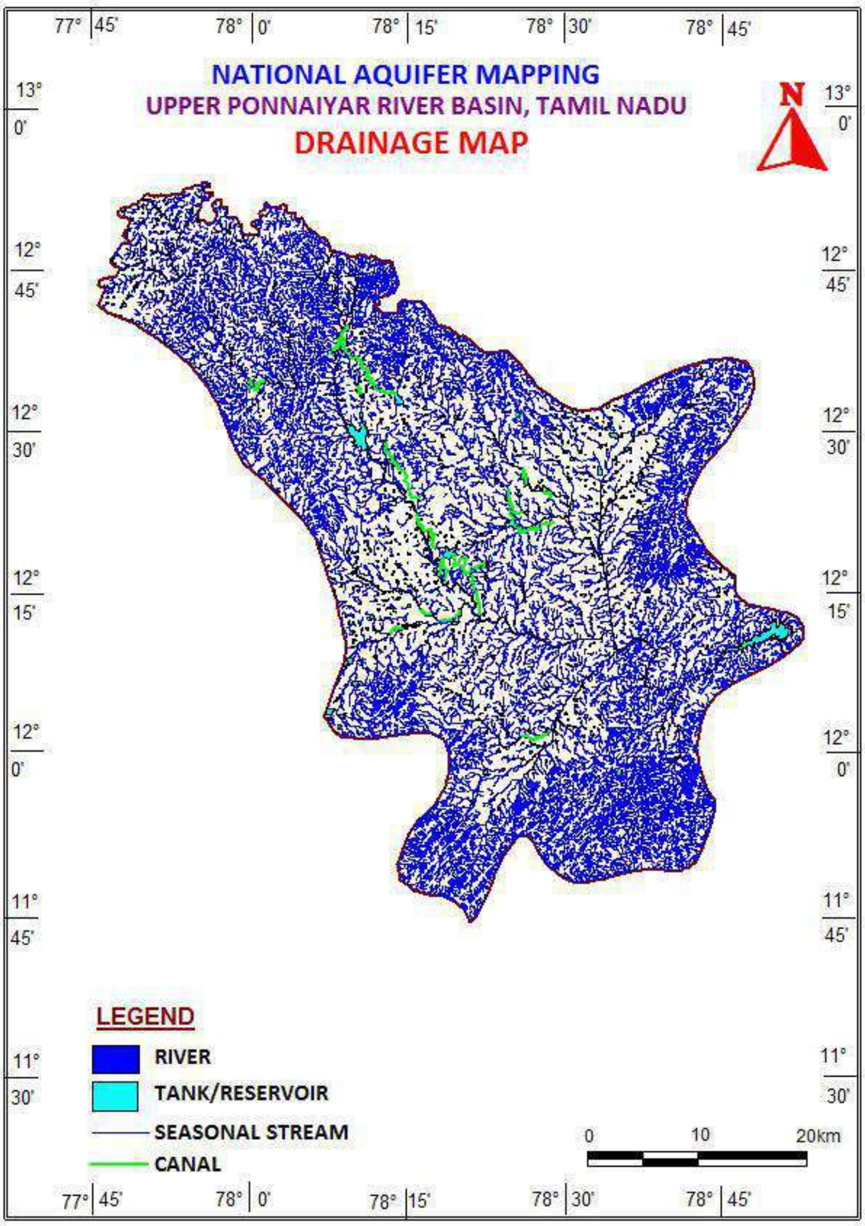


Figure 3.2. Drainage pattern of Upper Ponnaiyar River Basin

The details of important minor basins in the study area are furnished in **Table 3.1.**

Table : 3.1. Details of important minor basen in Upper Ponnaiyar River basin

Sl. No	River Basin	Area (Ha)	Minor Basin	Area
1	Ponnaiyar	**958126**	Hosur	107863.63
			Kaveripattinam	78914.09
			Kambainallur	78720.21
			Pambar	128213.16
			Vaniyar	165661.69
			Pappireddipatti (Part)	20978.25
				958126.00

3.3. Soil

Major soils occurs in the basin are; Black soils, mixed soils, red loamy and sandy soils, gravelly and sandy soils. Red loamy and sandy soils are predominant in Hosur and Harur taluks. Vast stretches of loamy soils and black soils occur in Dharmapuri and Krishnagiri taluks.

The soils of the study area have been classified into 6 soil series (figure 3.3) based on the surveys conducted by the Soil Survey and Land Use Organisation of Tamil Nadu Agriculture Department**.**

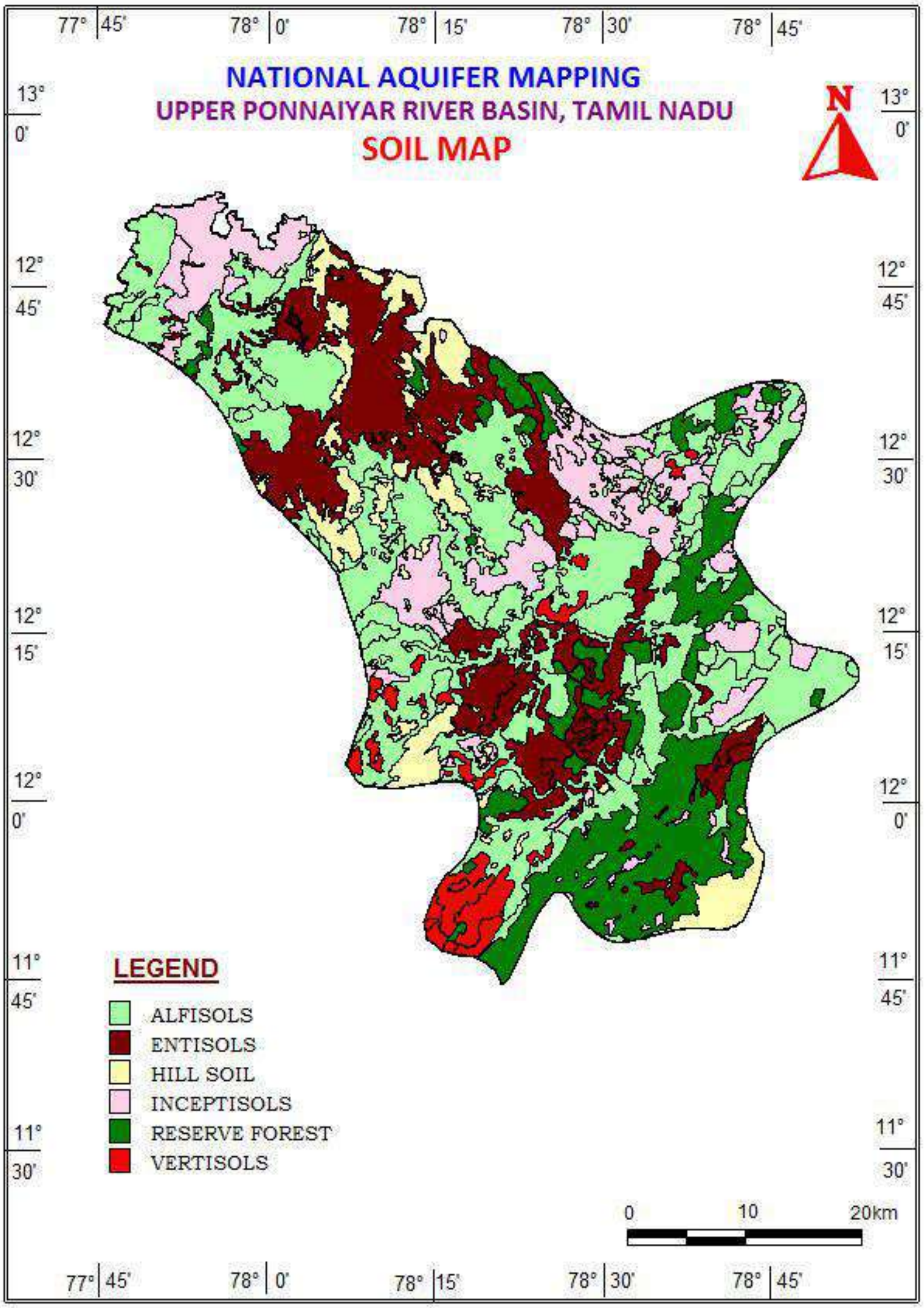


Figure 3.3. Distribution of Soils of Upper Ponnaiyar River Basin

4. GEOLOGY

4.1 General Geology

The study area forms part of the polymetamorphic and multistructural Archaean Complex of Peninsular India and is underlain by crystalline formations and localised patches of recent alluvial deposits. The general stratigraphic succession is presented in **Table.4.1** and the geological map of the study area is presented as **Figure 4.1**. The characteristics of important litho-units encountered in the study area are described briefly in the following paragraphs.

4.1.1. Charnockites

Charnockites are seen mainly in the southern eastern part of the basin. Bluish grey to dark grey coarse-grained Charnockites occupy the hill ranges bordering the basin. They are banded, gneissic, granulitic and/or garnetiferous at places. The massive variety exhibits foliation of weathering prominently in NNW – SSE direction, dipping 30 to 50 degrees due southwest. Jointing is a common feature in Charnockites and two sets are observed predominantly *viz.* N 30 – 50° E to S 30 – 50° w with 50° due SE/NW to vertical and N – S joints with vertical dips.

4.1.2. Gneiss

Greenish to greenish grey hornblende-bearing gneisses varying in texture from very fine to coarse-grained occur as prominent bands southwest of Dharmapuri and around Kadathur, Dasampatti and Uthangarai. These rocks are well-foliated, trending N30E – S30W. Joints are also common and three sets are prevalent; i) N30E – S30W with steep to vertical dips toward SE, ii) E – W with vertical dips and iii) N – S with vertical dips.

4.1.3. Granites and Biotite Gneisses

Granites and Biotites gneisses occur extensively in the northern and northwestern parts of the basin. They are pinkish white to greyish white in colour and have well-developed foliations trending NNE – SSW with dips due southeast. These gneisses are considered to be part of the 'Peninsular Gneissic Complex'. They are extensively jointed with 5 to 6 sets of predominant joints.

4.1.4. Amphibolites, Syenites, Carbonatites, Pyroxenites and Dunites

Amphibolites occur as thin bands associated with iron ore bands around Alambadi (78 39 00 – 12 07 00). Exposures of syenites are few and isolated. They occur as lenticular bodies intruding granitic gneisses and generally run parallel to their foliations. They are found scattered in the

Pinkkili hills around Dasampatti, Erranahalli, Malanur, Papparappatti and in the high ground off Jogipatti. The rocks range in colour from grey to white and pink, coarse grained and sometimes Corrundum-bearing. Carbonatites occur near massifs of alkali syenite at Jogipatti and also around Samalpatti and Dasampatti. Ultramafic rocks like pyroxenites and dunites are also wide-spread in the area and are often found associated with Charnockites and gneisses. Pyroxene granulites are noticed as isolated patches in the hills northwest and southeast of Palacode, to the north of Atturnahalli and around Popadi.

4.1.5. Meta Gabbro - Ferruginous Quartzites

Small bands of ferruginous quartzites, trending ENE – WSW are observed in the study area. Most of these constitute prominent topographic features, apparently having withstood the process of weathering. Small bands of these formations are seen to the north of Jagadevipalayam, south of Indur and near Nallampalli.

4.1.6. Basic rocks and Quartz Veins

Gneisses and Charnockites in the study area are intruded by dolerites, pegmatites and quartz veins. Dolerites occur as dykes, a number of which are seen between Dharmapuri and Morappur. They generally trend in NNW – SSE direction. Dark coloured continuous ridges of dolerite dykes are common in many places in the study area. The exposures are generally bouldery and weathered into reddish soil. Pegmatite veins are not as common as dolerites in the study area. Veins of quartz are seen near Palayam, Tippampatti and just south of Dharmapuri town.

4.2. Sub-surface Geology

In the crystalline rocks, the thickness of weathered zone varies considerably depending on the lithounit and geomorphology. Data of bore wells drilled by Central Ground Water Board and the State Ground and Surface Water Resource Data Centre (SG&SWRDC) indicate that it varies from 1.5 to 39.0 m in the area. Potential fracture zones have been encountered down to a maximum depth of 211 metre below ground level (m. bgl) in the exploratory bore wells drilled by Central Ground Water Board in the basin.

4.3 Structural Features

The crystalline rocks in the study area exhibit multi-structural and poly-metamorphic complexity. Many of the hillocks show distinct structural features. The regional structure shows several tightly folded anticlines and synclines with plunging and overturned fold axes. Anticlinal structures are seen near Jagadevipalayam, Kaveripattinam, east of Tirthamalai and near Urigam, whereas synclines are seen west of Harur and south of Uthangarai, in Sundamalai and Kaverimalai hillocks, south of Krishnagiri and also in Pallipatti hillocks.

A number of lineaments and prominent fault and fracture systems have been deciphered from aerial photos and satellite imagery. There are a number of regional faults running in NNE – SSW direction. The Eastern Ghat Fault running along Nagavathi River passes northwest of Samalpatti synclinorium. Kottapatti shear zone, Mettur fault, Tirtham fault and Ramanadoddi fault are some of the other prominent faults in the area. A number of other lineaments run parallel and perpendicular to these faults. Minor faults are also seen in large numbers, indicated by the displacement of dykes. The drainage courses are by and large structurally controlled. Three sets of joints are common in the area. One set is parallel to the foliation with dips varying from 30 to 50 degrees. The other two sets are perpendicular to the fold axes and are steep – dipping. Sheet jointing is also common in Charnockites.

Table 4.1 Stratigraphic sequence of geological formations in Upper Ponnaiyar Aquifer system, Tamil Nadu.

Era	System	Age	Lithology
CENOZOIC	Quaternary	Recent	Soils River Alluvium Colluvium
		UNCONFORMITY	
AZOIC	Archaean	Archaean	Ferruginous quartzites and Quartz veins, Ultrabasic to alkaline intrusives Carbonatites Dunite Pyroxenite Syenite Diabase Amphibolites Peninsular gneiss Granite gneiss Biotite gneiss Hornblende gneiss Charnockites

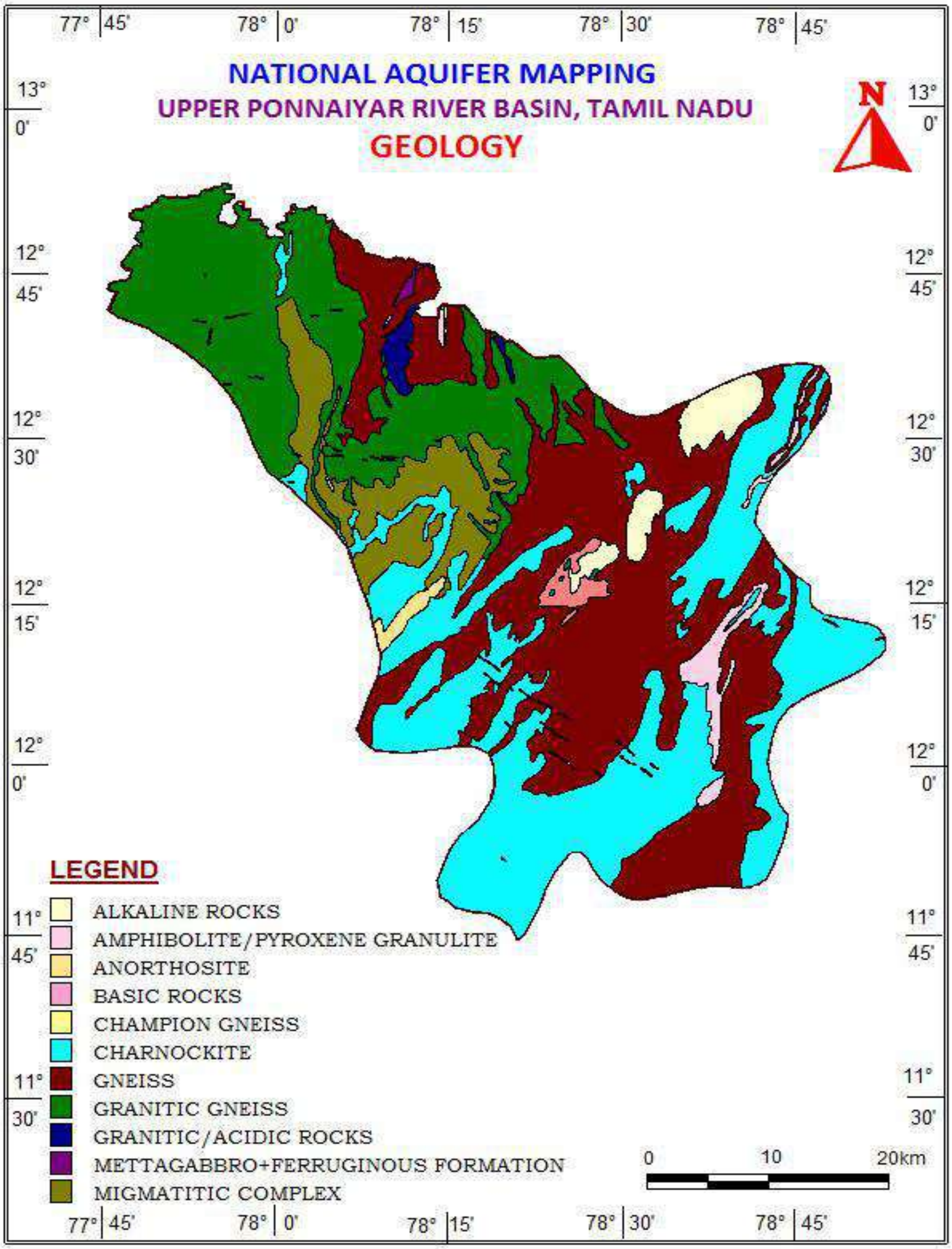

NATIONAL AQUIFER MAPPING
UPPER PONNAIYAR RIVER BASIN, TAMIL NADU
GEOLOGY
N
LEGEND
ALKALINE ROCKS
AMPHIBOLITE/PYROXENE GRANULITE
ANORTHOSITE
BASIC ROCKS
CHAMPION GNEISS
CHARNOCKITE
GNEISS
GRANITIC GNEISS
GRANITIC/ACIDIC ROCKS
METTAGABBRO+FERRUGINOUS FORMATION
MIGMATITIC COMPLEX
0
10
20km
77° 45'
78° 0'
78° 15'
78° 30'
78° 45'
13° 0'
12° 45'
12° 30'
12° 15'
12° 0'
11° 45'
11° 30'

Figure 4.1 Geology map of Upper Ponnaiyar River Basin

5 DATA AVAILABILITY & DATA GAP ANALYSIS

Data available with Central Ground Water Board (CGWB), South West Coastal Region (SECR), Chennai, pertaining to exploratory wells drilled, geophysical exploration, depth to water level data monitored from Ground Water Monitoring Stations and Ground Water Quality at the monitored stations, were compiled and analysed for its adequacy in connection with Aquifer Mapping Studies in Upper Ponnaiyar Aquifer system.

Data Gap Analysis (DGA) was carried out based on available data of exploratory wells, to decipher the aquifer geometry & aquifer parameters. Depth to water level data and water quality data were considered to understand the ground water regime & quality in the study area.

Considering the available data and its analysis, the need for generating additional data has been arrived. Upper ponnaiyar basin, the phreatic aquifer is mostly de-saturated and dry, Hence, both the weathered, partially weathered and first fractured of the aquifer are considered as single aquifer system, which termed as weathered aquifer and rest are fractured aquifer.

5.1 Data availability

During the project period, existing data of CGWB since inception i.e. exploration, depth to water levels, water quality, geophysical logging, ground water resource data, results of earlier studies have been collected and compiled. In addition to this, various thematic layers such as geology, soils, land use/land cover, geomorphology, etc., from various State/Central Government agencies have been collected, complied and used in this study.

5.2 Data Gap Analysis

Based on the existing data on various themes, data gap analysis has been carried followed by detailed survey, which was taken up and data were generated. The details of data available and subsequently data generated.

5.3. Groundwater Exploration data

A total of 77 Nos of exploratory wells have been drilled in the basin underground water exploration activity of the CGWB, SECR, Chennai before National Aquifer Mapping project. 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, 68 Nos of additional exploratory wells were drilled in the aquifer mapping area of the basin as part of the data generation shown in **Figure 5.1**.

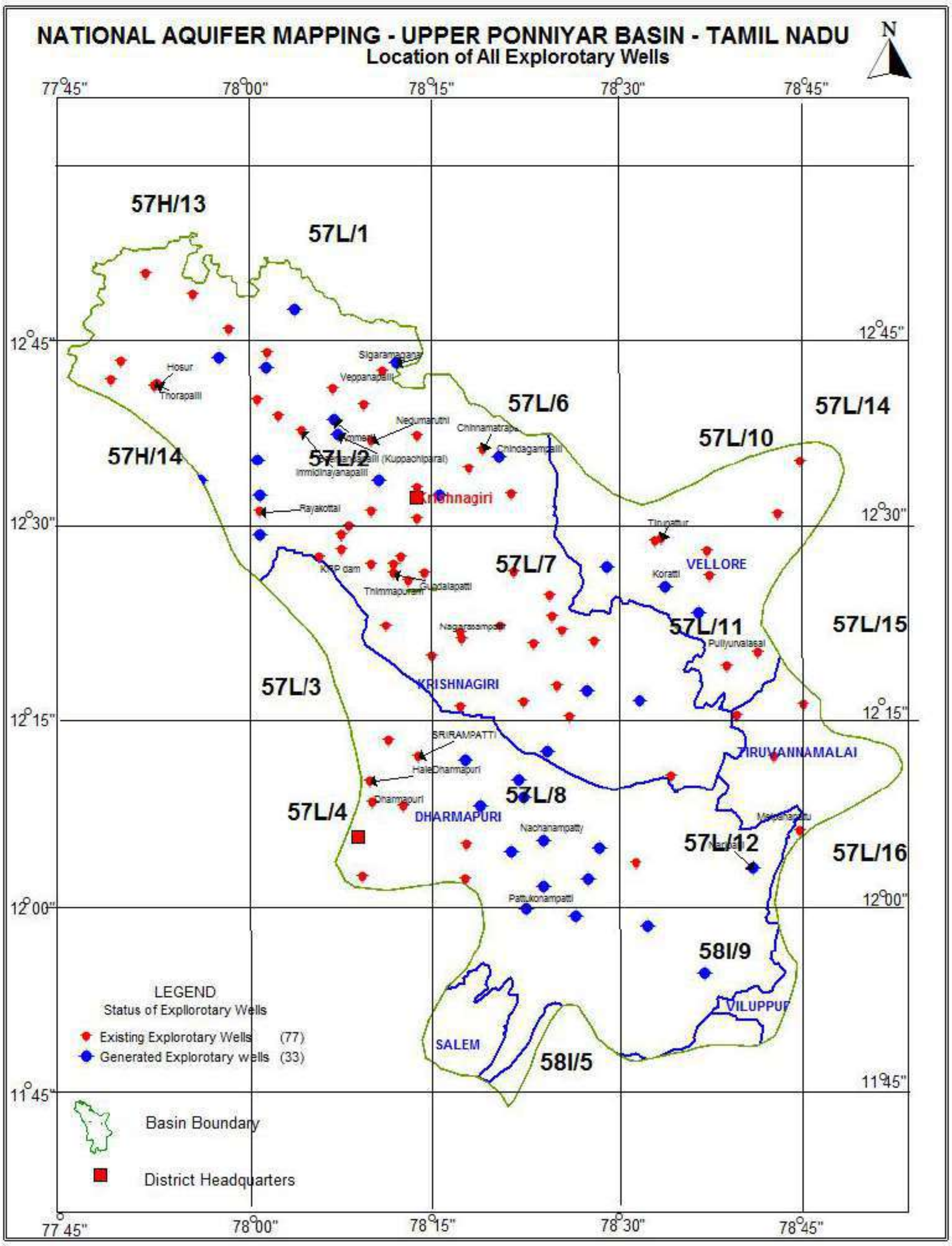


Figure. 5.1. Locations of Groundwater Exploration wells.

5.4. Geophysical data

In order to supplement the exploration data, geophysical survey was carried out in the basin. A total of 56 Nos of VES were conducted in the basin under various study mainly of ground water exploration activity of National Aquifer Mapping project. These VES locations were plotted on the 1:50,000 scale topographical map. Additional 186 Nos of VES were carried out in the aquifer mapping area of the basin as part of the data generation shown in **Figure 5.2**. The data such as layers information and thickness of layers were generated and utilised to depict the prevailing aquifer systems of the basin wherever the borewell data are not available.

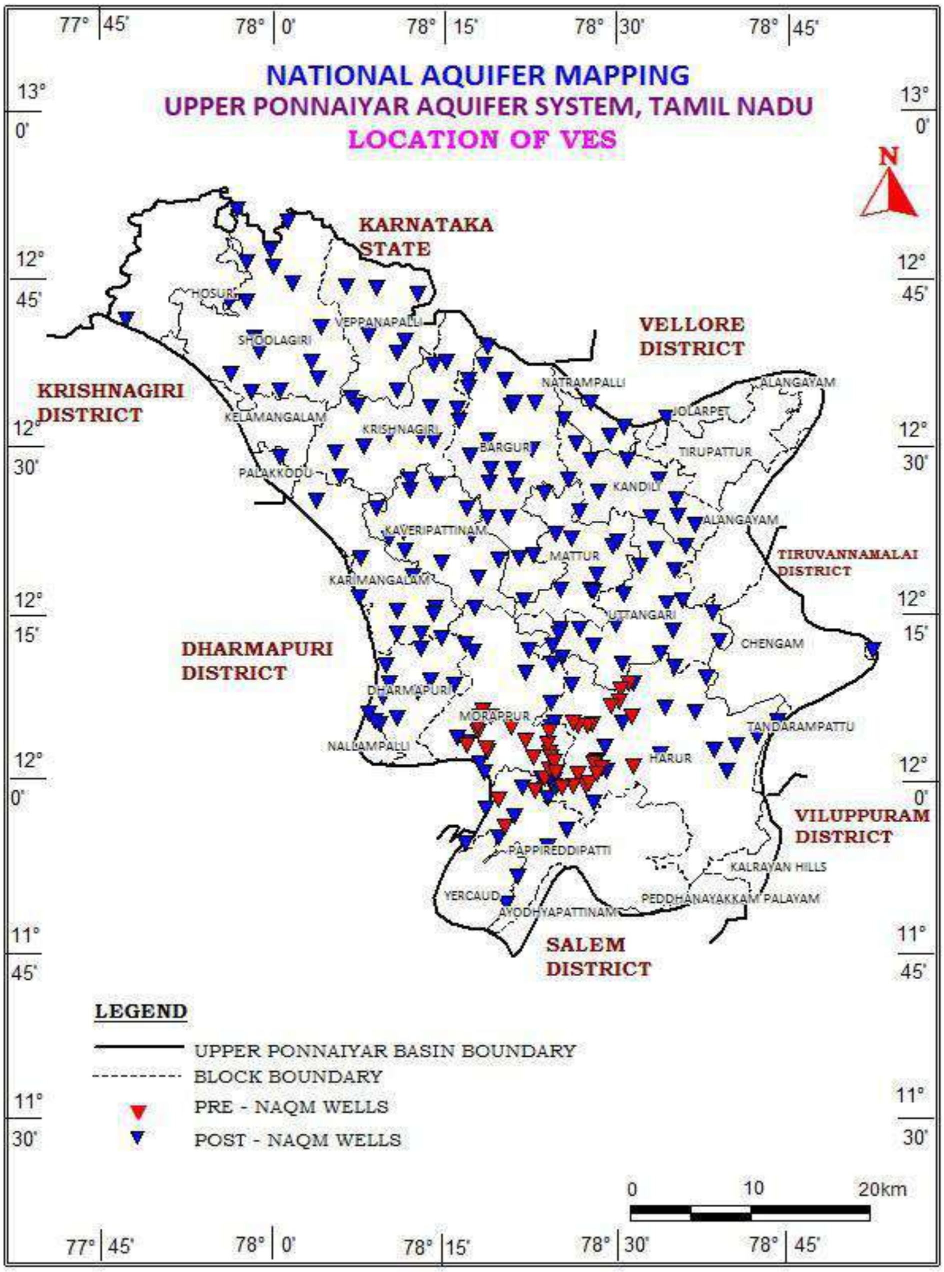


Figure. 5.2. Locations of VES

5.5. Groundwater level monitoring

The periodical monitoring of ground water levels implies the groundwater recharge and discharge (natural and manmade) occurring in the aquifer systems. In the basin, 18 Nos groundwater level monitoring wells are monitored periodically. These well locations were plotted and identified the data gap. To fill data gap in the basin, 298 Nos of wells were established and groundwater levels were monitored periodically shown in **Figure 5.3**. The 32 Nos borewells drilled for specific purposes were also included for groundwater level monitoring in the basin.

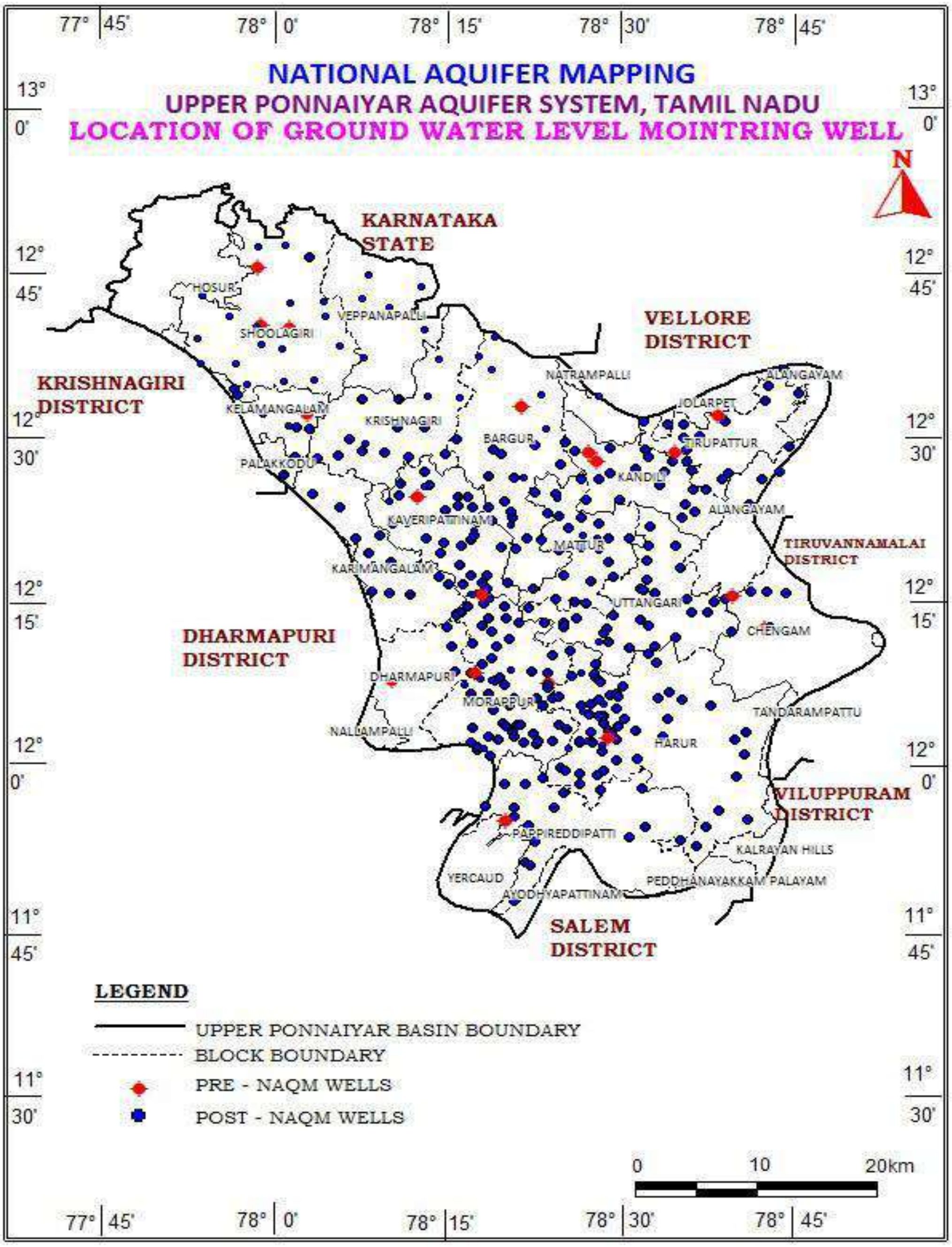


Figure. 5.3. Locations of Groundwater level monitoring

5.6 Groundwater Quality Analysis

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 In the basin, groundwater quality of 18 Nos of wells were monitored periodically. To fill data gap in the basin, additional1008 Nos of water samples were collected and submitted for analysis shown in Figure 5.4.

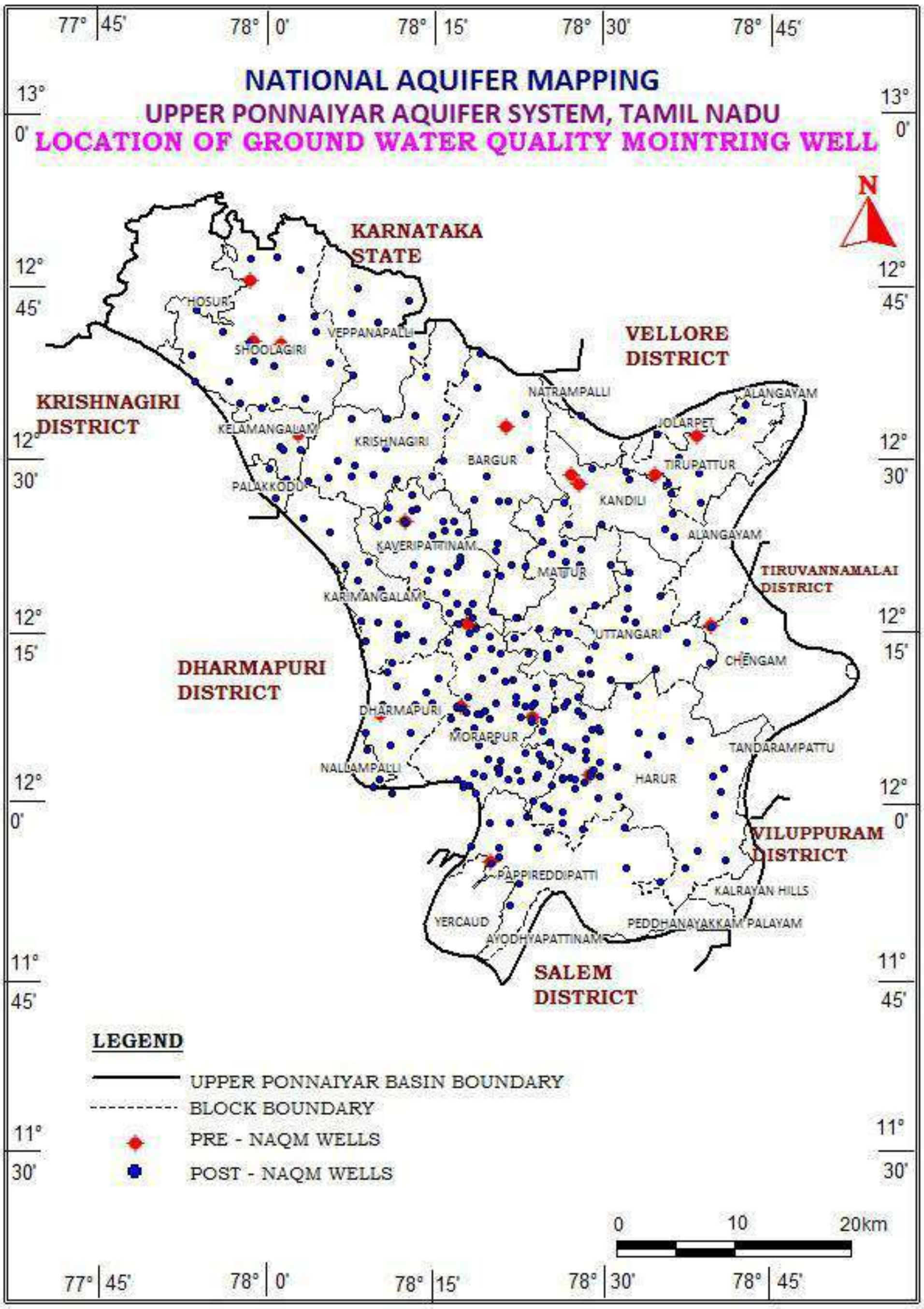


Figure. 5.4. Locations of Groundwater quality monitoring wells

5.7 Sub-surface lithological information

5.7.1 Status of Ground Water Exploration

Ground water exploration through drilling was taken up by CGWB in the study area since 1988. So far 109 wells have been drilled to know the thickness of the top weathering and the existence of deep seated fractures. Sites for drilling were selected based on hydrogeological, geophysical and remote sensing studies. The wells, ranging in depth from 100 to 300 m.bgl. were drilled in the study area. A numerous number of tube/bore wells have been drilled in the study area by various State Government agencies too.

The exploratory drilling carried out by CGWB has revealed the presence of productive fractures in the area underlain by crystalline rocks. Productive fracture zones have been encountered in crystalline rocks in the depth range of 16.70 to 160 m.bgl. A few of the wells have been abandoned due to poor yield.

The aquifer mapping study in the basin reveals that the presence of two distinct aquifer systems in the hard rock consolidated formations. The aquifers are;

a. **Weathered aquifer**, comprises of weathered formations, partially weathered and some extent first fractures of charnockites and granitic gneisses rock formations. The depth ranges from 5 to 39 m and contains water during monsoon season and become dry later. Northern part of basin, the aquifer thickness shallow, depth restricted to 15 m and southern portion of the basin thickness is more, depth extends up to 39 m. The formations yield maximum of 100-500 lpm and sustain for 1 to 2 hrs. of pumping and transimissivity value of aquifers ranges between 30 and 120 m^2/day.

b. **Fractured aquifer,** comprises of mainly of fractures (secondary porosity) developed during tectonic disturbances**,** occurs at depth ranges from 9 to 160 m bgl and contains water, the formations yield maximum of 30 to 400 lpm and sustain for 2 to 4 hrs. of pumping. The transimissivity value of aquifers ranges between 20 and 80 m^2/day.

c. **Massive**, thickness and depth not constant everywhere, varies place to place.

5.7.2 Yield Characteristics of Wells & Aquifer Parameters

The yields of successful exploratory wells drilled in Dharmapuri district ranged from 0.2 lps (Volyampatty) to 16.44 lps (Chinnamattarappally). A perusal of the data reveals that higher yields have been obtained in wells drilled in granitic gneisses in comparison to those drilled in Charnockites. Yield characteristics of bore wells drilled in the study area as wells as various parameters of the aquifers tapped have been determined through pumping tests conducted in them. The details of tests conducted and parameters computed. Specific Capacity of wells in the district ranged from 0.44 lpm/m (Marandahally) to 118 lpm/m (Chennappalli). The wells recorded transmissivity values ranging from 1 m^2/ day (Koladasapuram) to 188 m^2/ day (Chennappalli) with low to very low permeability values.

5.7.3. Problems Encountered during Drilling Operations

Drilling operations in the study area is generally hassle – free and the only problems encountered during drilling are of low penetration and wearing out of drilling bits while drilling through massive rocks. Back pressure of water may also affect the penetration rate in case of high yielding wells occasionally.

The exploratory well data and VES data, which are distributed throughout the study area in all the two major aquifers are considered for preparation of various models (figure 5.5). The basic details viz., location of the exploratory wells, its geographical coordinates, depth of drilling along with casing details, depth-wise lithological information, depth of fractures encountered along with its cumulative yield, information on thickness of soil, weathered, fractured and massive formations for each exploratory well is compiled and brought under the desired format. The drilling depth varies from 60 to 300 m bgl with casing ranging from 5 to 34 m bgl.

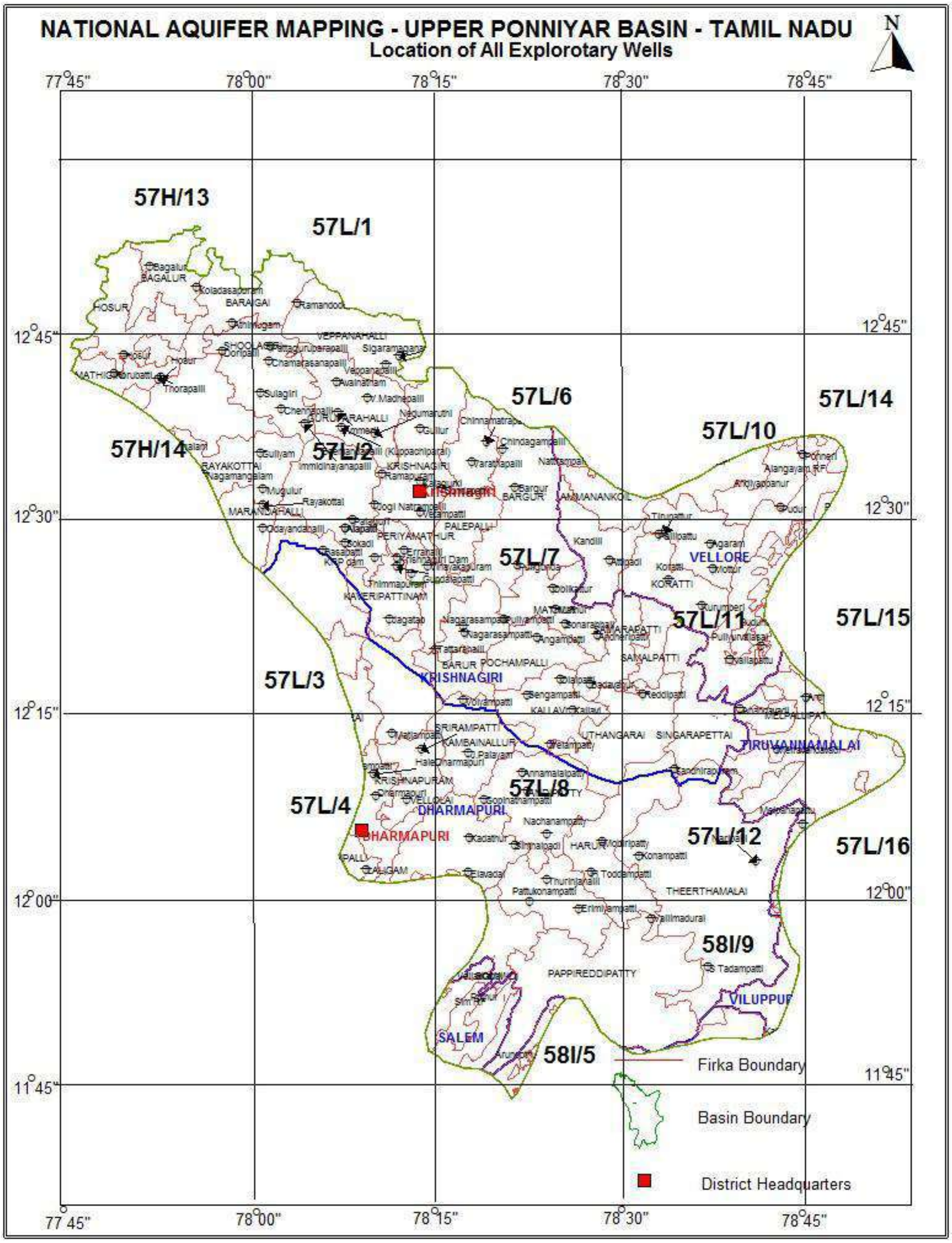


Figure 5.5. Spatial distribution of exploratory wells and VES

5.8 Aquifer Dispossition

2D model Aquifer Dispossition:

Based on the Hydrogeological studies and lithology encountered during drilling, the Aquifer geometry in 2 dimensions (vertical and lateral extent) is deciphered using Rockworks software. The isopach maps and Aquifer unit - I (Weathered Aquifer) and Aquifer Unit - II (Fractured Aquifers) are presented in figure 5.6 and 5.7 repectively.

Three aquifers were deciphered as given below. 2D multi strip logs of representative exploratory wells, combination of lithology profile and 2D multi strip logs, 3D lithology models, lithology fence diagrams, fracture profiles along with strip logs and integrated fracture fence diagram with 3D multi-log are presented in Figures in subsequent pages.

Table 5.1: Database required for preparation of lithology and aquifer models.

Data - 1

Bore	Depth1	Depth2	Lithology
Hale Dharmapuri	0	9	Weathered
Hale Dharmapuri	9	36	Fractured
Hale Dharmapuri	36	223	Massive

Data - 2

Bore	Depth1	Depth2	Aquifer
Hale Dharmapuri	15.53	17.53	1st Fracture
Hale Dharmapuri	34.83	35.83	2nd Fracture

Data - 3

Bore	Type	Depth1	Depth2	Value(lps)
Hale Dharmapuri	Discharge	15.53	17.53	0.215
Hale Dharmapuri	Discharge	34.83	35.83	1.20

Data - 4

Bore	Depth1	Depth2	Stratigraphy
Hale Dharmapuri	0	1	Top soil
Hale Dharmapuri	1	9	Weathered
Hale Dharmapuri	9	15.53	SlightlyFractured
Hale Dharmapuri	15.53	36	Fractured
Hale Dharmapuri	36	223.00	Massive

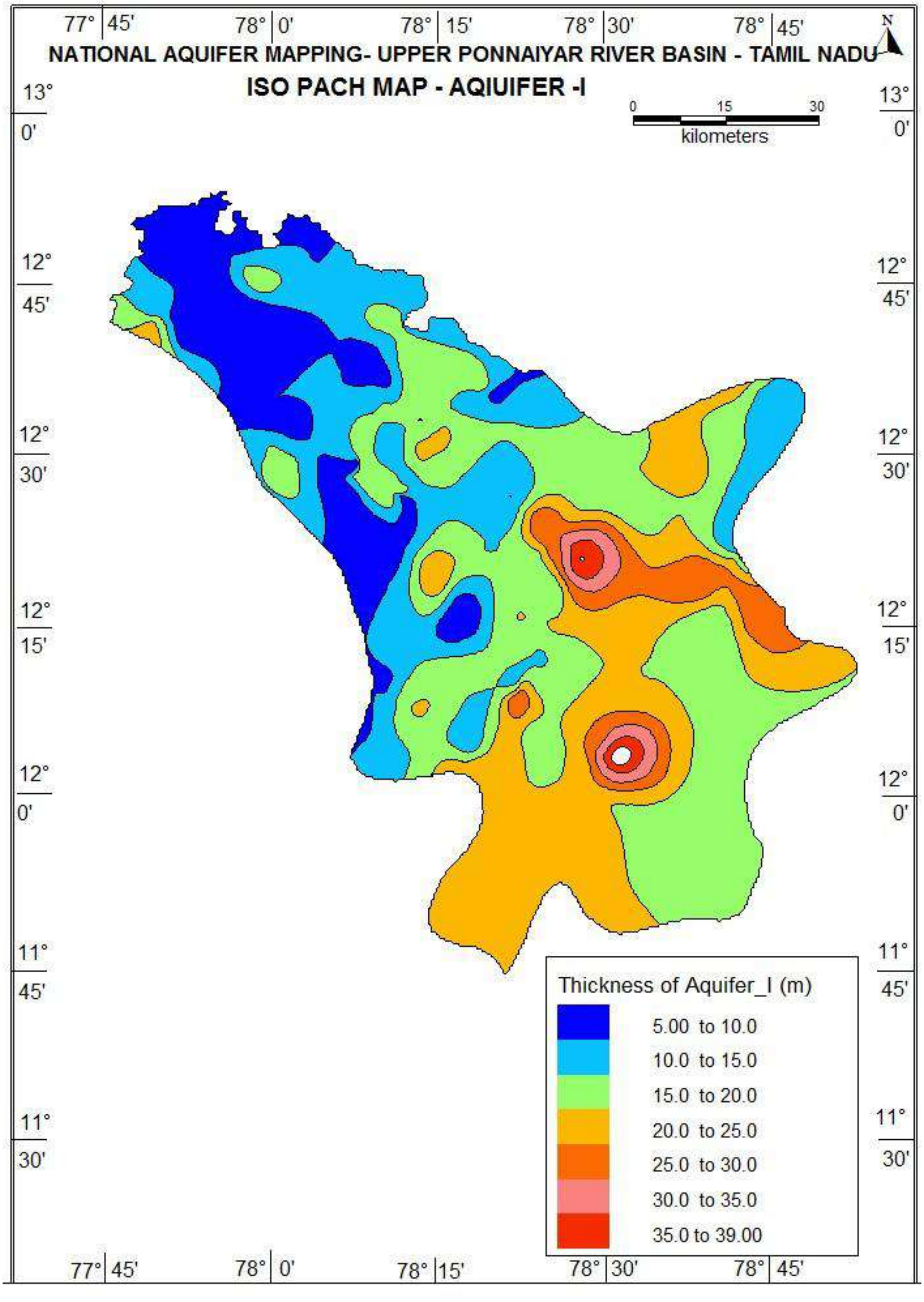


Figure: 5.6 Isopach of Aquifer - I (Weathered Aquifer)

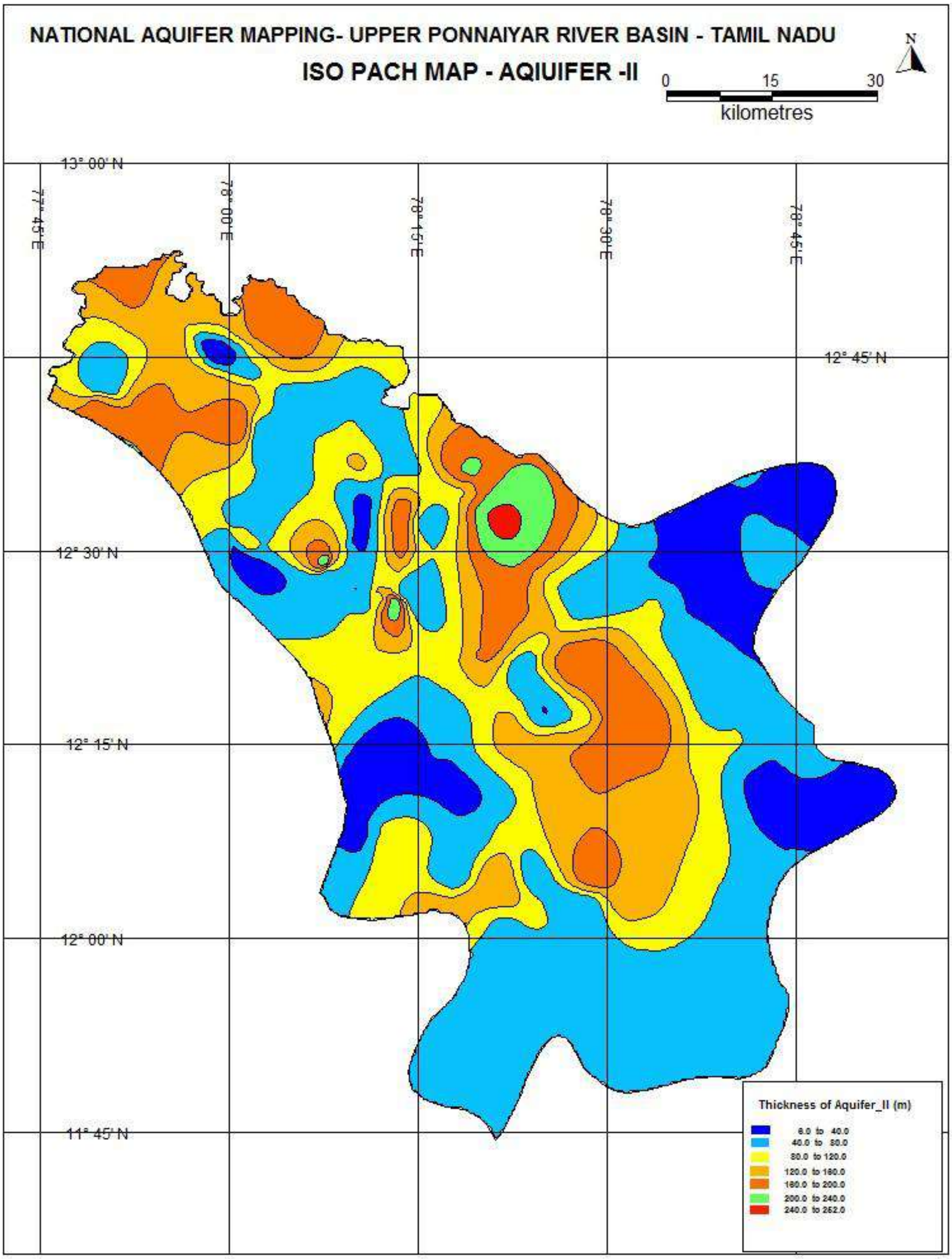
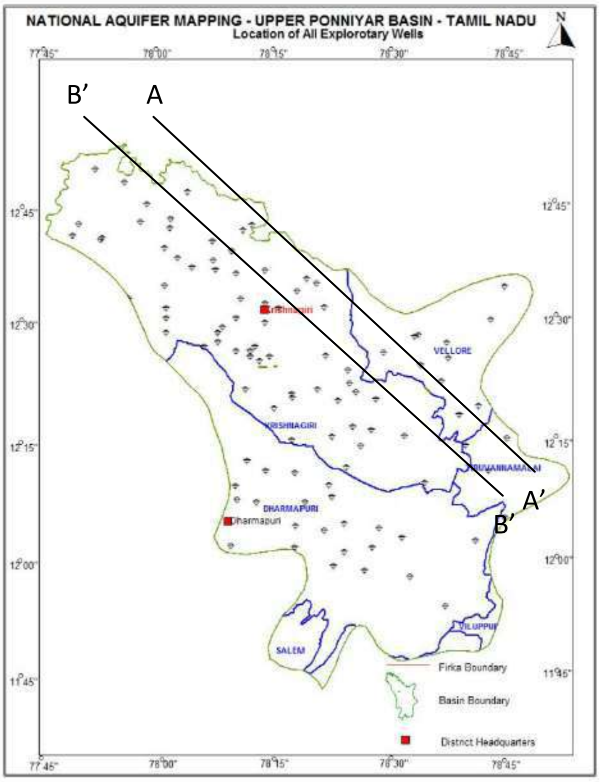
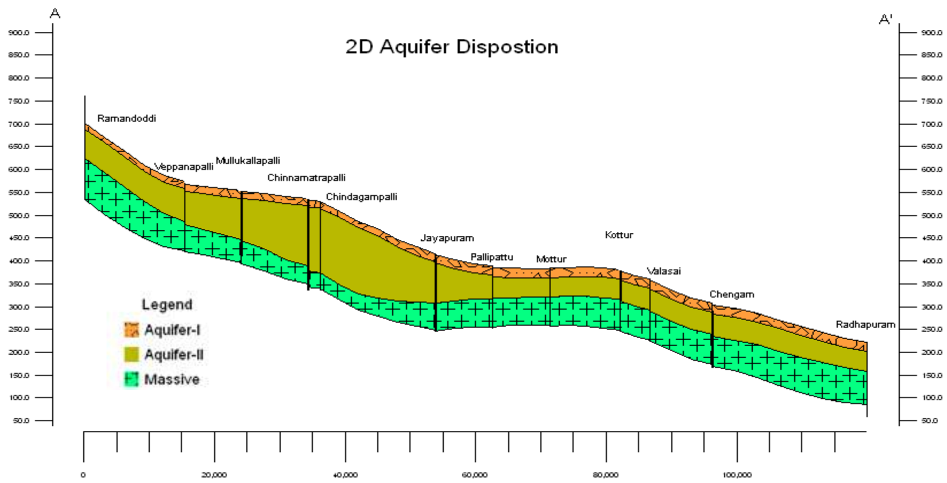
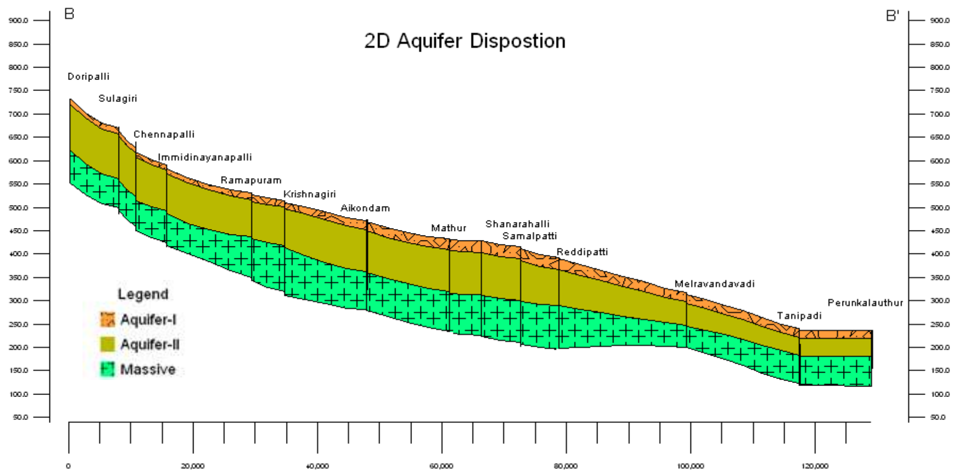


Figure: 5.7 Isopach of Aquifer - II (Fractured Aquifer)

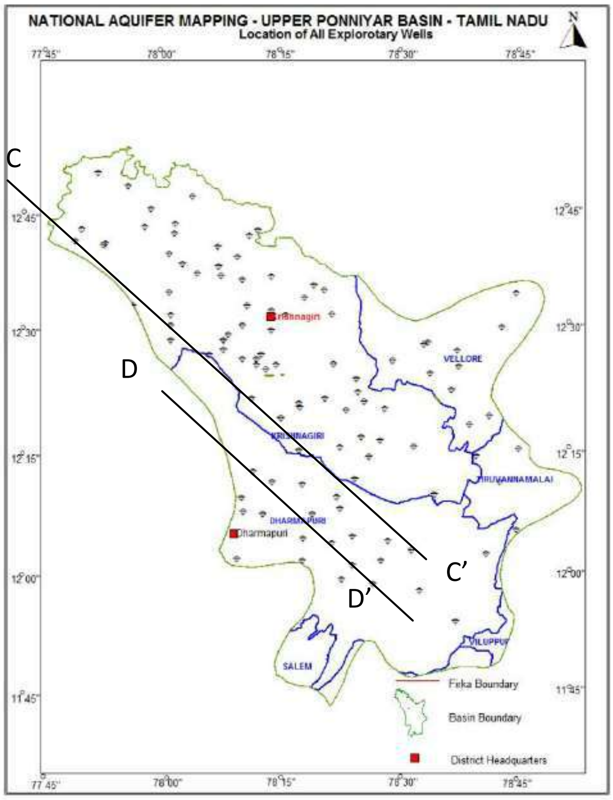
2D Aquifer disposition

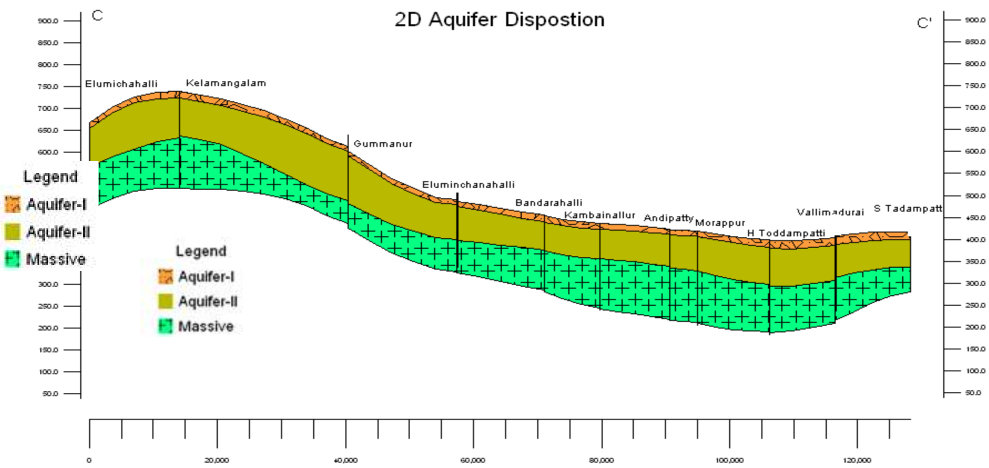


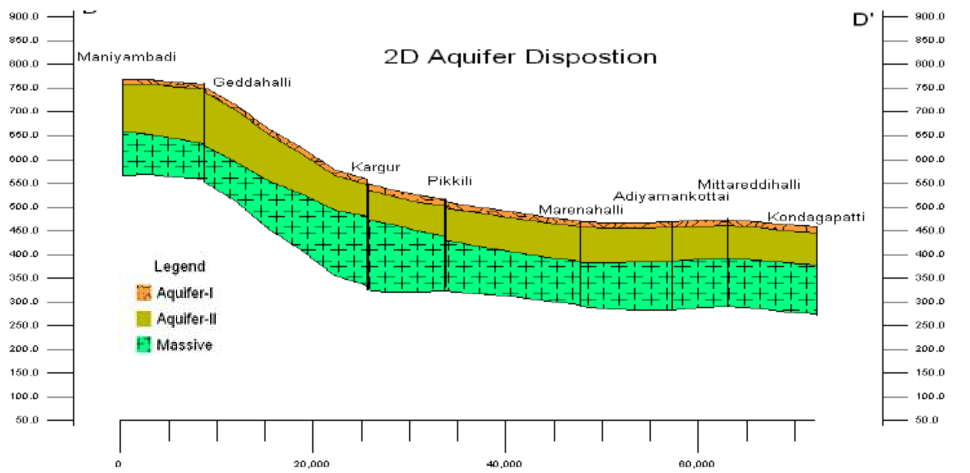




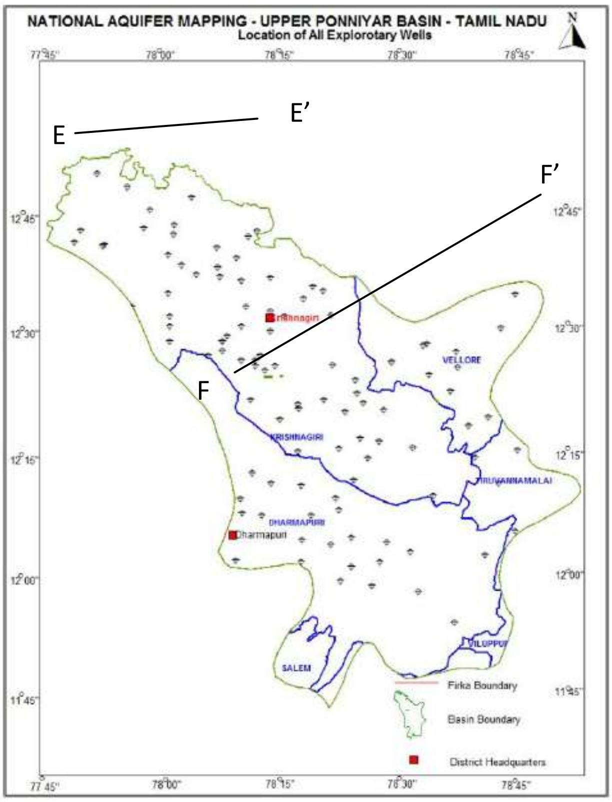
2D Aquifer disposition

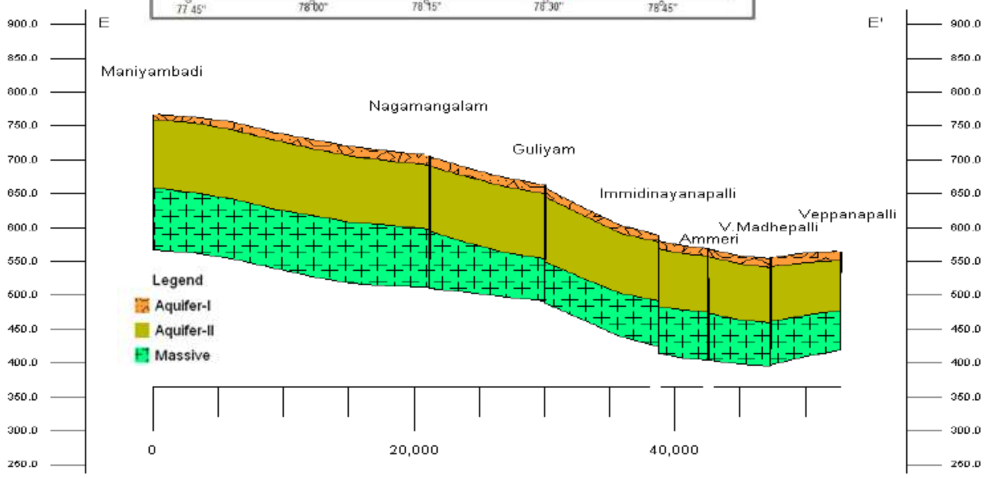


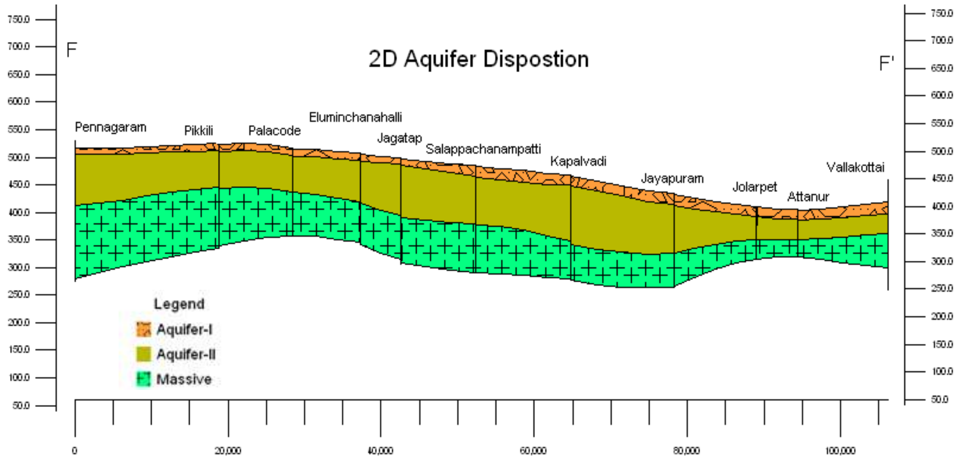




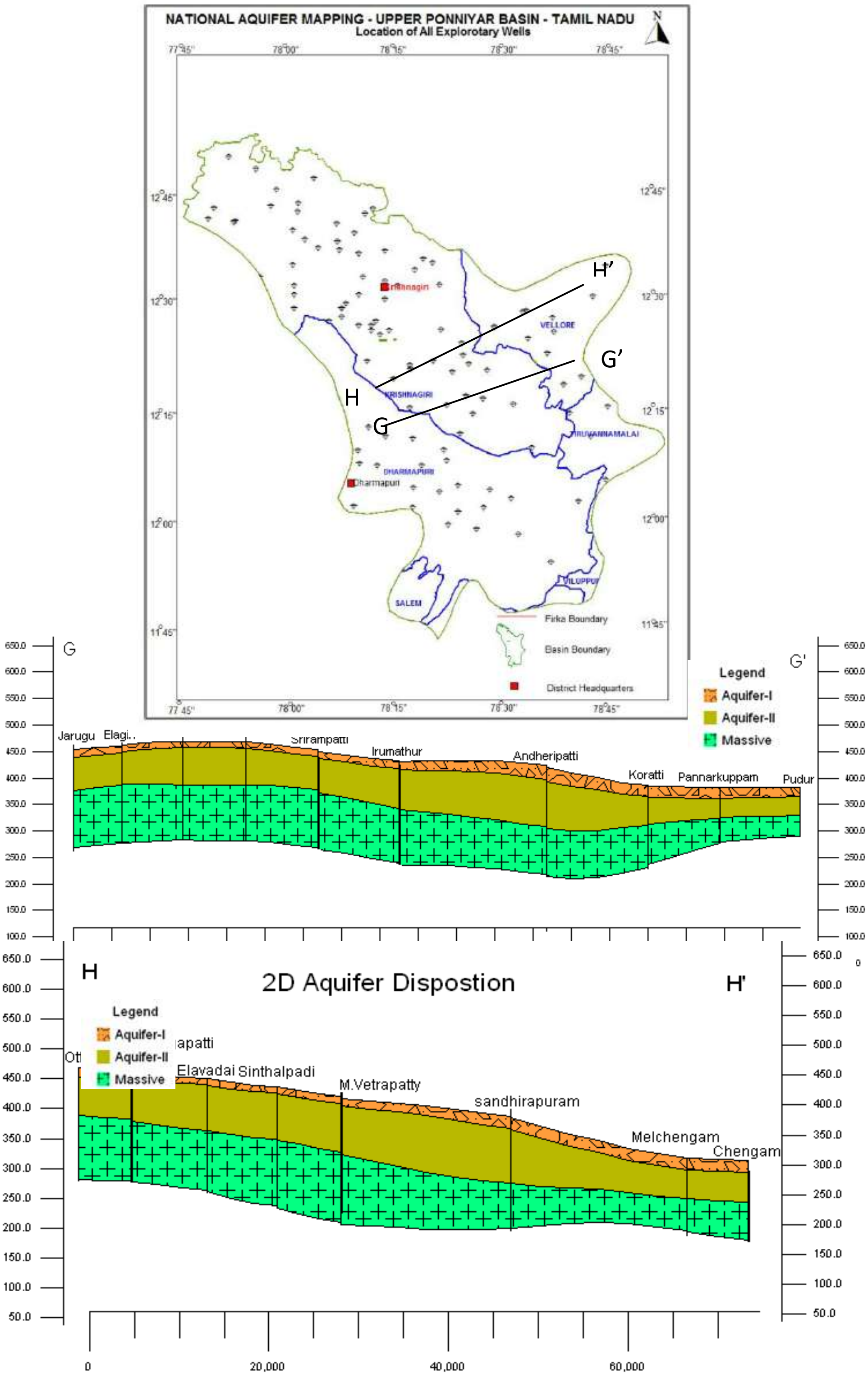
2D Aquifer disposition



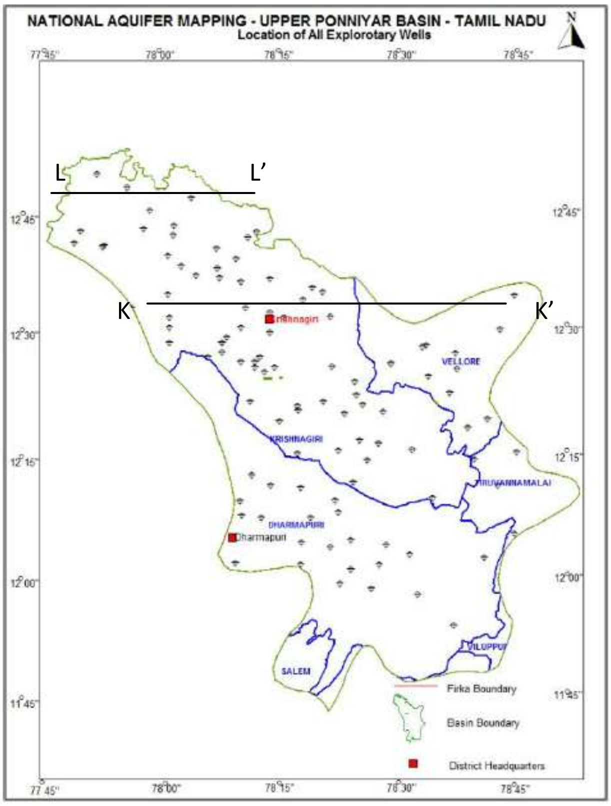


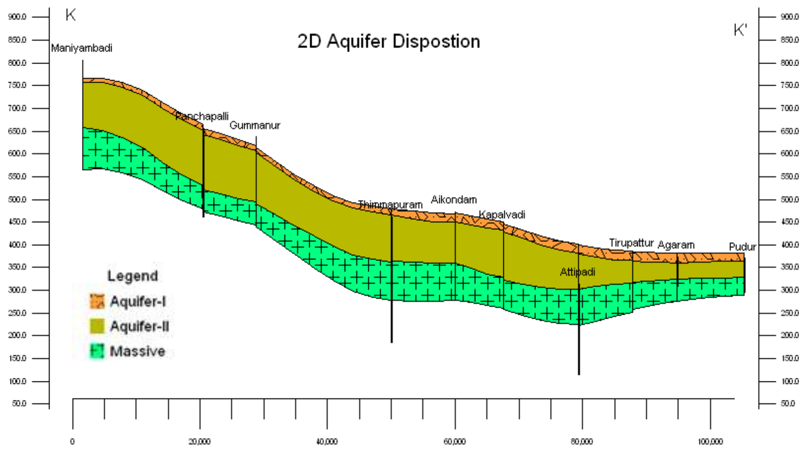


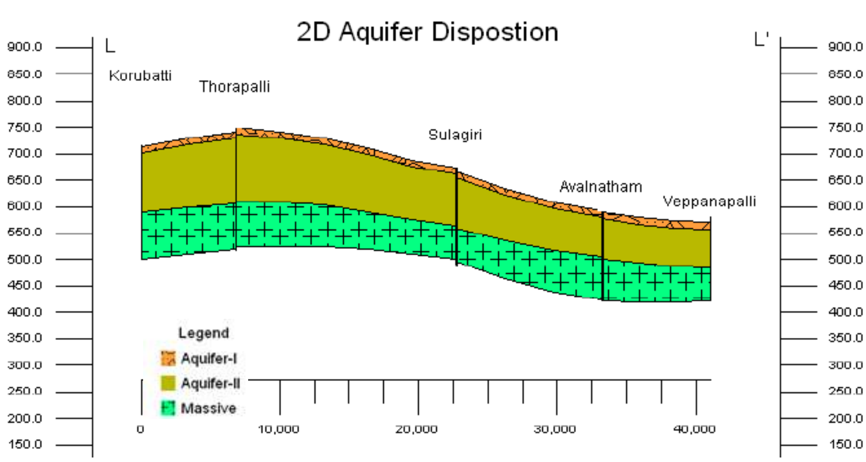
2D Aquifer disposition



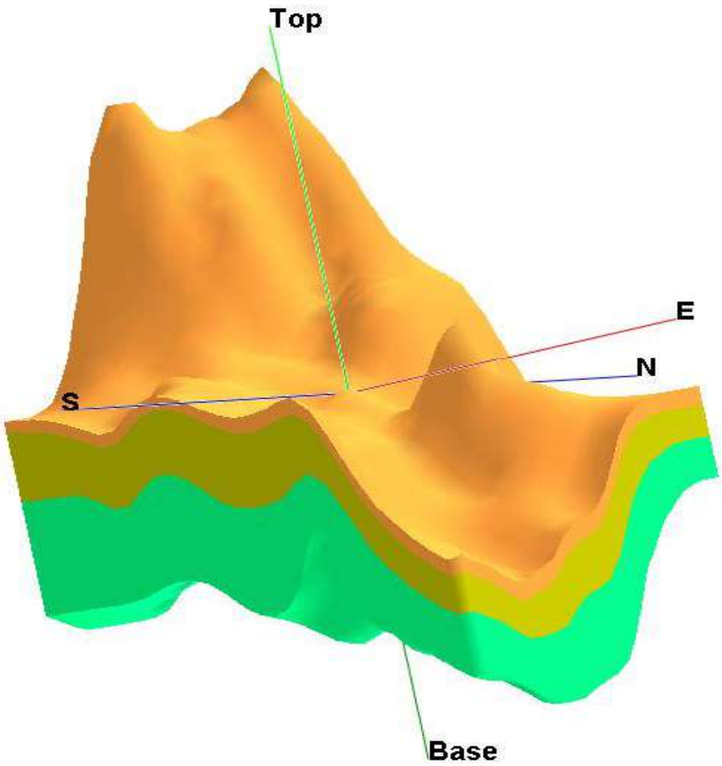
2D Aquifer disposition

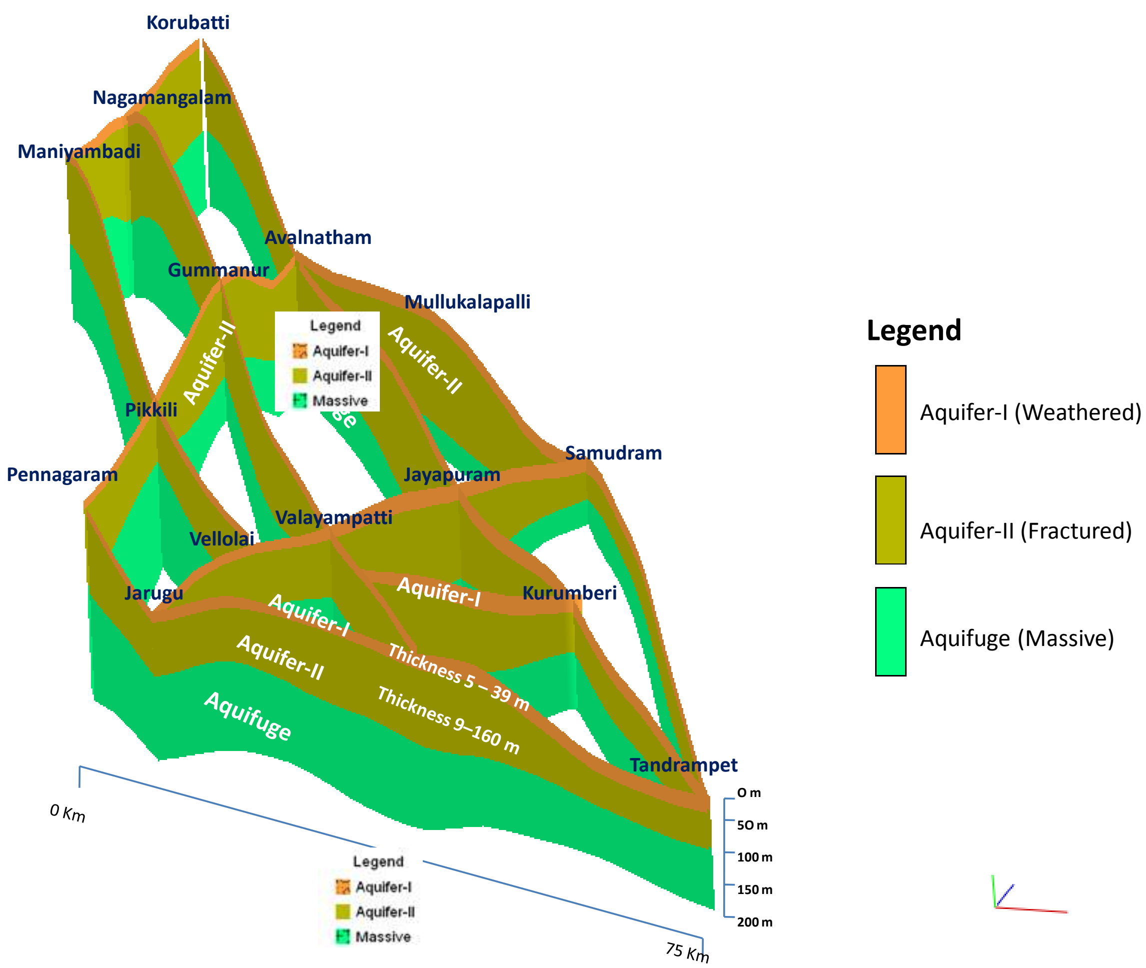






3D Aquifer Disposition – Upper Ponnaiyar Aquifer System





6. HYDROGEOLOGY

6.1 Aquifer Systems

The Upper Ponnaiyar river aquifer system is underlain by Archaean Crystalline formations with recent alluvial deposits of limited areal and vertical extents along major rivers. The occurrence and movement of ground water are controlled by various factors such as physiography, climate, geology and structural features. The important aquifer systems in the study area are constituted by weathered, fissured and fractured crystalline rocks and the recent alluvial deposits.

6.2. Ground water in crystalline formations

The water-bearing properties of crystalline formations which lack primary porosity depend on the extent of development of secondary inter-granular porosity either through weathering or fracturing. The occurrence and movement of ground water in these rocks are generally confined to such spaces. These aquifers are highly heterogeneous in nature due to variations in lithology, texture and structural features even within short distances. Ground water generally occurs under phreatic conditions in the weathered mantle and under semi-confined conditions in the fissured and fractured zones at deeper levels. The thickness of weathered zone in the study area is in the range of less than 1m to more than 20m.

6.3 Aquifer & Well parameters

The yields of large diameter wells in the study area, tapping the weathered mantle of crystalline rocks range from 100 to 500 lpm. The wells are able to sustain pumping for 1 to 2 hours per day depending upon the local topography and characteristics of the weathered mantle. The yield of bore wells drilled down to a depth of 300 m. bgl by various state agencies mainly for domestic purposes range from 0.6 to 18.75 lps. The yields of successful bore wells drilled during the ground water exploration programme of CGWB ranged from 0.25 to 16.44 lps. The aquifer and well parameters of the wells show wide variations. A critical analysis of the data collected during exploratory drilling in the study area indicates that gneissic rocks have better yield prospects when compared to charnockites. The aquifer parameters determined from pumping tests in the exploratory wells of CGWB are furnished in as Annexure in table 5.1 and 5.2. The aquifer properties such as horizontal hydraulic conductivity, Specific yield and storativity used in the model was derived from 67 pumping tests results and is given in the table.

6.4 Water levels

6.3.1 Depth to Water levels (DTW) in phreatic zone

Ground water occurs under phreatic conditions in the weathered mantle of crystalline rocks and in the recent alluvial deposits. The water levels in this zone are being monitored four times a year through a network of 45 Hydrograph Stations by CGWB (18 wells tapping

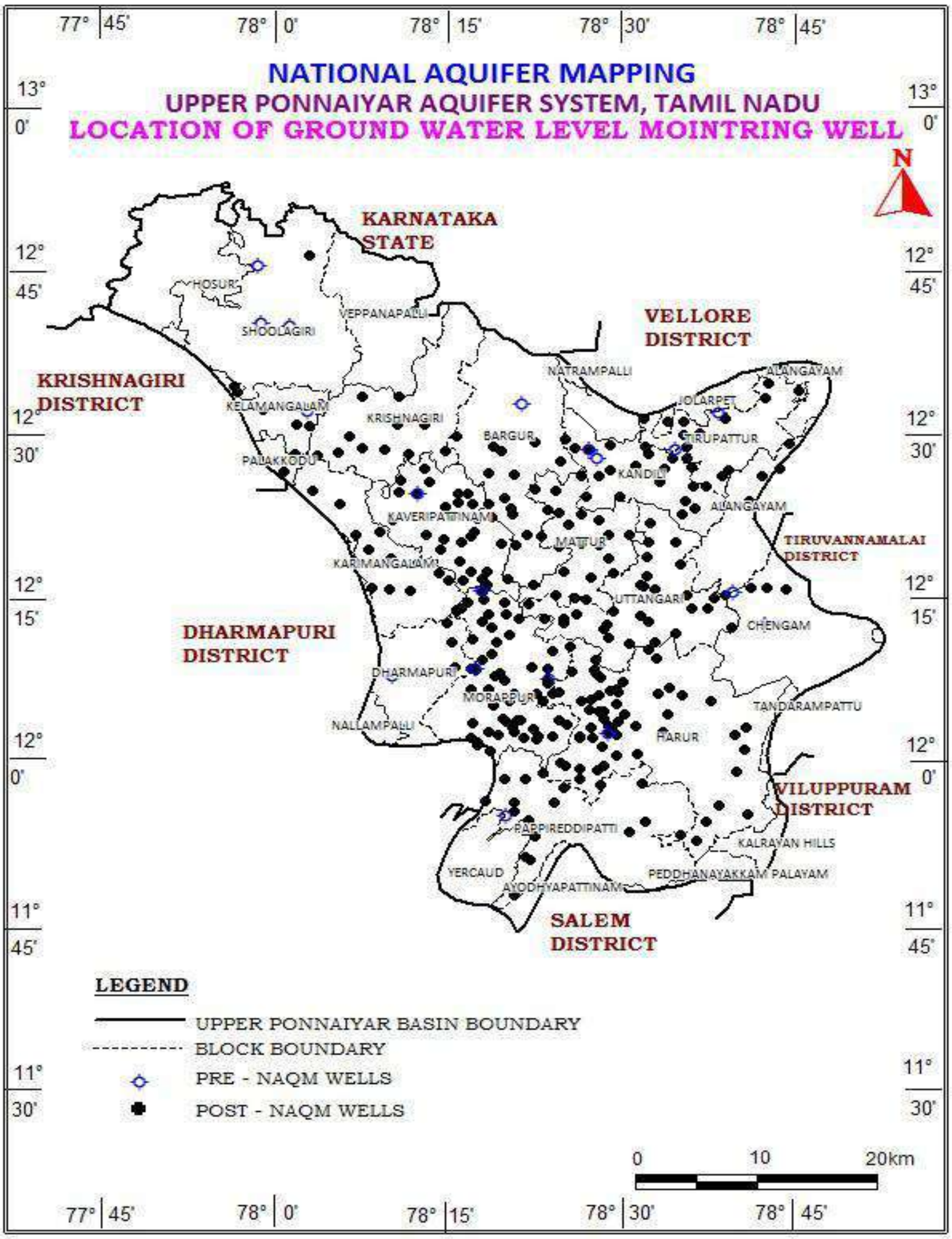


Figure 6.1. Location of Groundwater monitoring wells

phreatic aquifer and 27 wells tapping the deeper aquifer). The present analysis was carried out using the 405 key wells established under NAQUIM along with the existing monitoring wells. Locations of groundwater monitoring wells are shown in **Figure 6.1**.

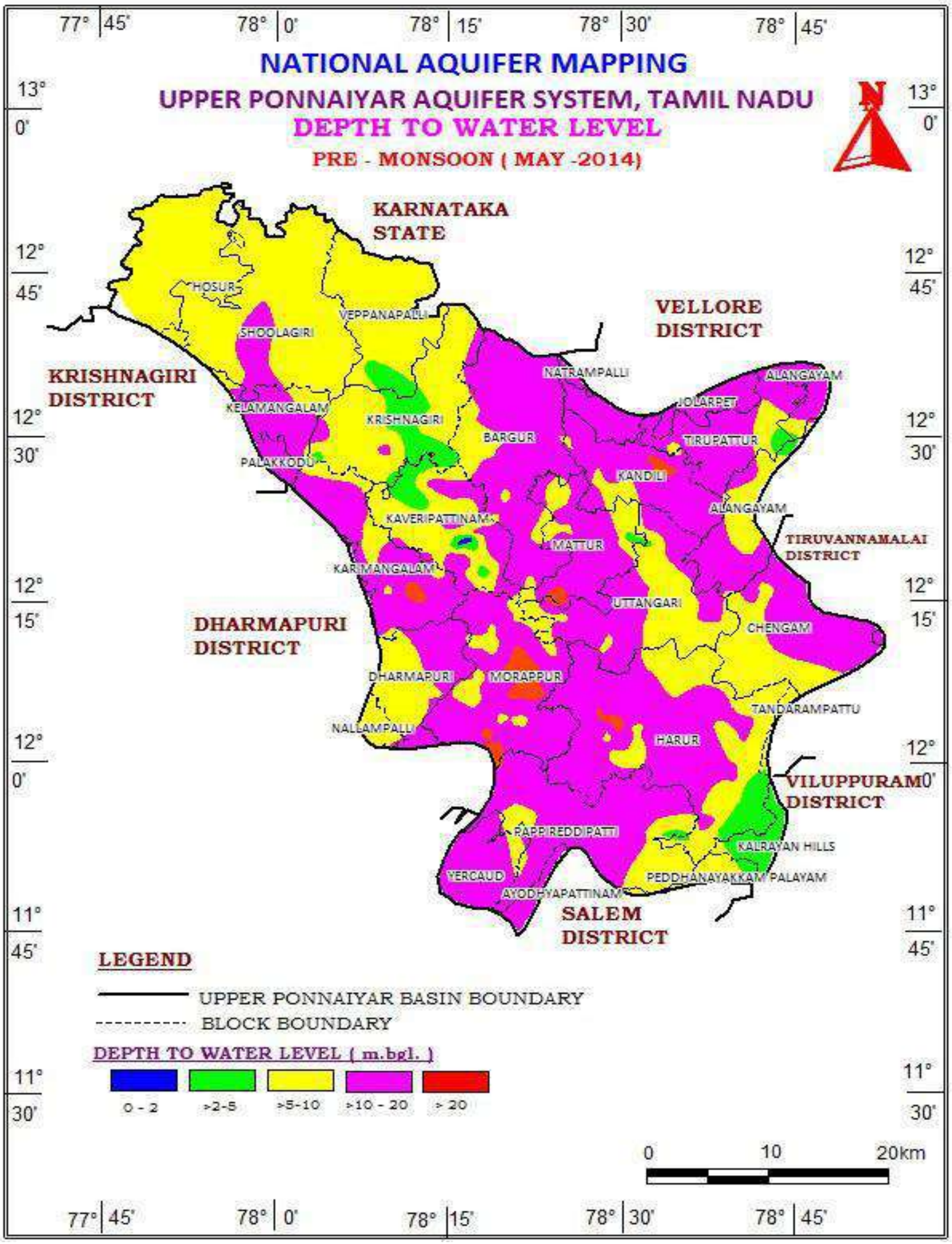


Figure 6.2. Depth to water levels (Pre-monsoon)

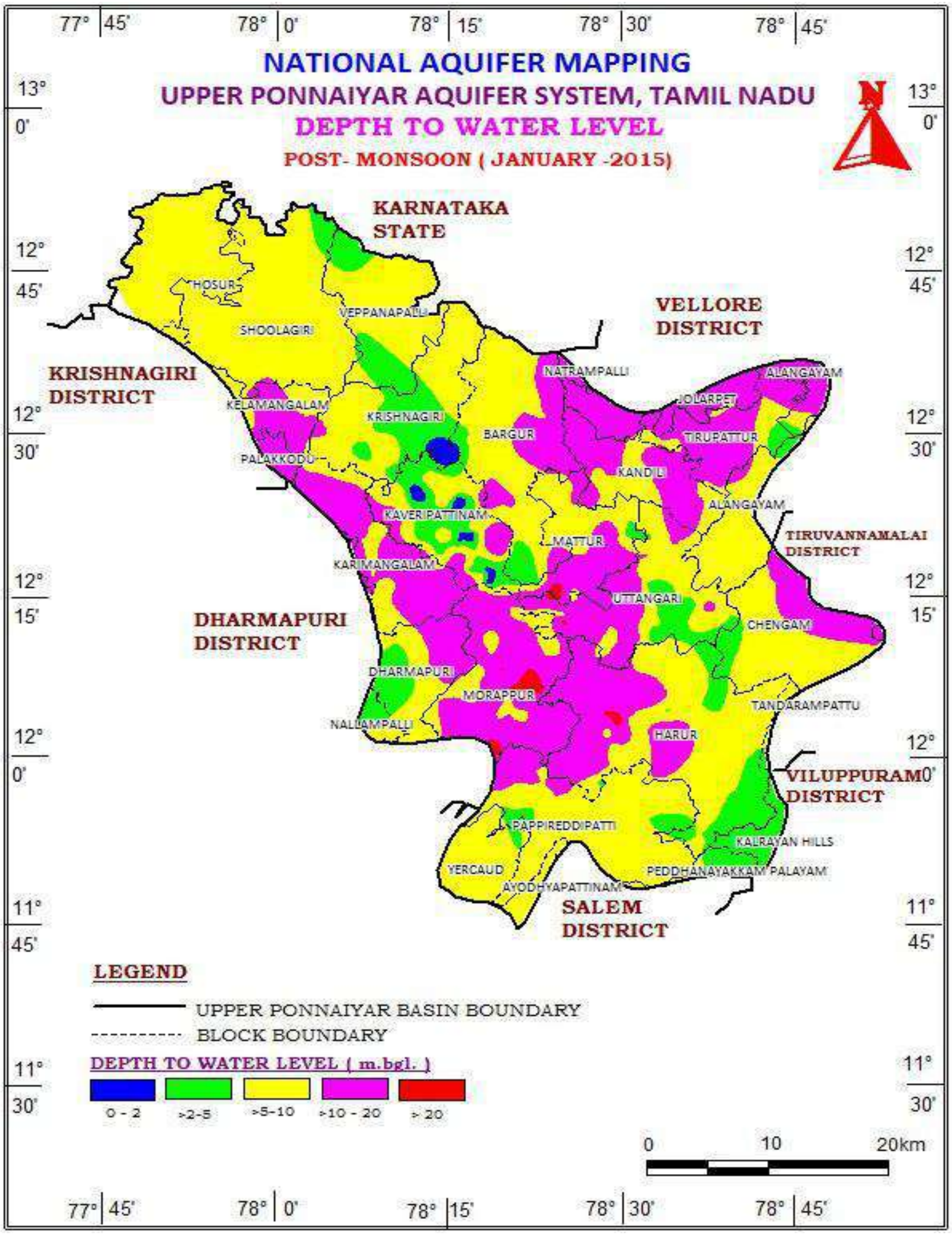


Figure 6.2. Depth to water levels (Post-monsoon)

Maps depicting the depth to water levels in the study area during **May 2014 (pre-monsoon) and January 2015 (post-monsoon)** based on the water level data of observation wells of both CGWB and key wells established under NAQUIM are shown in **Figure 6.2 and 6.3** respectively.

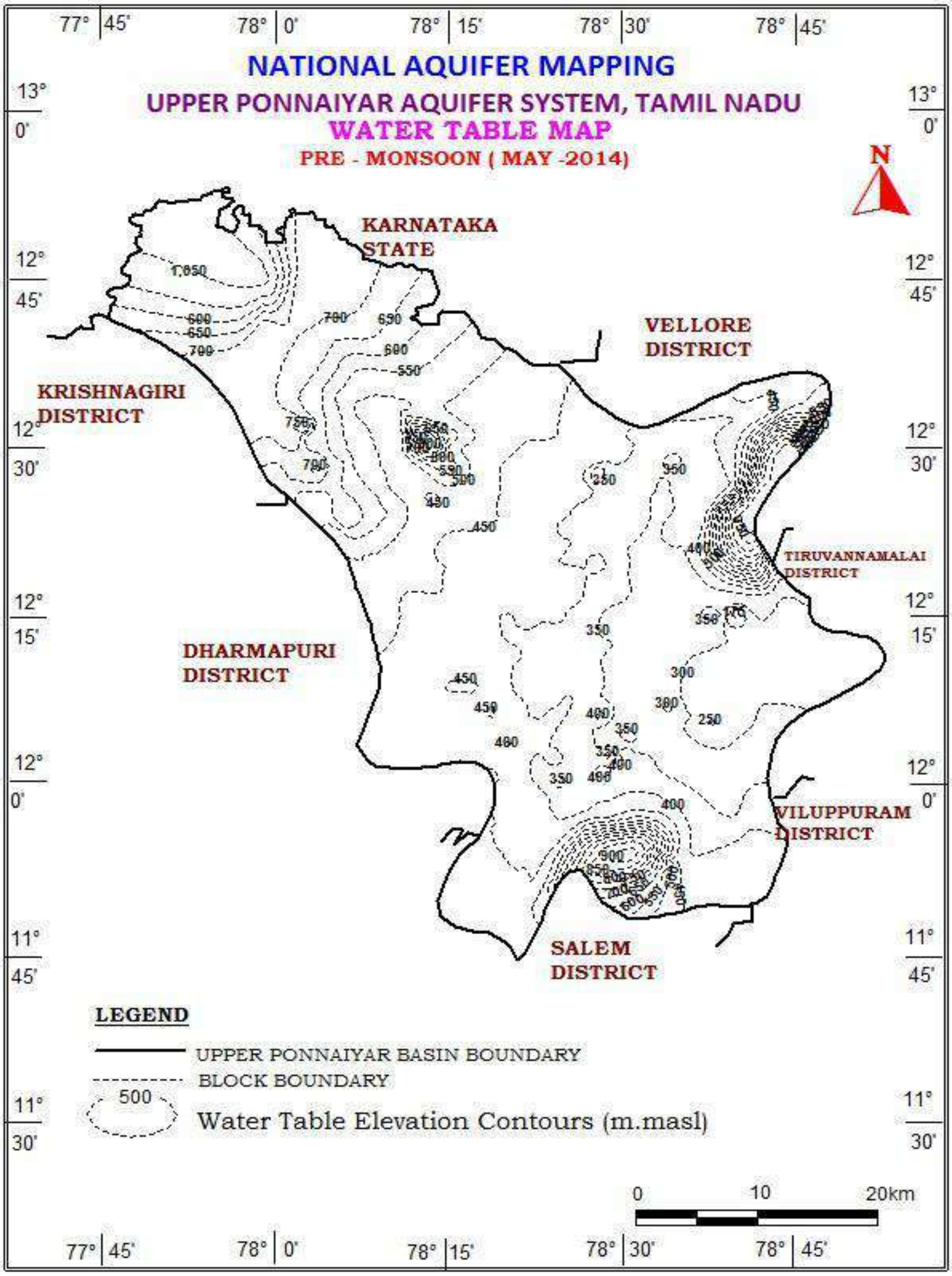


Figure 6.3. Water table elevation map (Pre-monsoon)

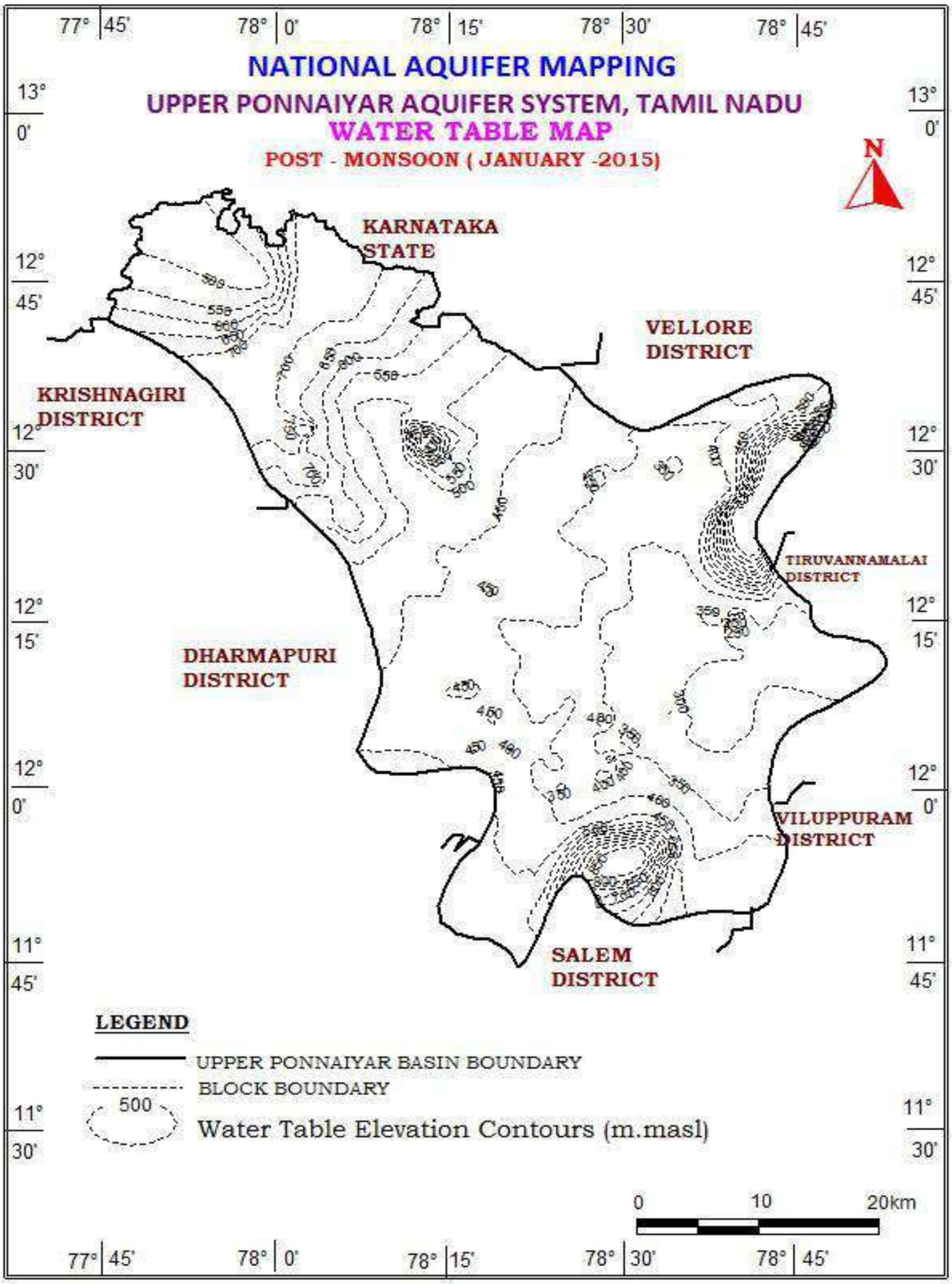


Figure 6.4. Water table elevation map (Post-monsoon)

During pre-monsoon (May 2014), the depth to water levels in observation wells tapping the phreatic aquifer in the basin ranged from 1.50 m.bgl (Location: Kavaikollai (Annanagar) – Kaveripattinam Block) to 28.50 m.bgl (Location: Budhinaikanpatti – Morappur Block). Depth to water level was in the range of 10 to 20 m.bgl. in about 60 percent of the wells analysed, whereas it was between 5 and 10 m.bgl. in 30 percent of wells. Four percent of wells analysed have recorded the water levels more than 20 mbgl, five percent of wells analysed have recorded depth to water level in the range of 2 to 5 and was less than 20 m.bgl in about one percent.

The shallow water levels in the study area were recorded in Kaveripattinam block.Water levels in the range > 2 to 5 m.bgl. were observed predominantly in Kaveripattinam, Krishnagiri and Veppanapalli blocks. Majority of observation wells in Hosur, Veppanappalli, Sulagiri, Krishnagiri, Kaveripattinam, Chengam, Uthangarai and Dharmapuri blocks showed water levels in the range of 5 to 10 m.bgl. Water level in the range >10 to 20 mbgl were observed in the Sulagiri, Karimangalam, Dharmapuri, Krishnagiri, Kaveripattinam, Bargur, Natrampalli, Mattur, Kandili, Jolarpet, Alangayam, Chengam, Uthangarai, Morappur, Harur and Pappireddipatti. Deepest water levels were observed in Morappur, Harur, Mattur and Karimangalam blocks.

6.3.4 Depth to piezometric surface (DTPZS)

6.3.4.1 Pre – Monsoon

During May 2014, the depth to piezometric surface in the deeper aquifer in the basin ranged from 0.85 m bgl (Location: Kaveripattinam– Kaveripattinam block) to 98.32 (Location: Bangarunatham – Sulagiri block). Depth to piezometric surface less than 2 mbgl was observed in one percent of wells analysed and noted in Kaveripattinam block. Two percent of wells analysed have recorded depth to piezometric surface in the range of 2 to 5 mbgl and noted in Kaveripattinam and Krishnagiri blocks. Sixteen percent of wells analysed have recorded >5 to 10 mbgl and noted in Kaveripattinam, Krishnagiri, Morappur and Uthangarai blocks. Fourty six percent of wells analysed have recorded >10 to 20 mbgl and noted in majority of the basin area.10 percent of the wells analysed have recorded >20 to 40 mbgl. Twenty five percent of wells analysed have recorded more than 40 mbgl range and noted predominantly in Hosur, Sulagiri, Veppanapalli, Krishnagiri, Bargur and Natrampalli blocks.

6.3.4.1 Post-monsoon

During post-monsoon (January 2015), depth to water levels in observation wells tapping the phreatic aquifer in the basin ranged from 0.01 m.bgl (Location : Karukkanchavadi –Krishnagiri Block) to 27 m.bgl (Location: Budhinaikanpatti – Morappur Block). Depth to water levels during the period was less than 2 m.bgl in about one percent of wells, between >2 and 5 m.bgl. in about five percent of the wells and between >5 to 10 m.bgl. in 30 percent of wells analysed. Water levels between >10 to 20 in sixty percent and deeper than 20 m.bgl were recorded in about four percent of observation wells.

The shallow water levels during the period were observed in parts of Krishnagiri and Kaveripattinam blocks. Water levels in the range of >2 to 5 m.bgl. were observed predominantly in Veppanappalli, Krishnagiri, Kaveripattinam, Dharmapuri, Chengam and Uthangarai blocks. Water levels in the range of >5 to 10 m.bgl were observed in the major part of the study area during the period. Deep water levels during the period were observed in isolated pockets in Morappur, Harur and Mattur blocks.

During Jan 2015, the depth to piezometric surface in the deeper aquifer in the basin ranged from 2.85 m bgl (Location: Kaveripattinam - Kaveripattinam block) to 99.70 (Location: Nerlagiri – Veppanapalli block). Five percent of wells analysed have recorded depth to piezometric surface in the range of >2 to 5 mbgl and noted in Kaveripattinam and Krishnagiri blocks. Twenty three percent of wells analysed have recorded >5 to 10 mbgl and noted in Kaveripattinam, Krishnagiri, Morappur, Bargur, Alangayam, Chengam and Uthangarai blocks. Fourty percent of wells analysed have recorded >10 to 20 mbgl and noted in majority of the basin area. Ten percent of the wells analysed have recorded >20 to 40 mbgl. Twenty two percent of wells analysed have recorded more than 40 mbgl and noted predominantly in Hosur, Sulagiri, Veppanapalli, Krishnagiri, Bargur and Natrampalli blocks.

6.5 Water Table Elevation

Maps showing the elevation of ground water table in shallow aquifers in the study area during May 2014 and January 2015, along with flow lines showing the direction of ground water movement is shown in **Figure 6.3 and 6.4** respectively. Elevation of ground water table during May 2014 ranged from 172.96 m. above MSL (Location: Anandavadi, Chengam Block) to 994.30 m. above MSL (Location: Kambakudi, Tiruppathur Block) The gradient is toward east and northeast in general.

6.5 Water Level Fluctuation :

Water level fluctuations in the observation wells in an area between two periods is indicative of the net changes in the ground water storage during the period in response to the recharge and discharge components and is an important parameter for planning sustainable ground water development. The seasonal and long-term fluctuations of ground water levels in the phreatic zone in the basin have been analysed using the historical data of Network of groundwater monitoring wells of CGWB and observation wells of SG&SWRDC, Chennai.

6.5.1 Seasonal Water Level Fluctuations :

The seasonal water level fluctuation in the area has been analysed using the water level data of May 2014 and January 2015. As both southwest and northeast monsoons are active in the area during the period, the difference in ground water levels during January 2015 when compared with the water levels during May 2014 indicate the extent of replenishment of shallow aquifers due to the monsoon rainfall. The water level fluctuation in the study area ranged from a decline of 10.2 m. (Location: Chinnakamatchipuram, Bargur Block**)** to a rise of 11.15 m (Location: Mettupuliyur, Bargur Block) during the period.

The analysis indicates that water levels have risen during post-monsoon period in comparison to pre-monsoon in the major part of the study area, indicating replenishment of phreatic aquifer due to rainfall recharge in the major part of the study area. Rise in water levels during the period has been observed in more than 81 percent of the wells considered. The rise in water levels is in the range of 0 to 2 m. in about 46 percent of these wells, between >2 and 4 m. in about 19 percent and more than 4 m. in about 16 percent wells.

Fall in water levels is observed in about 19 percent observation wells in the study area during the period, indicating recharge insufficient to compensate the withdrawal of ground water from phreatic zone. Decline in water levels during the period was observed in isolated pockets of Kelamangalam, Krishnagiri, Karimangalam, Kaveripattinam, Bargur, Kandili, Mattur, Uthangarai, Morappur, Jolarpet and Tirupathur blocks.

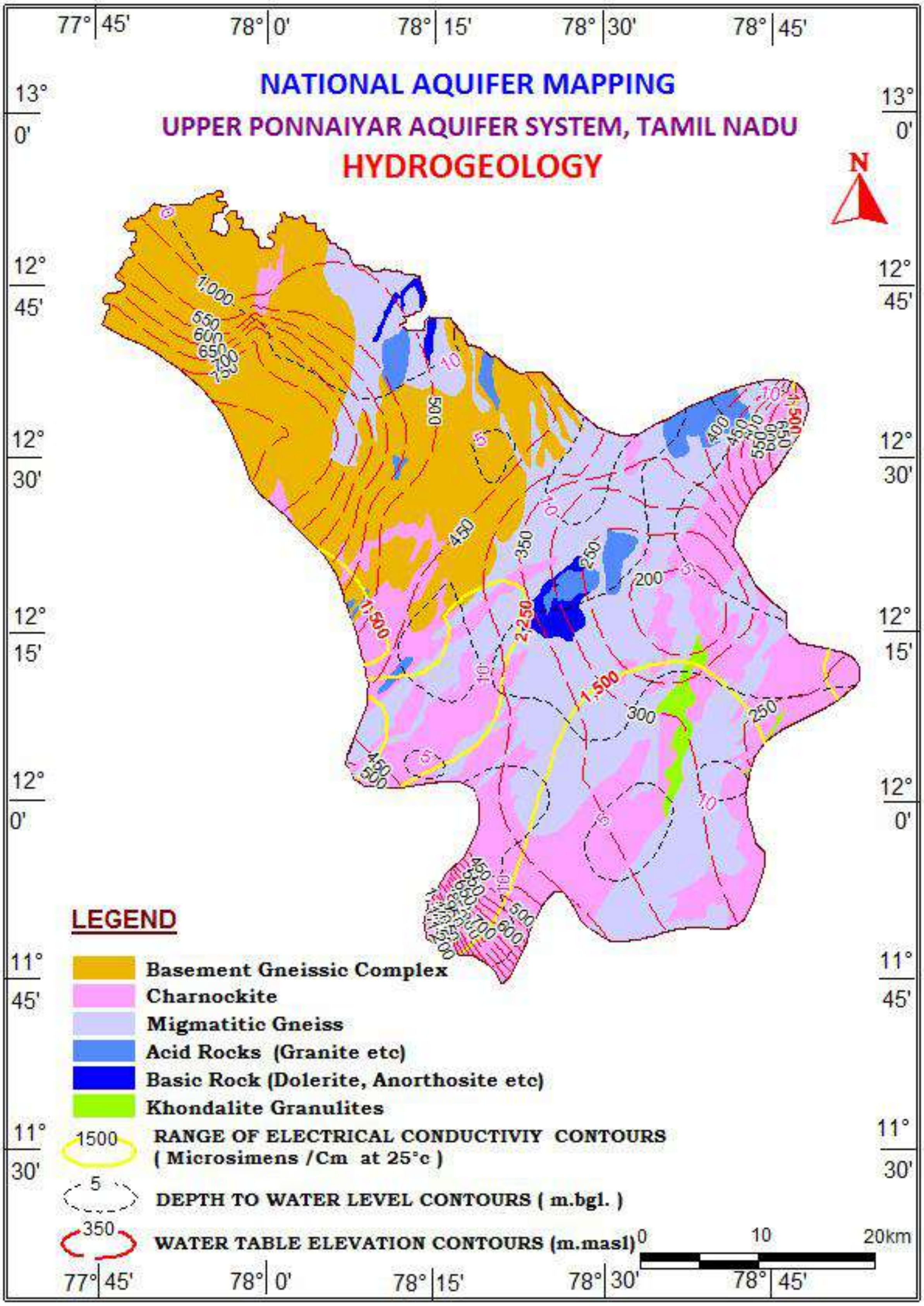


Figure 6.5. Hydrogeological map of Upper Ponnaiyar Aquifer System.

7. Groundwater Resources in Upper Ponnaiyar Aquifer System

The groundwater is mainly developed through dug wells and dugcum bore wells tapping the weathered zone, the yield of open wells vary from 1 to 3 lps. The dynamic groundwater resources (as on March 2011) of the study area have been assessed firka wise. The Net Groundwater Availability has been estimated as 789.82 mcm. The Annual Ground Water Draft is 1092.51 mcm and Stage of Groundwater Development is 138 %. Out of 58 firkas, 36 firkas have been categorised as ‘Over Exploited’, 2 as ‘Critical’, 12 as ‘Semi-Critical’ and 8 firkas as ‘safe’. The overall stage of groundwater development of the state is 138 %.

8. Hydrogeochemistry

Water samples collected in the study area in different aquifers (Aquifer-I & Aquifers-II) to assess the groundwater quality for drinking and irrigation purposes. The drinking water suitability has been assessed based on Bureau of Indian Standard (IS 10500:2012). The suitability of groundwater for irrigation purpose has been assessed based on USSL and Wilcox diagrams are shown Fig.10-14.

Table 8.1 The range of chemical constituents of ground water in different aquifers in Upper Ponnaiyar aquifer system, Tamil Nadu.

Parameters	Aquifer - I			Aquifer - II		
	Min	Max	Average	Min	Max	Average
pH	7.14	8.60	7.87	7.20	8.90	8.33
EC (µS/cm at 25 ° C)	287	7940	1638	500	6660	2670
Total Hardness as $CaCO_3$ (mg/L)	55	1600	530	60	1400	565
Calcium (mg/L)	8	352	75	16	232	92
Magnesium (mg/L)	6	282	86	2	177	73
Sodium (mg/L)	3	1196	143	10	1070	388
Potassium (mg/L)	0	140	7	1	134	47
Carbonate (mg/L)	0	18	1	0	30	20
Bicarbonate (mg/L)	98	854	377	85	848	378
Chloride (mg/L)	14	2244	281	15	971	348
Sulphate (mg/L)	1	142	64	13	432	223
Nitrate (mg/L)	5	293	104	1	175	98
Fluoride (mg/L)	0.02	2.90	1.06	0.1	3.16	1.605

Table 8.2 Ground water quality in different aquifers in Upper Ponnaiyar aquifer system, Tamil Nadu.

S.No	Parameters	Range	Classification	% of samples	
				Aquifer-I	**Aquifer-II**
1	Electrical Coductivity µs/cm at 25°c	< 750	Fresh	08	07
		75 1- 2250	Moderately Fresh	76	85
		2251- 3000	Slightly mineralized	13	04
		> 3000	Highly mineralized	03	04
2	Chloride mg/l	< 250	Desirable limit	57	66
		251-1000	Permissible limit	41	34
		> 1000	Above permissible limit	02	Nil
3	Fluoride mg/l	< 1.0	Desirable limit	52	33
		1.1- 1.5	Permissible limit	23	19
		>1.5	**Above permissible limit**	**25**	**47**
4	Nitrate mg/l	<45	Permissible limit	62	73
		46-100	**Above permissible limit**	27	23
		> 100		11	04

8.1 pH

pH is the measure of hydrogen or hydroxyl ion concentration in water. The pH scale is used to predict whether the water is acidic or basic in nature. The pH scale ranges from 0 to 14, the midpoint 7 is taken as neutral and waters having pH < 7 is called acidic, and having pH > 7 is called basic. pH is an important parameter in water chemistry, because geochemical reactions such as oxidation-reduction, dissolution-precipitation are pH dependent. For example, mineral solubility is enhanced under acidic pH, whereas high pH leads to precipitation of minerals such as calcite. Consequently, water having acidic pH would be more corrosive and alkaline pH would lead to the deposition of minerals (encrustation).

In the study area the pH ranged from 7.14 to 8.6 and 7.20 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 within the limit of drinking water standard of BIS 10500:2012.

8.2 Electrical Conductivity (EC)

EC is the indicator of the total mineral content of water and hence it indicates the total dissolved solids (TDS) present in water. TDS of water determines its usefulness to various purposes. Generally water having TDS <500 mg/L is good for drinking and other domestic uses. However, in the absence of alternative sources TDS up to 2000 mg/L may be used for drinking purposes. The distribution of EC in different aquifers are in shown in figures 1 and 2.

In shallow aquifer (Aquifer-I) the ground water quality is fresh in about 08% of sample analysed, as indicated by the EC value less than 750 µs/cm at 25^{o}C. In about 76% of the samples, the EC varies between >751 -2250µs/cm at 25^{o} C and in 13% of samples are between >2251and 3000 µs/cm at 25^{o} C indicating that the ground water is slightly mineralized and about 03% of groundwater samples the EC is more than 3000 µs/cm at 25^{o}C indicating that the ground water is highly mineralized.

In deeper aquifer (Aquifer-II), the ground water quality is fresh in about 07% sample analysed, as indicated by the EC value less than 750 µs/cm at 25^{o}C. In about 85% of the samples, the EC varies between >751and 2250µs/cm at 25^{o} C and 04% of water samples are between >2251 and 3000 µs/cm at 25^{o} C indicating that the ground water is slightly mineralized and about 04% of samples wells the EC is more than 3000 µs/cm at 25^{o}C indicating that the ground water is highly mineralized.

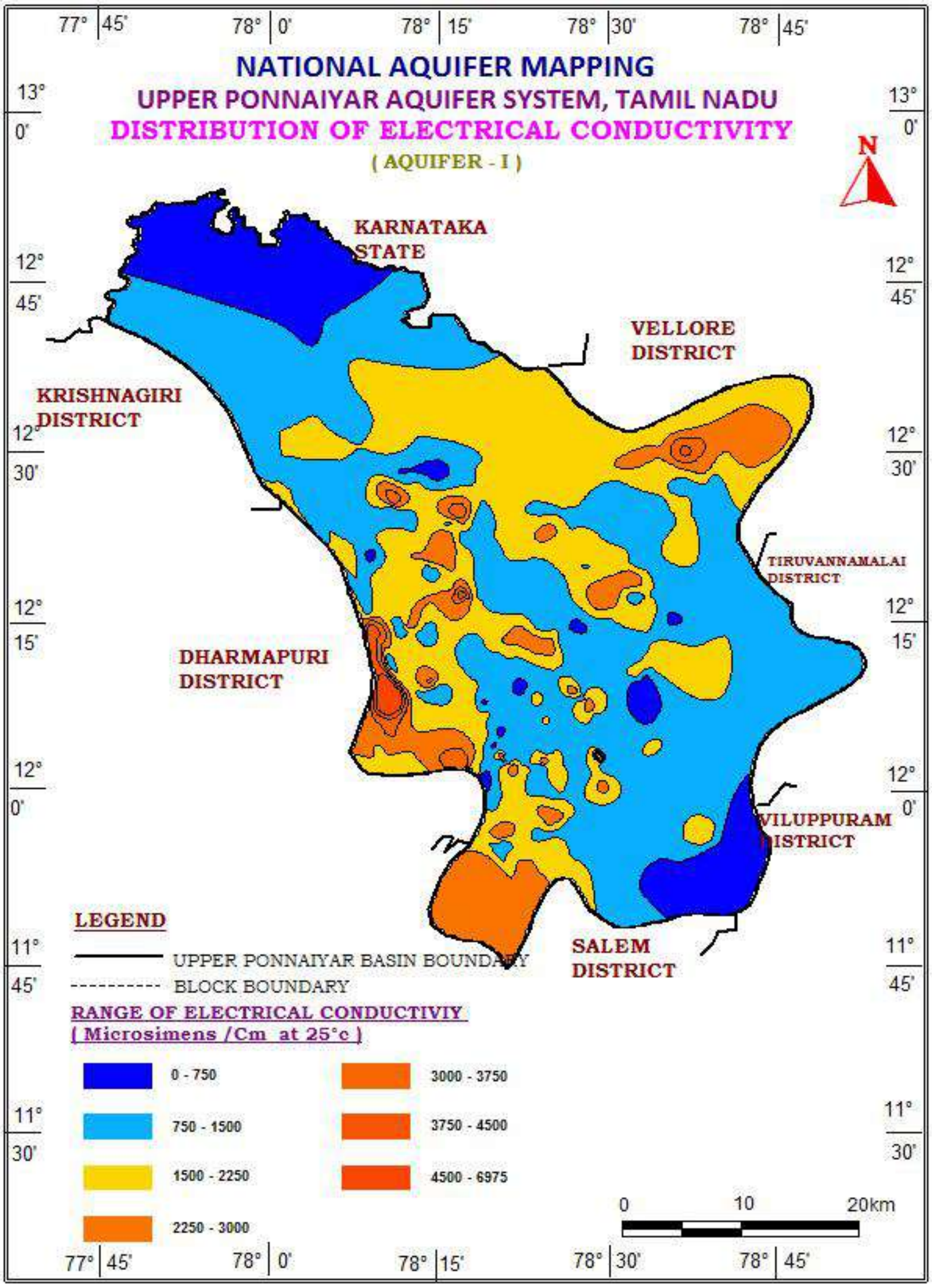


Figure 8.1 Distribution of Electrical Conductivity in shallow aquifer (Aquifer-I)

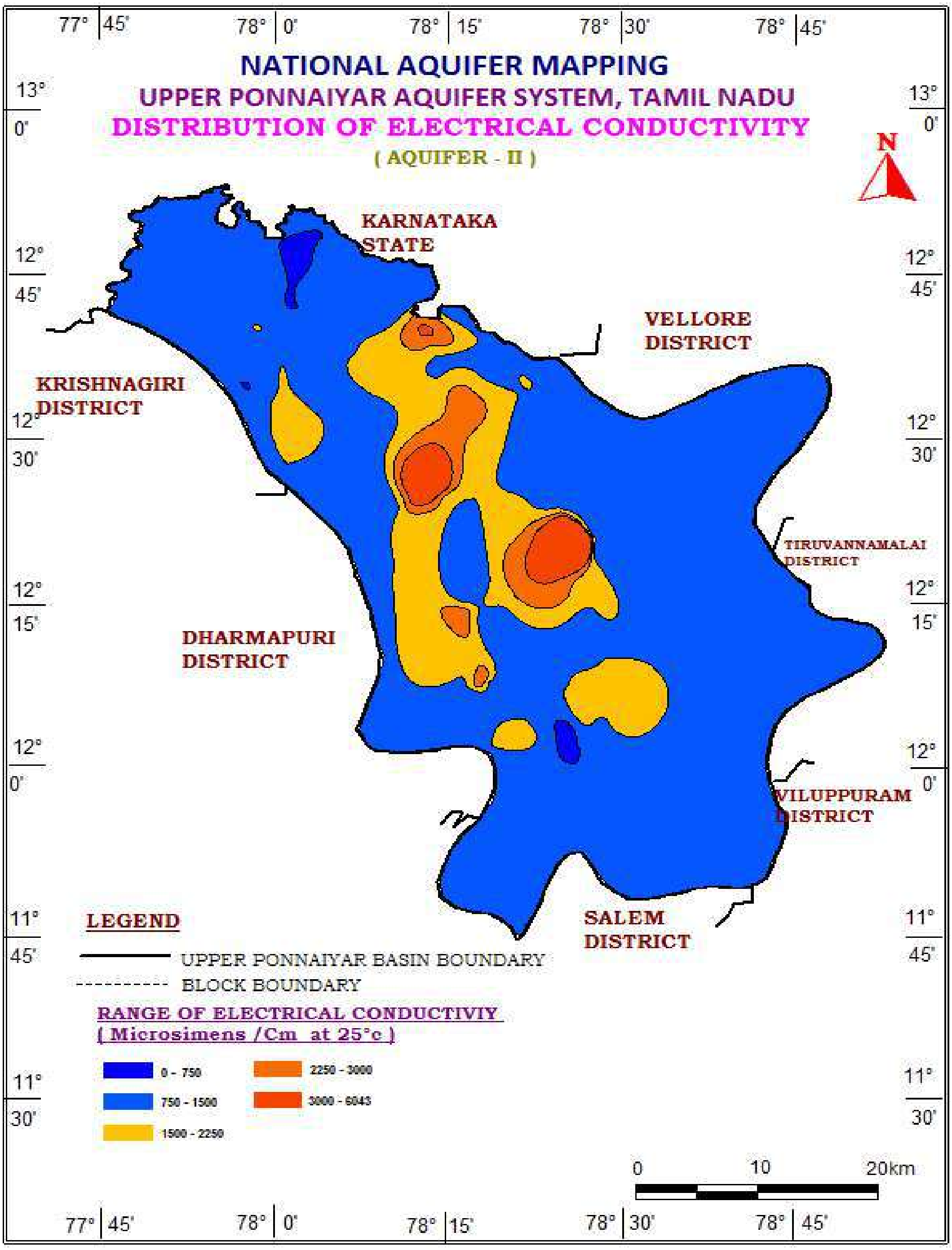


Figure 8.2 Distribution of Electrical Conductivity in Deeper aquifer (Aquifer-II)

8.3 Chloride

Chloride is one of the major anions in groundwater. The high mobility of the ion and the high solubility of chloride salts make the chloride ions present in waters. Moreover, chloride ions do not take part in any of the geochemical (or) biochemical reactions, hence it can be used as a good indicator of ground water pollution. Over 500 mg/L it imports saline taste to drinking water. BIS specified 250 mg/L as the desirable and 1000 mg/L as the permissible limit in the absence of alternate sources for drinking water. The spatial distribution of chloride concentration in groundwater in shallow and deeper aquifers (Aquifer-I & Aquifer II) are shown as figures 8.3 and 8.4 respectively.

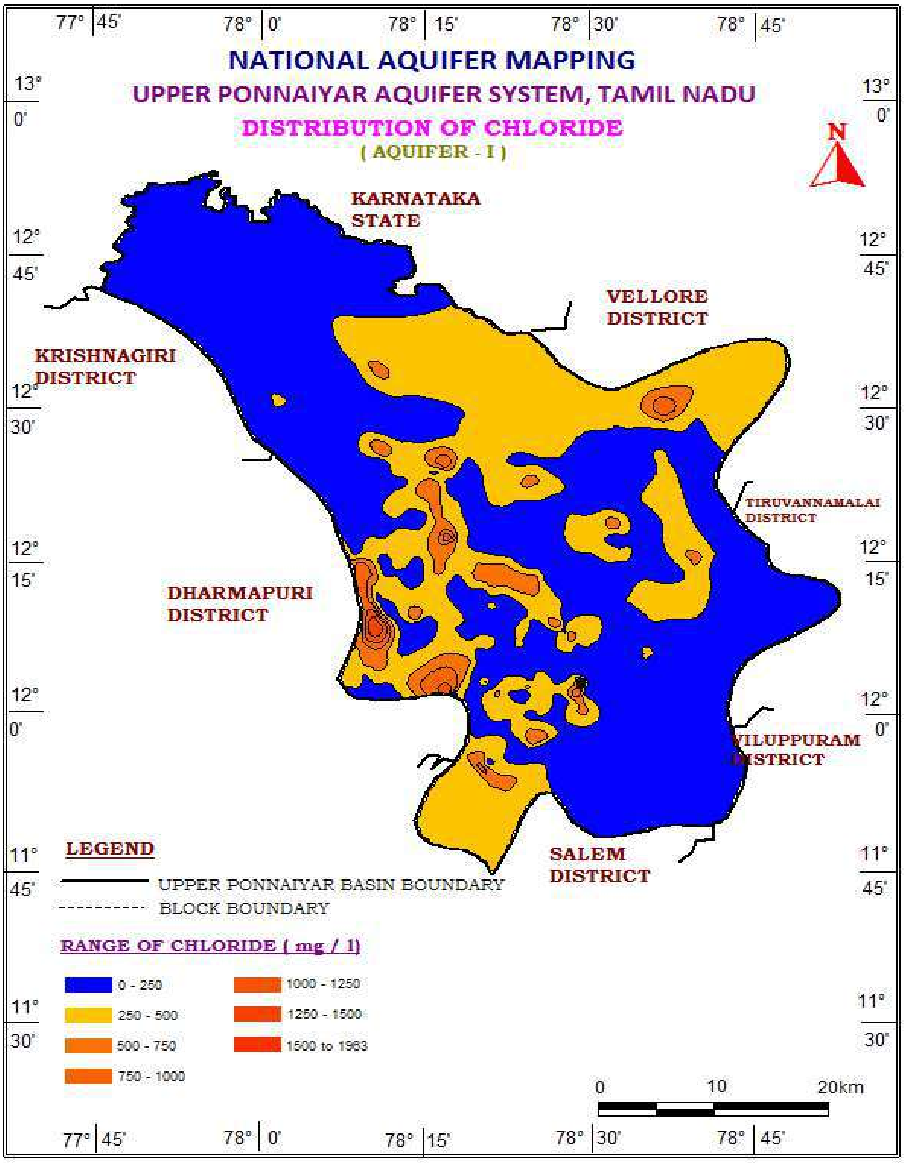


Figure 8.3 Distribution of Chloride in shallow aquifer (Aquifer-I)

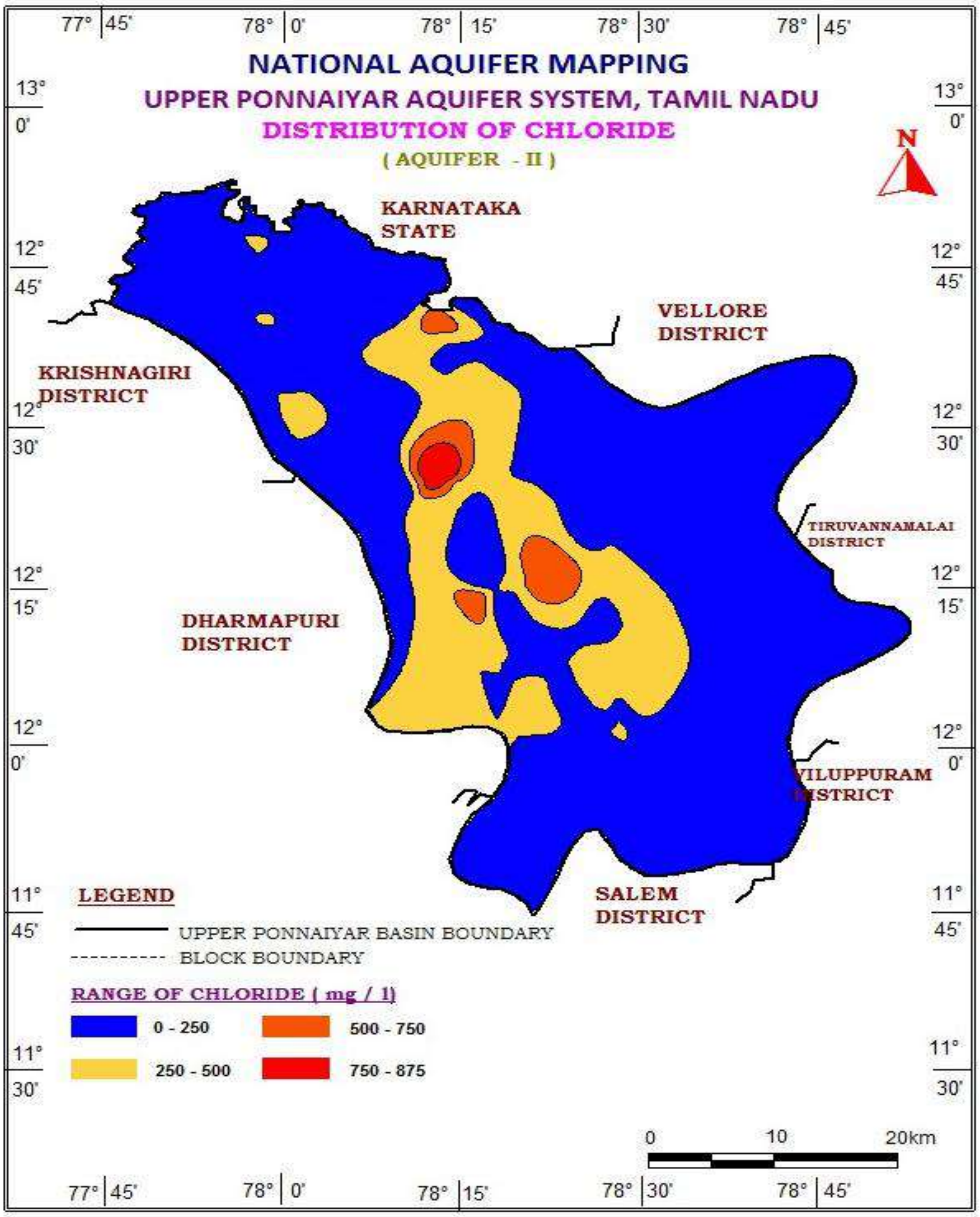


Figure 8.4 Distribution of Chloride in Deeper aquifer (Aquifer-II)

In shallow aquifer (Aquifer-I), the concentration of chloride ranged between 14 and 2244 mg/L with an average of 281 mg/L. About 57% of samples are within the desirable limit and 41 % of samples are within the permissible limit and about 2% of the samples are above the permissible limit of BIS drinking water standard. Higher concentration of chloride more than the permissible limit of 1000 mg/L was observed in the middle part of the study area

8.4 Nitrate

Nitrate is one of the major indicators of anthropogenic sources of pollution. The negative charge and high mobility favors 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 wastes, 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 spatial distribution of nitrate concentration in groundwater in shallow and deeper aquifers (Aquifer-I & Aquifer II) are shown figure as 8.5 and 8.6 respectively.

The concentration of Nitrate in the shallow groundwater (aquifer- I) ranged between 5 and 293 mg/L. About 62% of the samples showed nitrate below 45 mg/L, the desirable limit for drinking and about 27% of the samples showed nitrate between >45 and 100 mg/L and about 11% of the samples showed nitrate >100 mg/L, which are above permissible limit of BIS.

Nitrate in the deeper groundwater (aquifer –II) ranged between 1 and 175 mg/L. About 73% of the samples showed nitrate below 45 mg/L, the desirable limit for drinking and about 23% of the samples showed nitrate between >45-100 mg/L and about 11% of the samples showed nitrate more than 100 mg/L, which are above permissible limit of Burea of Indian standard (IS 10500:2012). Higher concentration of nitrate more than the permissible limit of >45 mg/L was observed in the middle part of the study area in both aquifers.

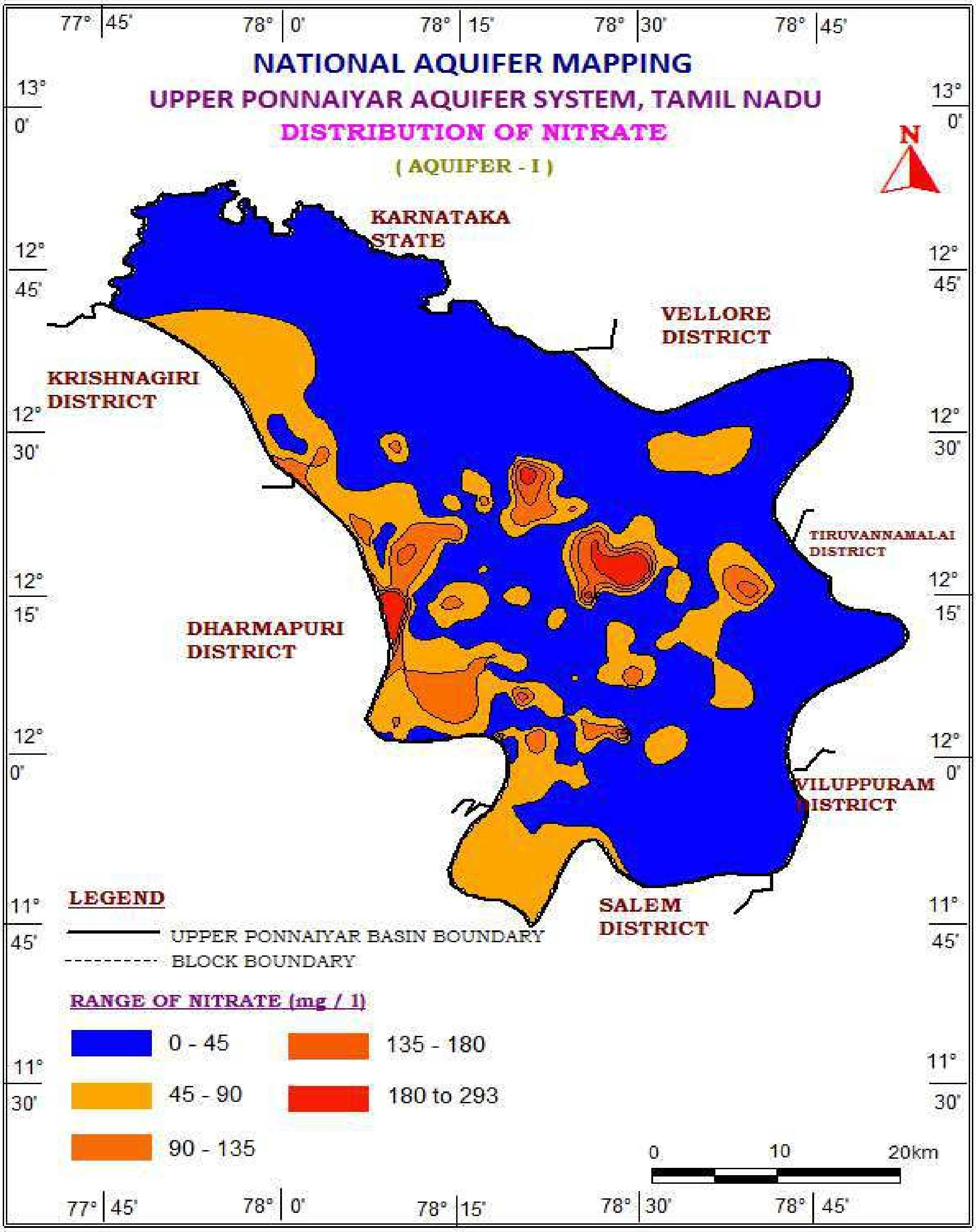


Figure 8.5 Distribution of Nitrate in shallow aquifer (Aquifer-I)

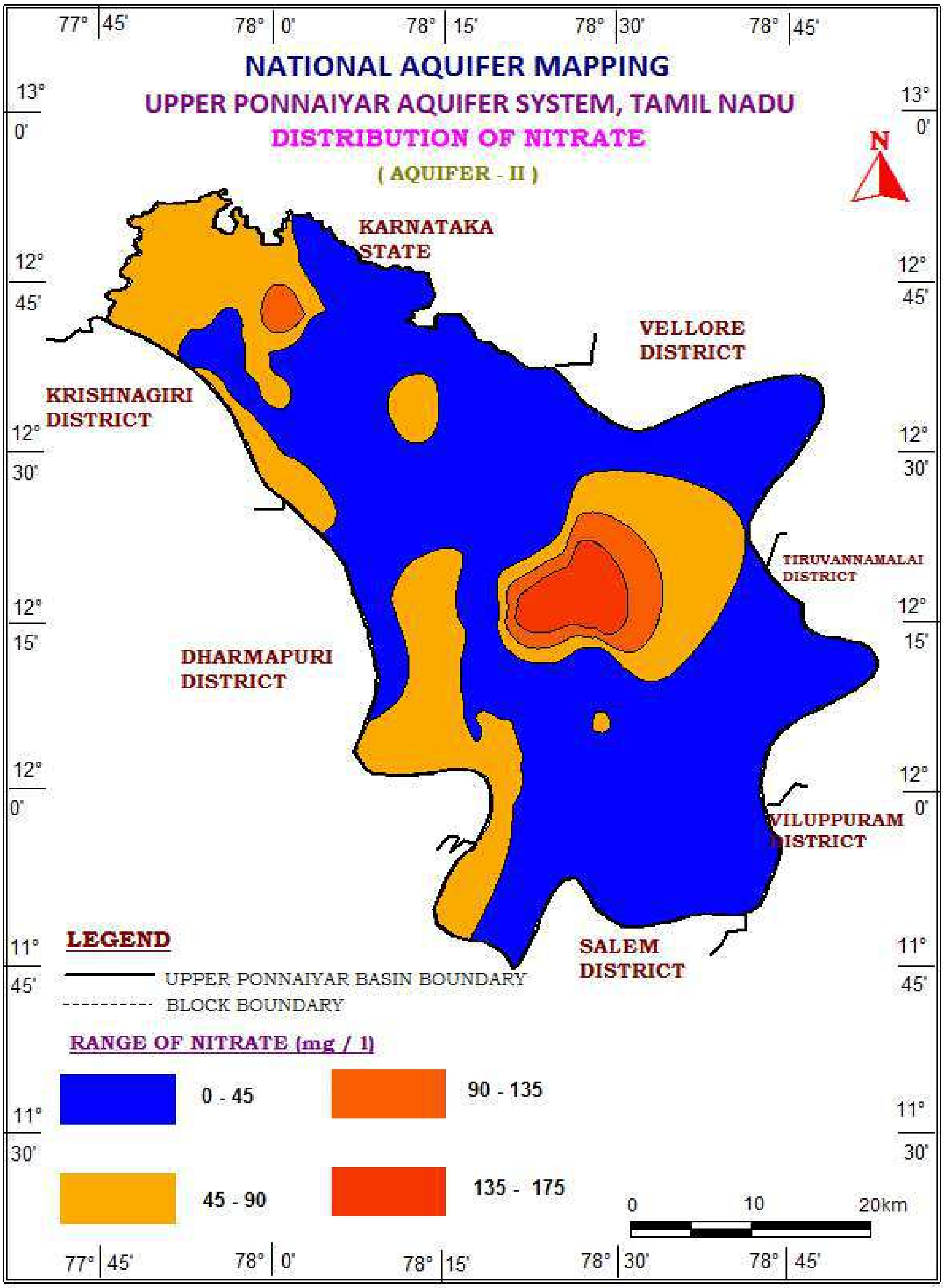


Figure 8.6 Distribution of Nitrate in Deeper aquifer (Aquifer-II)

8.5 Fluoride

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 phosphatic 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. The spatial distribution of fluoride in shallow and deeper aquifers Upper Ponnaiyar aquifer system, Tamil Nadu (Aquifer-I & Aquifer II) are shown figure 8. 7 and 8.8 respectively.

In the shallow groundwater, the concentration of fluoride ranged between 0.02 and 2.9 mg/L. About 52% of samples showed fluoride < 1mg/L, which is the desirable limit for drinking. About 23% of samples showed fluoride in the range of 1 to 1.5 mg/L, the maximum permissible limit in the absence of alternate sources. About 25 % of samples showed fluoride > 1.5 mg/L. These wells are located predominantly in the central part of the study area.

In deeper aquifers , in about 33% of wells showed fluoride is in the range of 0 to 1.0 mg/L, about 19%, it is in the range of >1to 1.5 mg/L and about 47% more than 1.5mg/L. It appears that more number of wells in deeper aquifers have fluoride more than 1.5mg/L .

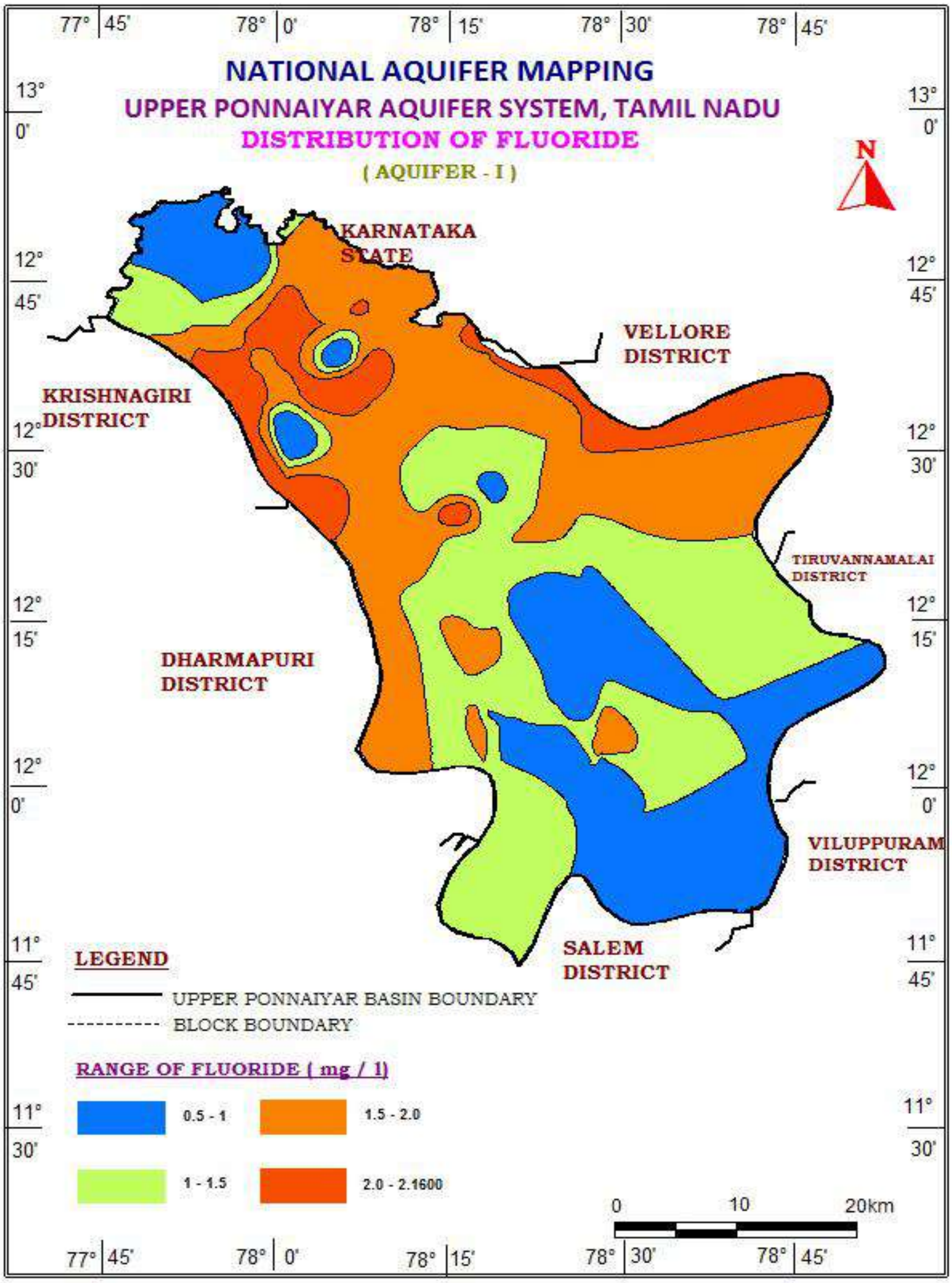


Figure 8.7 Distribution of Fluoride in shallow aquifer (Aquifer-I)

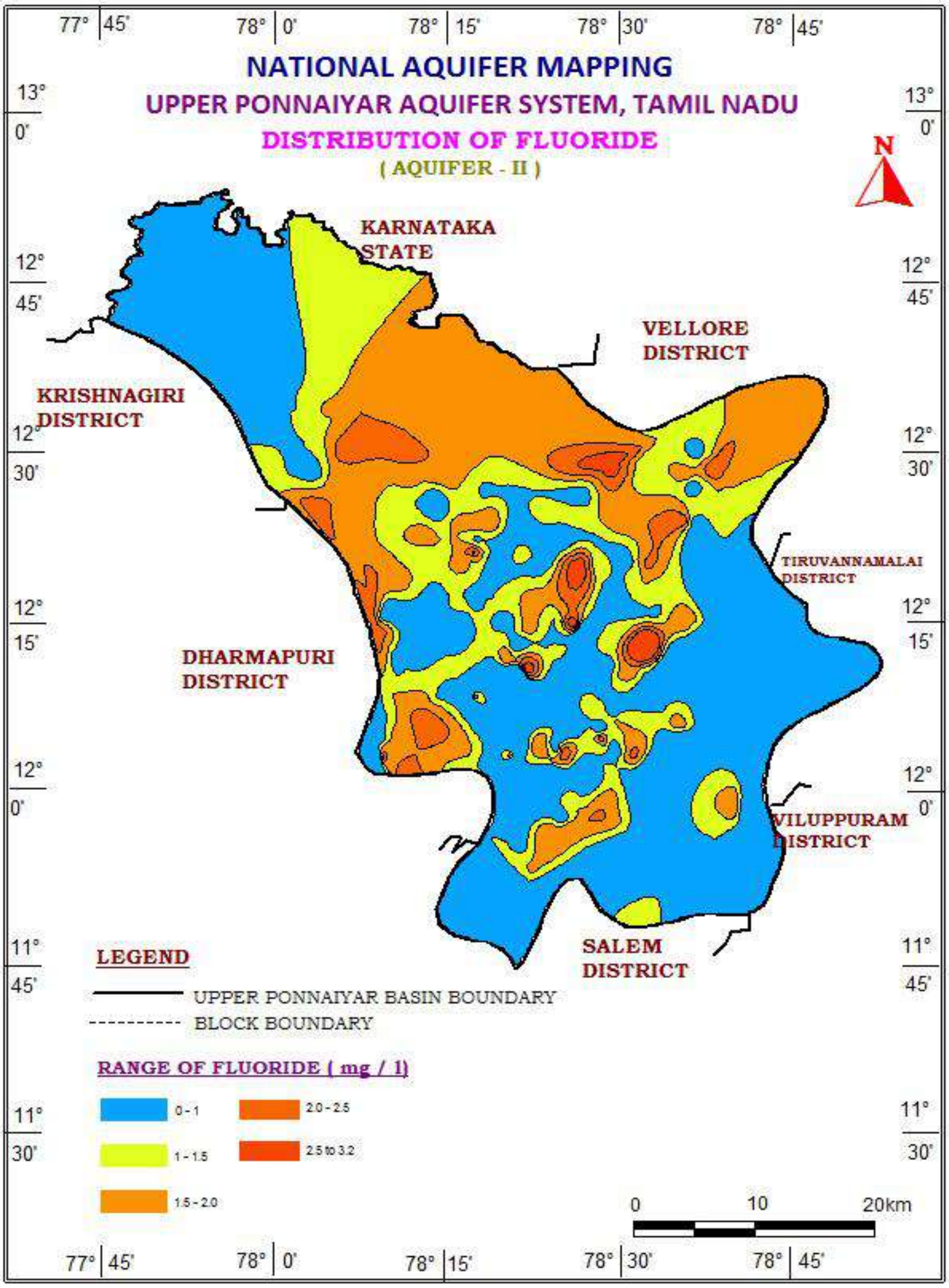


Figure 8.8 Distribution of Fluoride in deeper aquifer (Aquifer-II)

8.6 Hydrochemical Facies of groundwater

The geochemical evolution of groundwater can be understood by plotting the concentration of major cations and anion in the Piper's Trilinear diagram (Piper 1944). The plots of groundwater samples in shallow and deeper aquifers in Upper ponnaiyar aquifer system, TamilNadu (Aquifer-I & Aquifer II) are shown Fig 8.9 and 8.10 respectively. Plotting positions of samples in the two triangles signify the characteristics of cations and anions whereas the overall characteristics of the water are presented in the diamond-shaped field by projecting the position of plots in the triangular field. Generally, in the recharge areas, ground water would be relatively fresh which is indicated by the presence of bicarbonate type of water. As water moves through the aquifer, it is enriched with minerals, and ultimately it attains the seawater composition (NaCl type water). In shallow aquifer, about 53% of the groundwater samples are calcium chloride type, about 25% samples are calcium bicarbonate type and 12% are sodium chloride type, whereas in deeper aquifer, about 41% of the groundwater samples are calcium chloride type, about 29% samples are calcium bicarbonate type and about 30% are sodium chloride type, which indicate the enrichment with minerals in deeper aquifer.

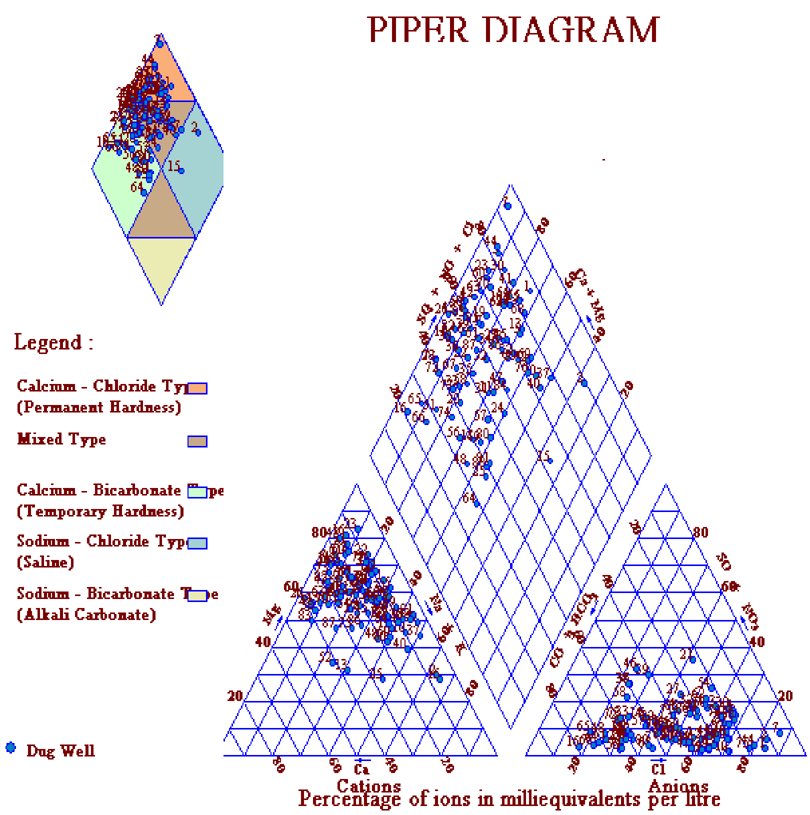


Figure 8.9. 9 Piper's Trilinear diagram for Shallow aquifer (Aquifer-I)

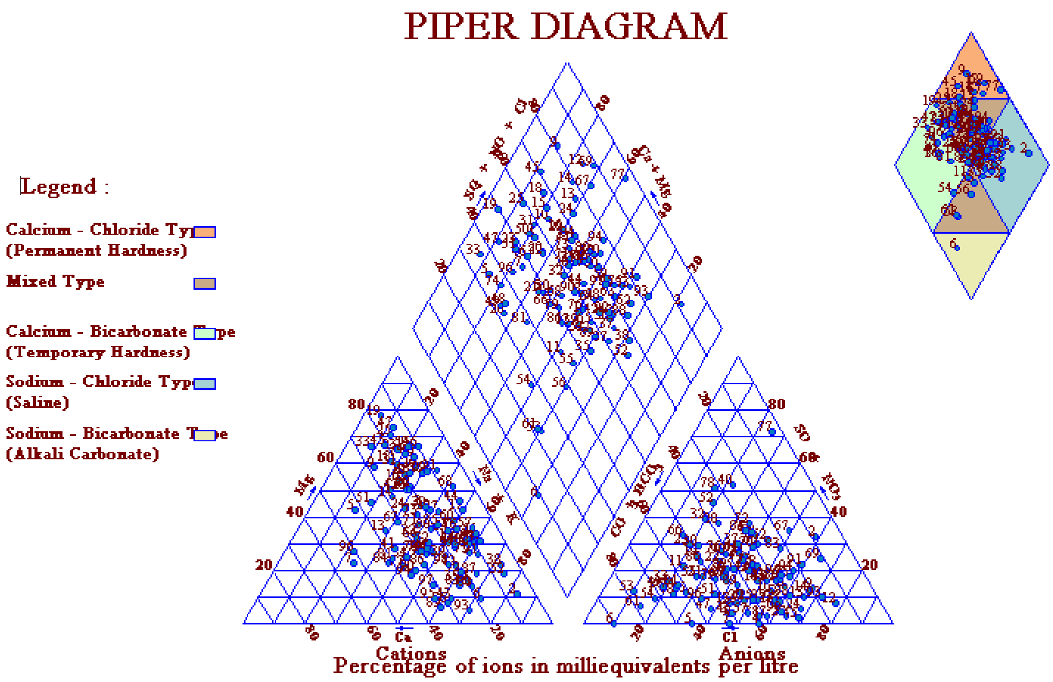


Figure 8.10 Piper's Trilinear diagram for deeper aquifer (Aquifer-II))

8.7 Suitability of Groundwater for Irrigation purposes

Most extensive use of ground water amounting to 80% of all consumption in the world is for irrigation of crops. If water, loaded with excessive amount of soluble salts is applied to the field, the salts increase the osmotic pressure of the soil solution. Consequently, crops cannot absorb enough water quickly to make up the loss of water by transpiration on hot summer days and so may wilt resulting low yield. The soluble salts also affect the soil structure, permeability and aeration, which affect the plant growth. If excessive amounts of sodium ions are in irrigation water, sodium will be absorbed by clay minerals, thus destroying the soil structure, leading to the formation of alkali soils. Hence, suitability of water for irrigation is assessed by mineralization and by a relation between concentration of sodium, calcium and magnesium. The classification of irrigation water has been attempted using U.S. salinity laboratory diagram and Wilcox diagram, which are based on sodium absorption ratio (SAR) and E.C. The U.S. salinity laboratory diagram (USSL) and Wilcox diagram for Aquifer I & II are shown in figures 8.11- 8.12 and 8.13-8.14 respectively.

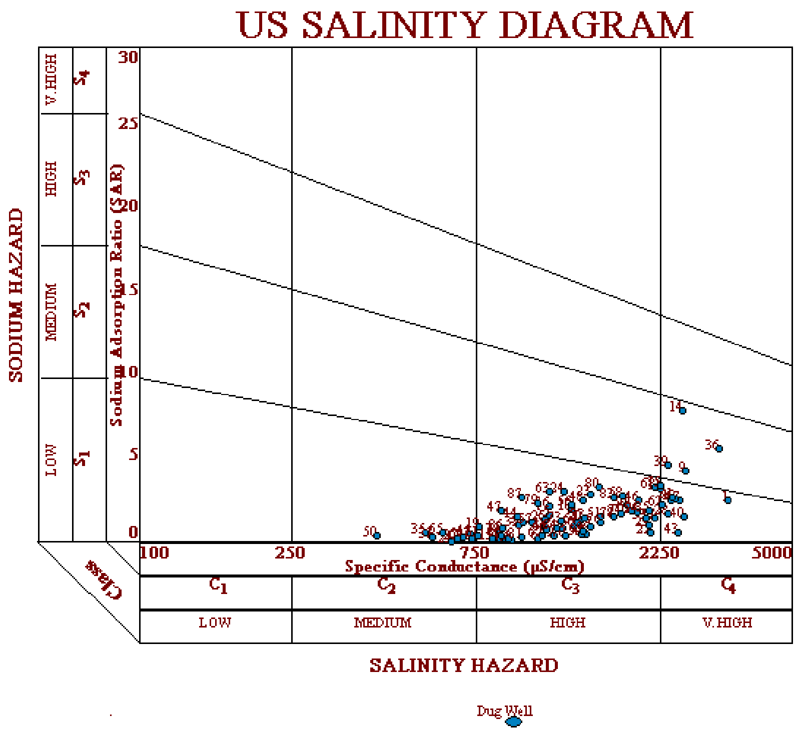


Figure 8.11 USSL diagram for shallow aquifer (Aquifer-I)

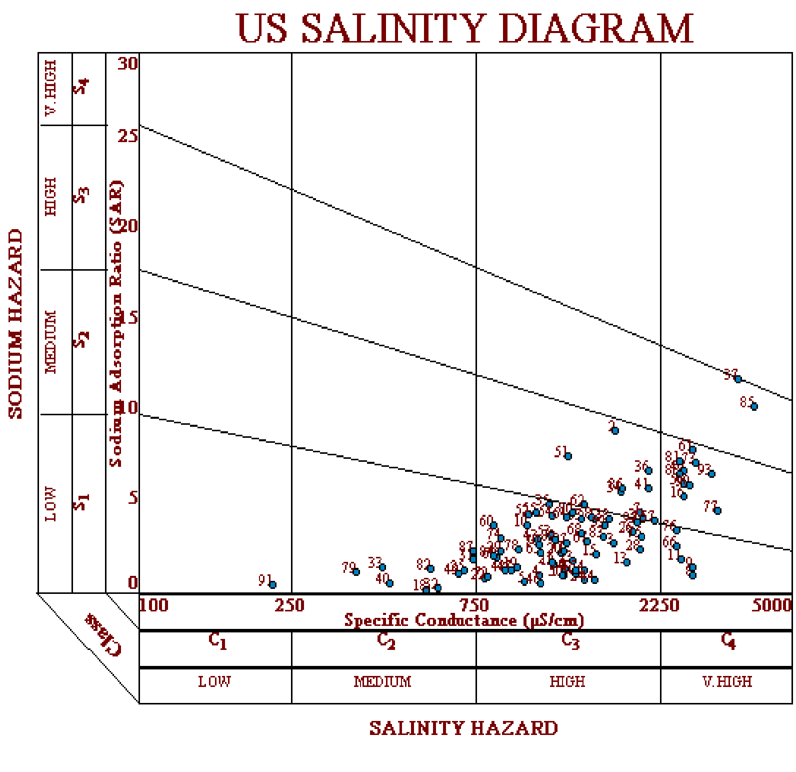


Figure 8.12 USSL diagram for deeper aquifer (Aquifer-II)

Samples plot in C_1S_1 field are low salinity and low sodium waters, good for irrigation and can be used on all soils. Few samples plot in C_2S_1 category for both aquifer I & II, which are medium salinity and low sodium waters are good for irrigation and can be used on almost all soils with little danger of the development of harmful levels of exchangeable sodium if moderate amount of leaching occurs and so these waters can be used without any special consideration for salinity control.

Majority of samples fall C_3S_1 category for both aquifer I & II, which are high salinity and low sodium waters require good drainage. Crops with good salt tolerance should be selected. Gypsum amendments make feasible the use of these waters. Comparatively more number of samples falls in C_4S_1, C_4S_2 & C_4S_3, and category from aquifer-II, which are very high salinity and varying content of sodium. These waters are not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. They may produce harmful levels of exchangeable sodium wherever such waters are used. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected. Gypsum amendments make the use of these waters feasible.

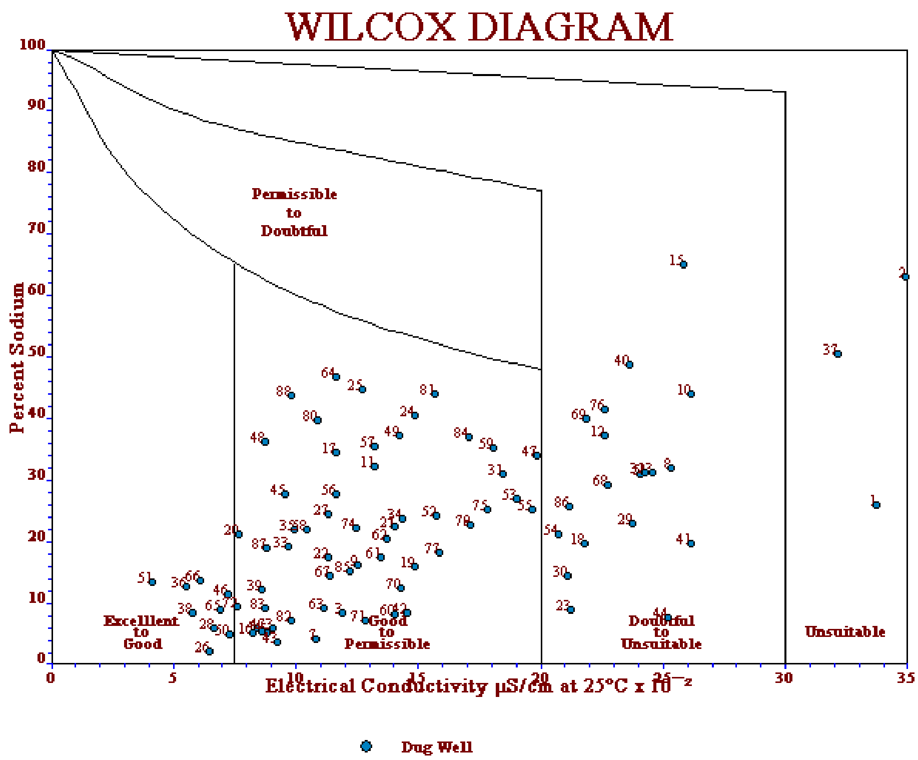


Figure 8.13 Wilcox diagram for shallow aquifer (Aquifer-I)

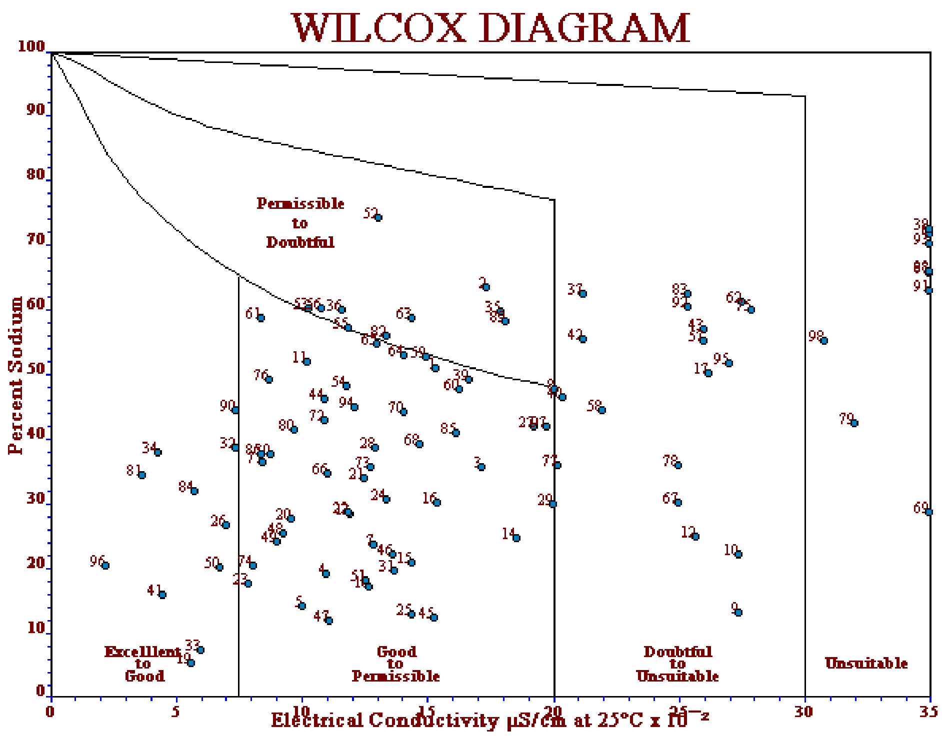


Figure 8.14 Wilcox diagram for deeper aquifer (Aquifer-II)

9. REGIONAL GROUNDWATER FLOW

Three-dimensional mathematical models of regional groundwater flow are beneficial to the management of groundwater resources as they allow the approximation of the components of hydrological processes and provide a mechanistic description of the flow of water in an aquifer. Such a modeling study was carried out in a part ofUpper Ponnaiyar aquifer system, Southern India. The study area is characterizedby weathered and fractured aquifer system with very heavy abstraction of groundwater for agricultural purposes. The model simulates groundwater flow over an area of **about 7130 square kilometers** with 143 rows, 92 columns, with two vertical layers on the regional model. The detailed study area is divided into rows and columns with a size of 2.5 sq.km grids (Figure.1). The model was simulated in steady and transient state condition using the finite-difference approximation of three-dimensional partial differential equation of groundwater flow in this aquifer from January 2010 to December 2014. The model was calibrated for steady and transient state conditions. There was a reasonable match between the computed and observed heads. Based on the modelling results, it is found that this aquifer system is stable at this pumping rate. The transient model was run until the year 2020 to forecast the dynamic groundwater flow under various scenarios of over pumpingand less recharge. The model predicts the behaviour of this aquifer system under various hydrological stress conditions.

Modelling objectives

Numerical three-dimensional groundwater flow model was developed for the Upper Ponnaiyar Aquifer system, Southern India with the following objectives,

- to simulate regional groundwater flow to identify the distribution of heads,
- Impact on the aquifer system due to various hydrological stresses.
- To develop few scenarios for proper understanding of the aquifer system.
- For Efficient and sustainable management of the aquifer system.

9.1 Model Input Parameters

The model was developed by incorporating geologic data, measured and inferred hydrologic data. Two sets of data are required for the development of a groundwater model as given in Table 9.1 The two sets of data are the physical framework and hydrological stresses.

Table 9.1 Data required in developing a numerical model

Physical framework	Hydrological stresses
Aquifer geometry Type of aquifer Aquifer thickness and lateral extent Aquifer characteristics	Groundwater abstraction and recharge Solute concentration Aquifer stress

Groundwater flow equation

Anisotropic and heterogeneous three-dimensional flow of groundwater, assumed to have constant density, and described by the partial-differential equation given by Rushton and Redshaw (1979) was used to model the groundwater flow in this study

$$\frac{\delta}{\delta x} K_{xx} \frac{\delta h}{\delta x} + \frac{\delta}{\delta y} K_{yy} \frac{\delta h}{\delta y} + \frac{\delta}{\delta z} K_{zz} \frac{\delta h}{\delta z} - W = S_s \frac{\delta h}{\delta t}$$

Where,

K_{xx}, K_{yy}, K_{zz} - components of the hydraulic conductivity tensor

h - potentiometric head

W - source or sink term,

S_s - specific storage

t - time

MODELLING PROTOCOL

The modelling protocol used in this study for the construction of a numerical model involves the following steps:

- Data collection, acquisition and processing of primary data
- Conceptual model building

- Numerical model building
- Model application
- Result generation.

These steps are given in a form of a flowchart (flowchart1).

9.2 Computer Code

The computer software program MODFLOW (McDonald and Harbaugh 1998) developed by the United States Geological Survey (USGS) was used for the present study. The computer program uses the finite-difference technique and block-centered formulation to solve the groundwater flow equation for the three-dimensional steady and transient flow in heterogeneous media. The pre and post processor, **Visual Modflow version 4.6 of 2014** was used to give input data and process the model output. Modelling studies were carried out in the hydrogeological modeling cell of the SECR, CGWB, Chennai.

The conceptual model of the system was arrived from the detailed study of geology, borehole lithology, geophysical resistivity survey & logs, cross sections and water level fluctuations in wells. Groundwater of the study area is found to occur in the weathered formations and in the fractured/jointed formations. Groundwater is found to occur in unconfined conditions in the weathered formation and unconfined/confined in fractured formation.

Boundary conditions

The study area forms a part of the upper Ponnaiyar aquifer syatem. The boundary conditions modeled are as per the watershed boundary (Figure 9.2).The western boundary of the study area is the Upper Cauvery River Basin and eastern boundary is bounded by Upper Palar River basin. The Ponnaiyar river flows from the northern boundary to the eastern boundary and was modeled as river boundary. The inward entry from the north into the system and outward flow in the eastern part was modeled as variable head boundaries. Except these two regions, the remaining boundary was modeled as no flow boundary as the flow from outside the boundary is negligible. There are two dams within the area namely Krishnagiri dam and Sathanoor dam. These two regions were modeled as general head boundary.

The aquifer top and bottom were derived mainly based on the lithology of boreholes and by intensive field surveys. The study area has been vertically divided into two layers. First unconfined layer comprises of the top soil and weathered formation, which is underlain, by fractured/jointed formation, which occurs under unconfined/confined conditions.

9.3 Grid Design

The geographic boundaries of the model grid covering 7130 km^2 of the study area were determined using the map module. The map was projected using the metric coordinates in the map module and then imported into the MODFLOW. The finite-difference grid was superimposed on the study area was constructed based on the conceptual model representing the physical properties of the groundwater system. The gird network has a constant spacing 2.5 km by 2.5 km. The model gird discretised into 3120 cells with 143 rows and 92 columns, and vertically by 2 layers **(figure 9. 1).** The length of model cells is 2500 m along the east - west and 2500 m along the north- south directions of the study area.

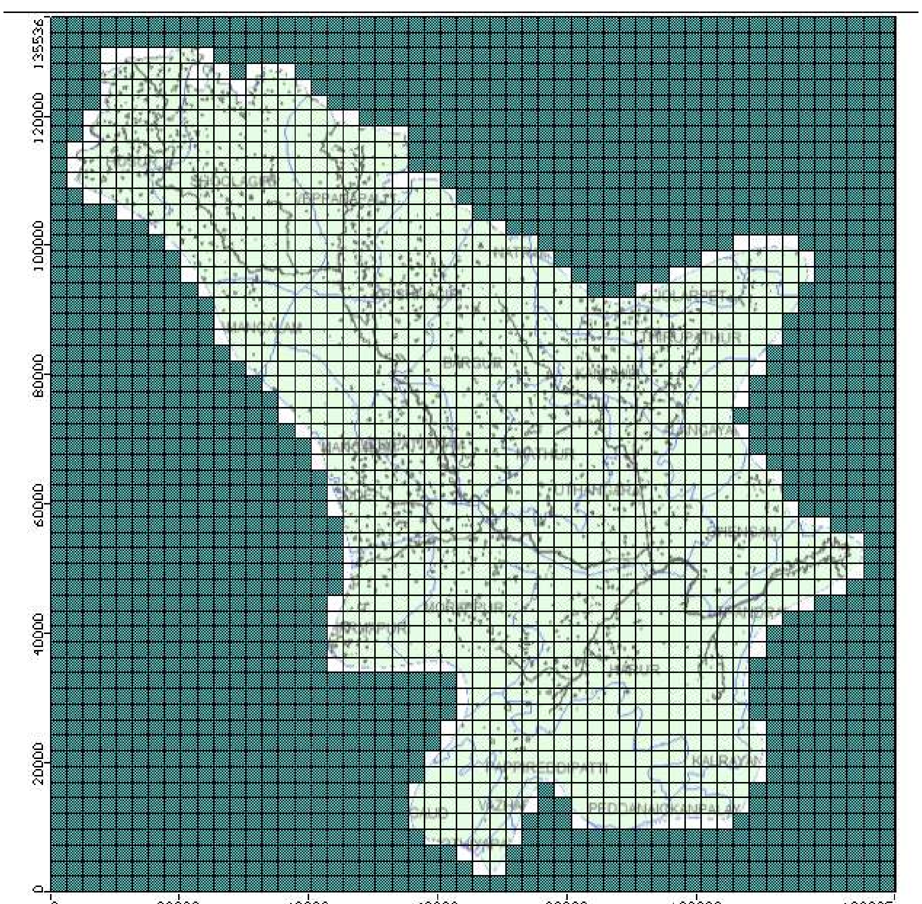


Figure 9.1 Discretisation of the study area

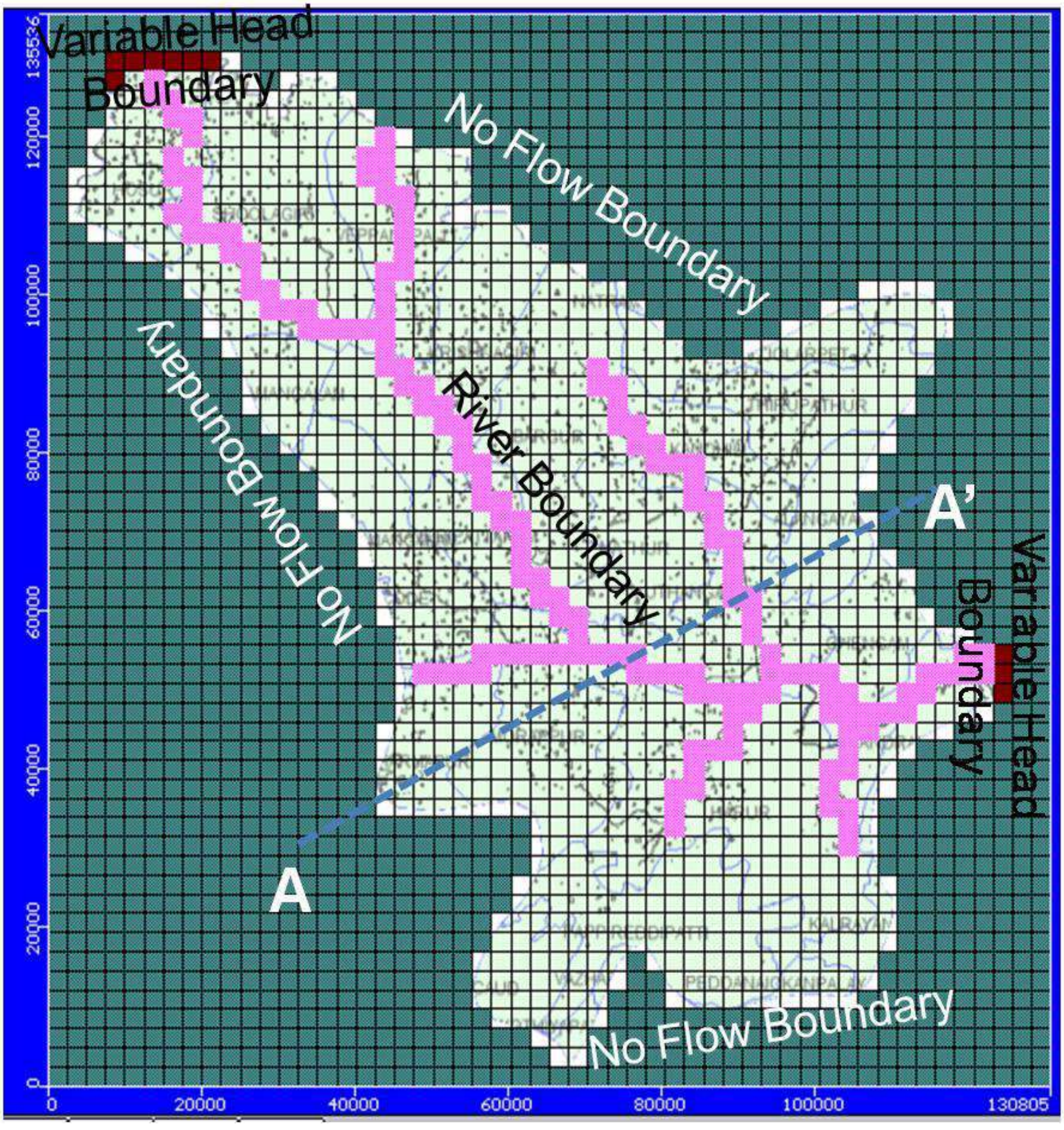


Figure 9.2 Boundary condition of the study area

9.4 Input Parameters

Initial Groundwater head

The initial groundwater head of the study area is shown in figure 9.3. After detailed analysis of the hydrographs, rainfall and water level fluctuation, it was decided that the groundwater head data of Jan 2010 represents the spatial groundwater distribution of the study area. During this period the rainfall was also normal and the groundwater fluctuation was representative of the normal year.

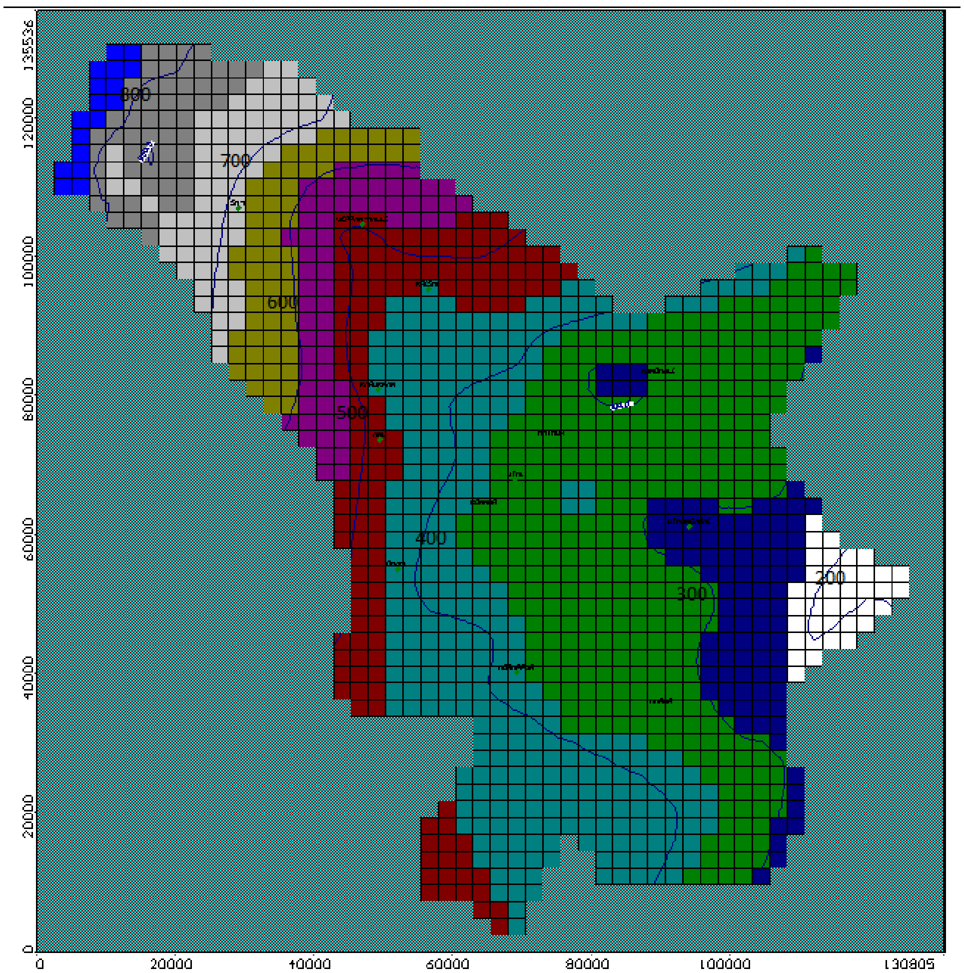


Figure.9.3 Initial groundwater head of the study area during Jan 2010

Aquifer Geometry

The aquifer geometry includes defining the aquifer top, bottom of I[st] layer and bottom of II[nd] layer for all the cells (Figure 3a, b & c). They were mainly derived from the sub-surface characterization using the lithologs, resistivity data and geological field work. These values were extrapolated for the entire area considering the lithological variations and field study of well sections. The Ist layer is characterized by weathered formation with a maximum thickness of 39m and is underlained by fractured/jointed formation with a maximum thickness of 169m.

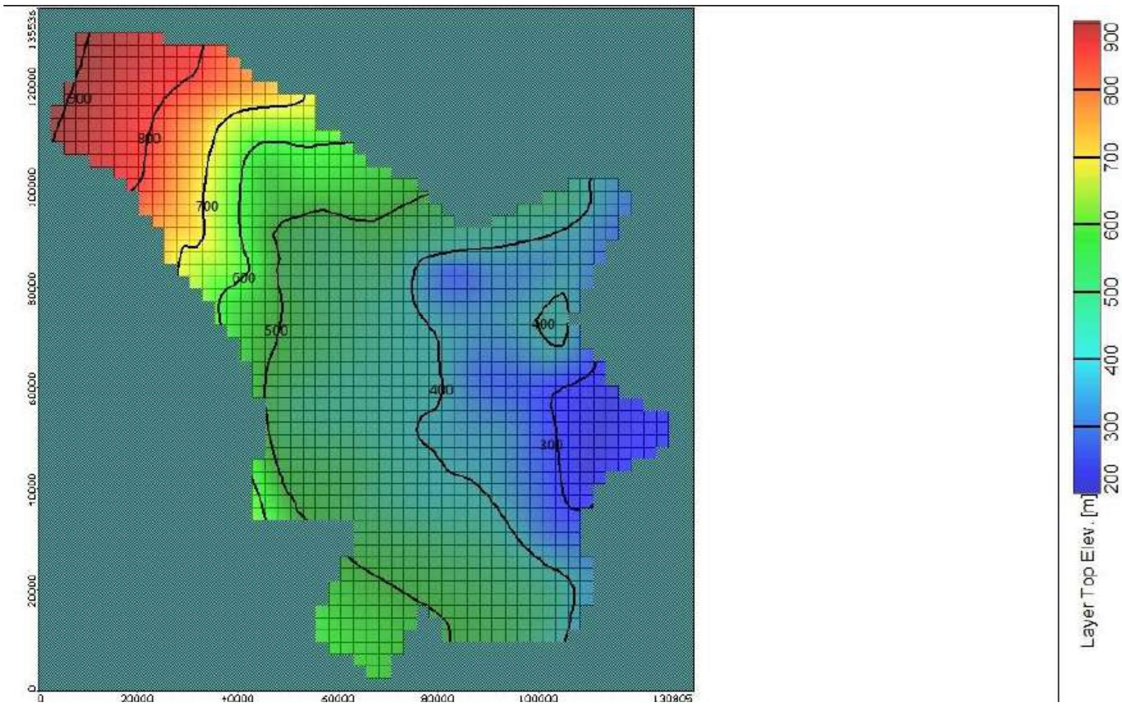


Figure 9.3a Top elevation of the study area

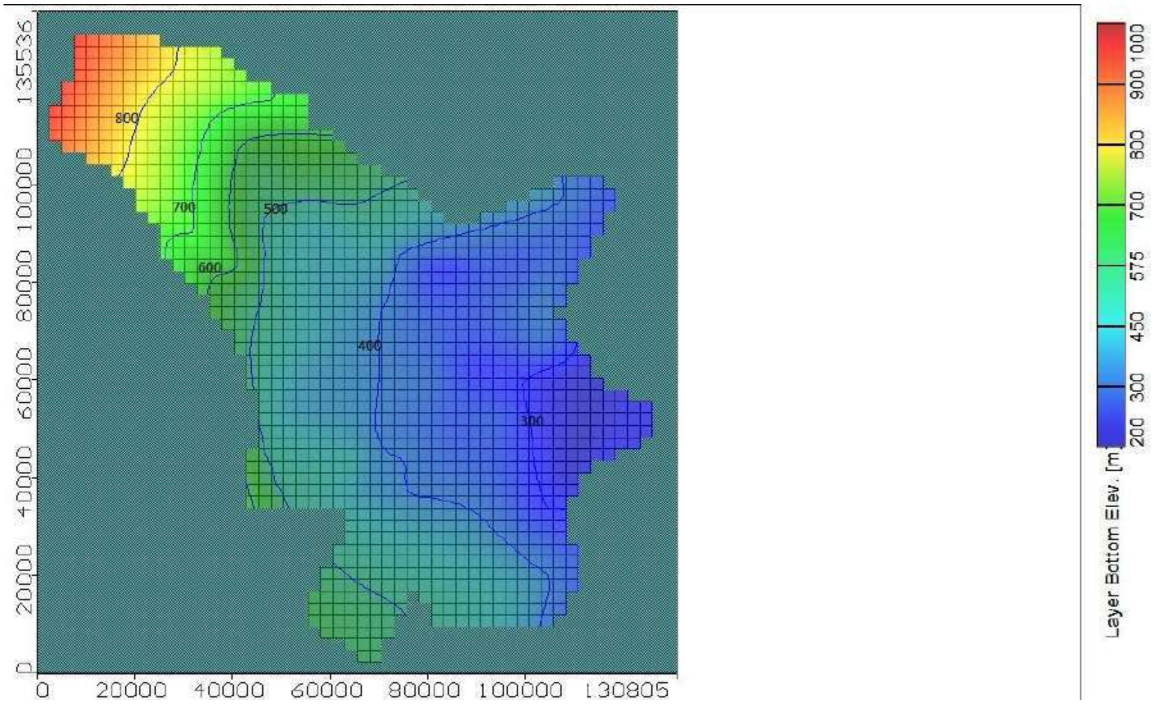


Figure 9. 3b Bottom elevation of the Ist layer of the study area

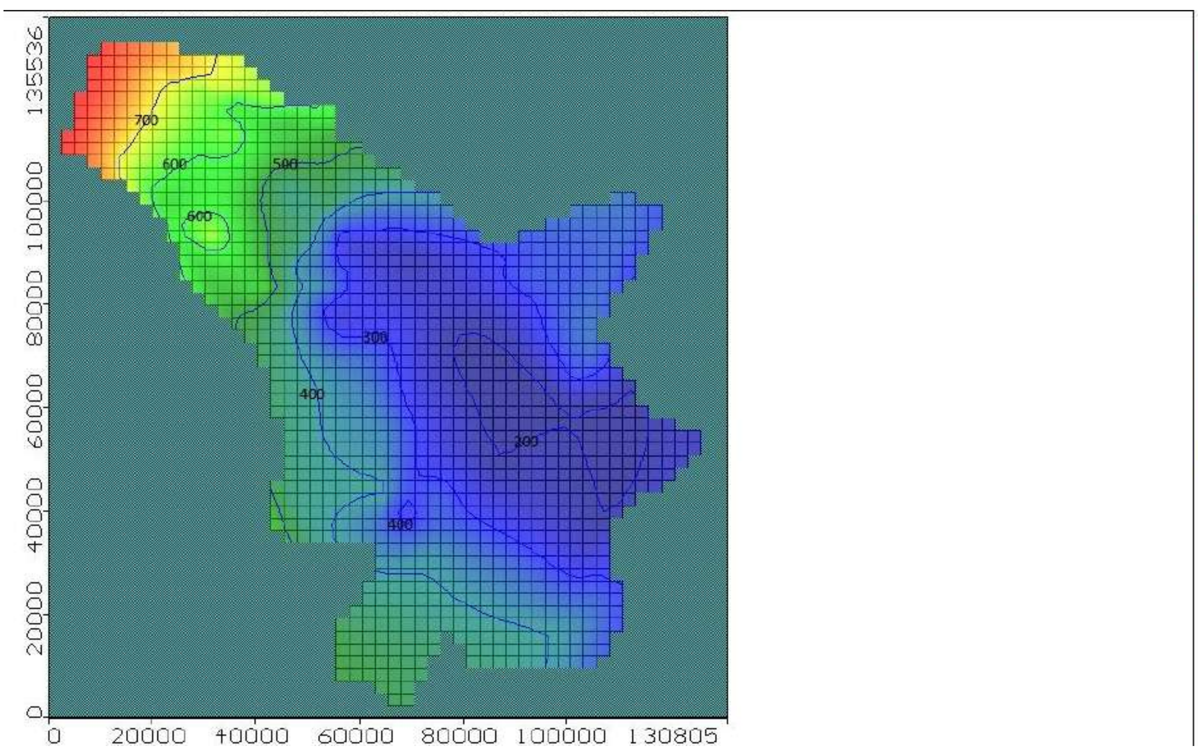


Figure 9.3c Bottom elevation of the IInd layer of the study area

Model sections along two directions X-X' and Y-Y' are given below

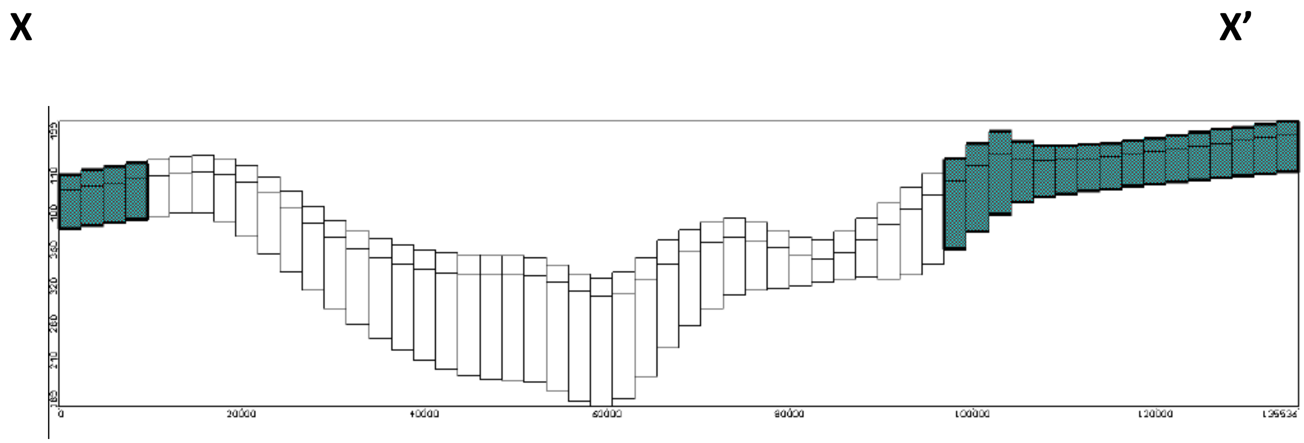


Figure 9.3d Section along x-x' direction

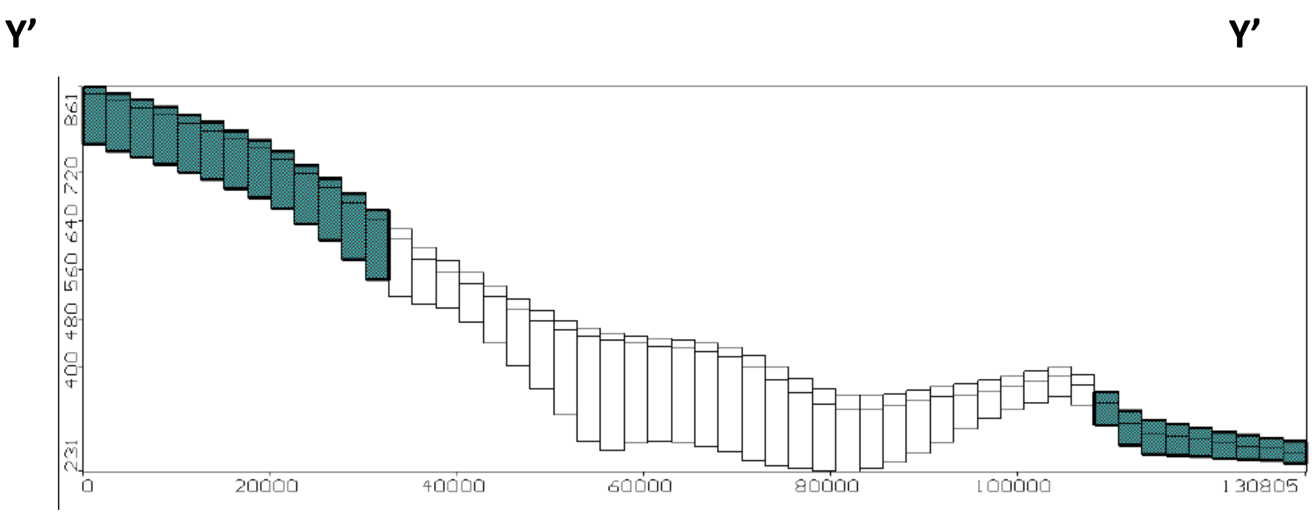


Figure 9.3e. Section along Y-Y' direction

Aquifer characteristics

The aquifer properties such as horizontal hydraulic conductivity, specific yield and storativity (figure 9.4a and b) used in the model were derived from 67 pumping tests results and is given in the Table 9.2.

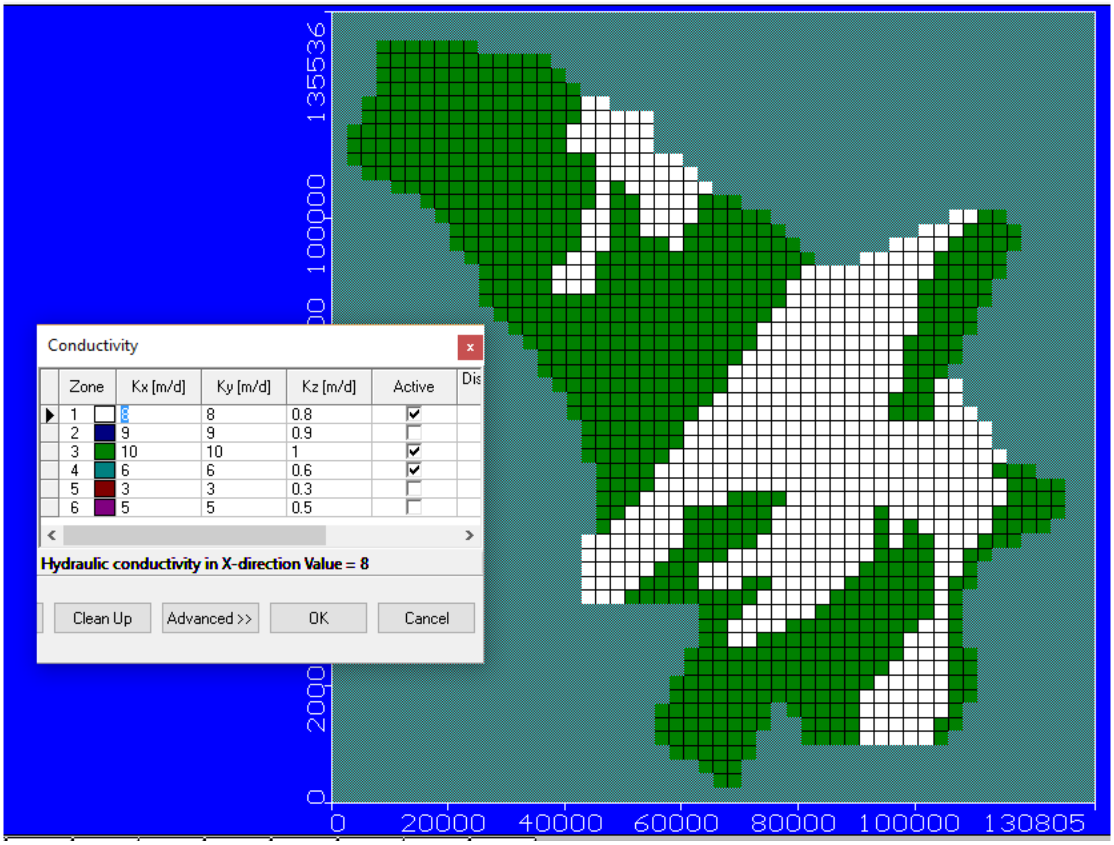


Figure 9.4a Hydraulic Conductivity values for Aquifer I (Weathered)

Groundwater Abstraction

The groundwater of the study area is abstracted for irrigation, drinking water supply and domestic purposes. Agriculture activity of the study area is mainly dependant on groundwater resource and small region of canal/dam command area. The Land use and land cover map was prepared to demarcate the area under cultivation. Information on the number of wells (open and bore wells) available in the study area (figure 9.5a&b) was collected from the department of economics & Statistics and also from the electricity board. The data obtained from electricity board included the number of wells energized and their horse power of the pump. The domestic and drinking water requirement of the study area was calculated based on population.

Table 9.2 Groundwater draft details

BLOCK	Basin area (sq.km)	Aquifer-I		Aquifer -II	
		DW	Draft basin area (m3/yr)	BORE WELL	Draft basin area (m3/yr)
Bargur	518	5201	6590707.2	1682	15985728
Hosur	301	346	347299.5032	4968	37399940.72
Kaveripattinam	184	4838	6130713.6	696	6614784
Kelamangalam	120	457	90250.97143	460	681325.7143
Krishnagiri	474	7155	9066816	641	6092064
Mathur	305	9298	11782425.6	415	3944160
Shoolagiri	619	1603	1928509.31	2472	22304780.17
Uthangarai	410	10013	12688473.6	865	8220960
Veppanapalli	363	6604	8368588.8	533	5065632
Tandarpet	168	12438	16900.77632	0	0
Chengam	221	11551	27249.34626	0	0
Alangayam	232	3820	9333.479771	0	0
Tirupathur	292	4474	24475.15396	0	0
Jolarpet	160	5616	20451.52264	0	0
Kariamangalam	314	12593	14651358.99	1837	16029468.63
Dharmapuri	216	3978	3049969.371	1993	11460386.42
Morappur	422	12884	14977885.27	1274	4443144.793
Harur	854	12681	16069363.2	2816	10705305.6
Pappireddipati	456	8110	10276992	1797	6831475.2
Vazhapadi	14	6965	486475.0866	2328	487802.1543
Yercaud	148	0	0	155	220781.5291
Kalrayan hills	68	1049	141724.5381	208	84305.15898
Peddanaickanpalayam	46	6322	640899.072	2122	645359.616
Ayothiyapattinam	24	8998	1205525.878	1496	601289.1912

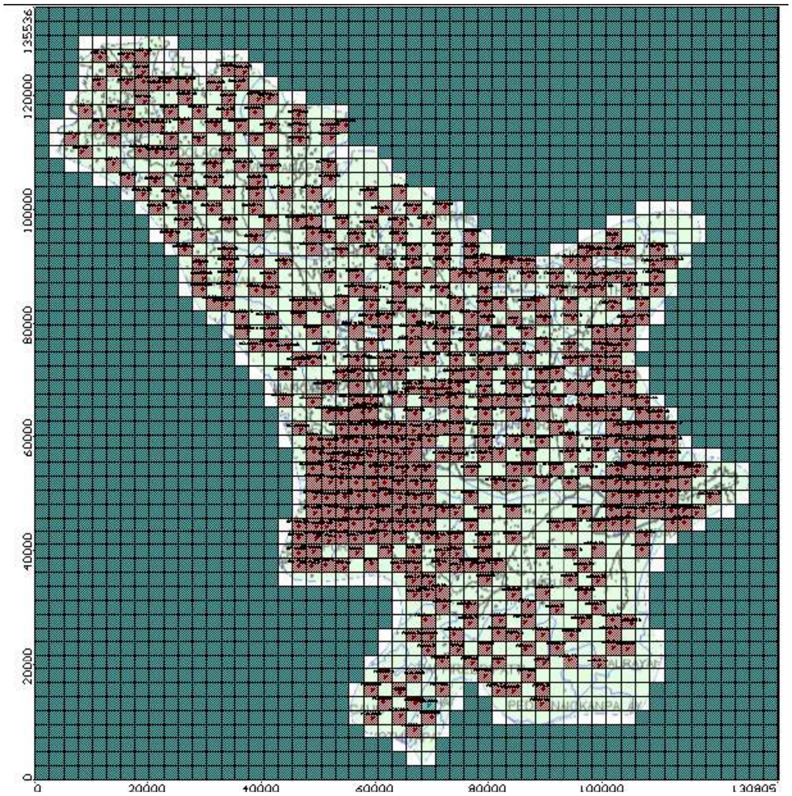


Figure 9.5. Distribution of pumping wells

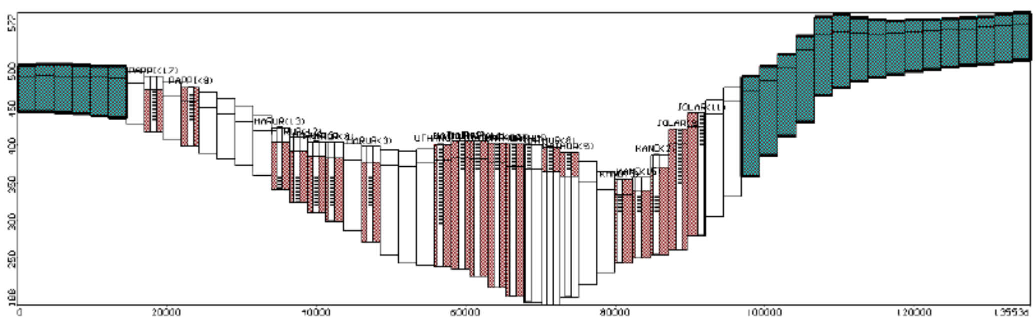


Figure 9.5b . Sectional view of the pumping wells

Groundwater Recharge

The recharge of the study area aquifer varies considerably due to differences in landuse pattern, soil type, geology, topography and relief. The recharge to the aquifer system is from rainfall, irrigation and inflow from the river and storage tanks. Rainfall is the principal source of groundwater recharge. The rainfall hydrograph were studied to understand the recharge pattern in the study area. The aquifer gets recharged and groundwater level shoots with rainfall above 40 mm. The entire portion of the study area is geologically covered by top soil, weathered and fractured/jointed formation. The infiltration capacity of formation ranges from 0 – 12 % (Groundwater resources estimation committee report, 1997). The table 9.3 shows the rainfall infiltration factor used in modeling for groundwater recharge calculation.

Table 9.3 Rainfall vs infiltration factor used in groundwater recharge calculations

S.No	Rainfall (mm)	Infiltration factor (%)
1	0 -40	0
2	40 -100	8
3	100 -200	10
4	200 -300	12
5	300 -400	10

The rate of leakage between the river and aquifer was estimated using the difference between the river head and groundwater head. The rivers situated in the study area and its contribution to groundwater recharge was calculated based in the difference between the head in the adjoining wells and reservoir head. The data of the river head was inputted in the model. The Ponnaiyar river flows only for few days during August, September & October.

Three recharge zones have been demarcated in the study area and they comprise of top soil zone, weathered Gneissic/charnockitic formation and ultramafics zone. The recharge zones of the study area is shown in figure.9.6

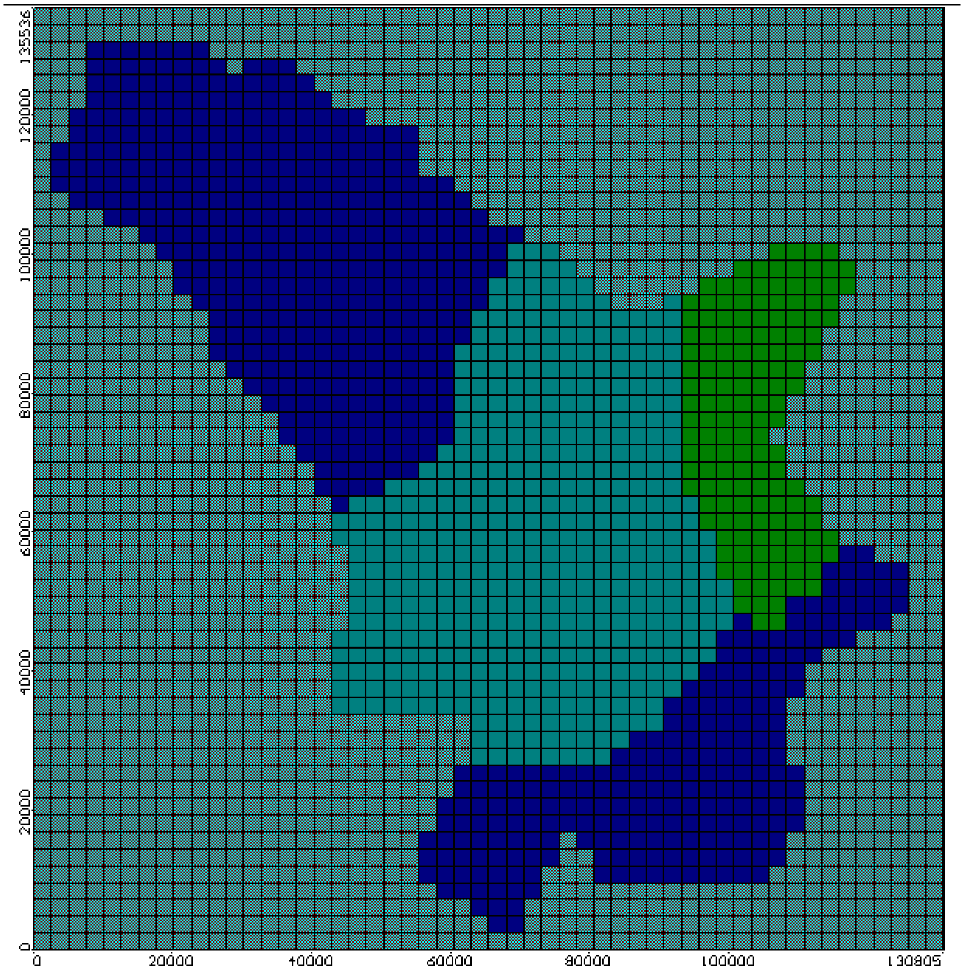


Figure 9.6 Recharge zones of the study area

9.5 Model Calibration

The calibration strategy was to initially vary the best known parameters as little as possible, and vary the poorly known or unknown values the most to achieve the best overall agreement between simulated and observed. Steady state model calibration was carried out to minimize the difference between the computed and field water level condition. Steady state calibration was carried out with the water level data of Jan 2010 in 17 wells distributed over the study area. Out of all the input parameters, the Specific yield value is the only poorly known as only 21 pumping tests data were available in this area. The lithological variations in the area and borehole lithology of existing large diameter wells were studied. Based on this, it was decided to vary hydraulic conductivity values upto 10% of the pumping test results for layer in order to get a good match of the computed and observed heads (Fig. 7). The figure indicates that there is a very good match between the calculated and observed water heads in most of the wells of the study area. Root mean square error and the mean error were minimized through numerous trial runs.

Transient state simulation was carried out for a period of 5 years from Jan 2010 to Dec 2014 with monthly stress periods and 24 hour time step. The trial and error process by which calibration of transient model was achieved by several trials until a good match between computed and observed heads over space and time. The hydraulic conductivity values incorporated in the transient model were modified slightly from those calibrated by the steady state model. Based on the close agreement between measured and computed heads from Jan 2010 to Dec 2014 at 17 observation wells distributed throughout the aquifer, the transient models were considered to be calibrated satisfactorily. The sensitivity of the model to input parameters were tested by varying only the parameter of interest over a range of values and monitoring the response of the model by determining the root mean square error of the simulated heads compared to the measured heads.

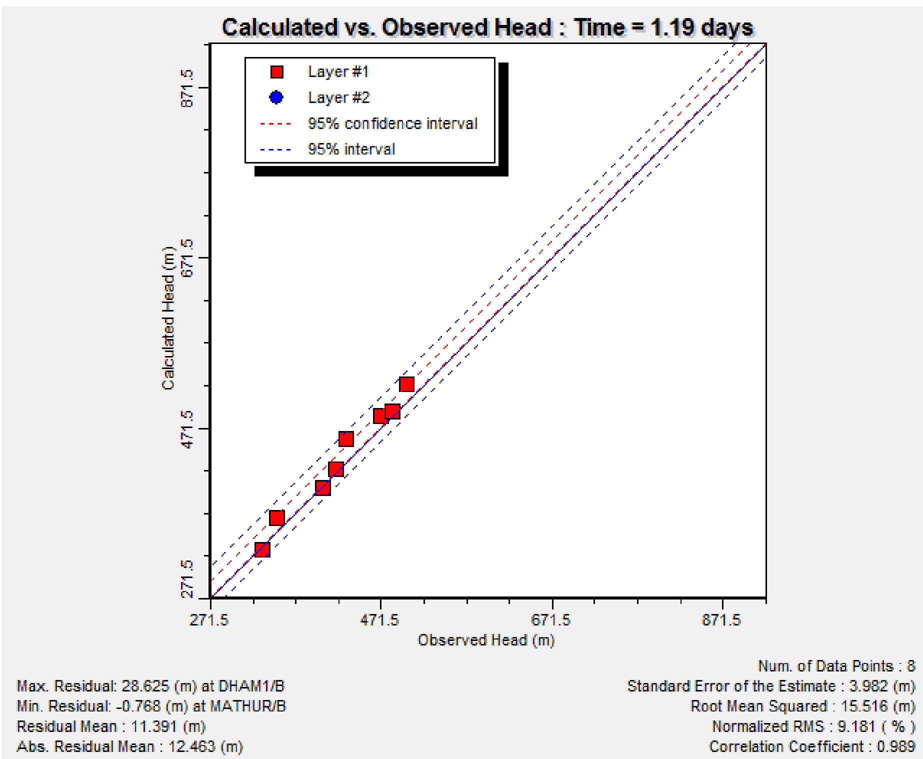


Figure 9.7 Computed and observed heads

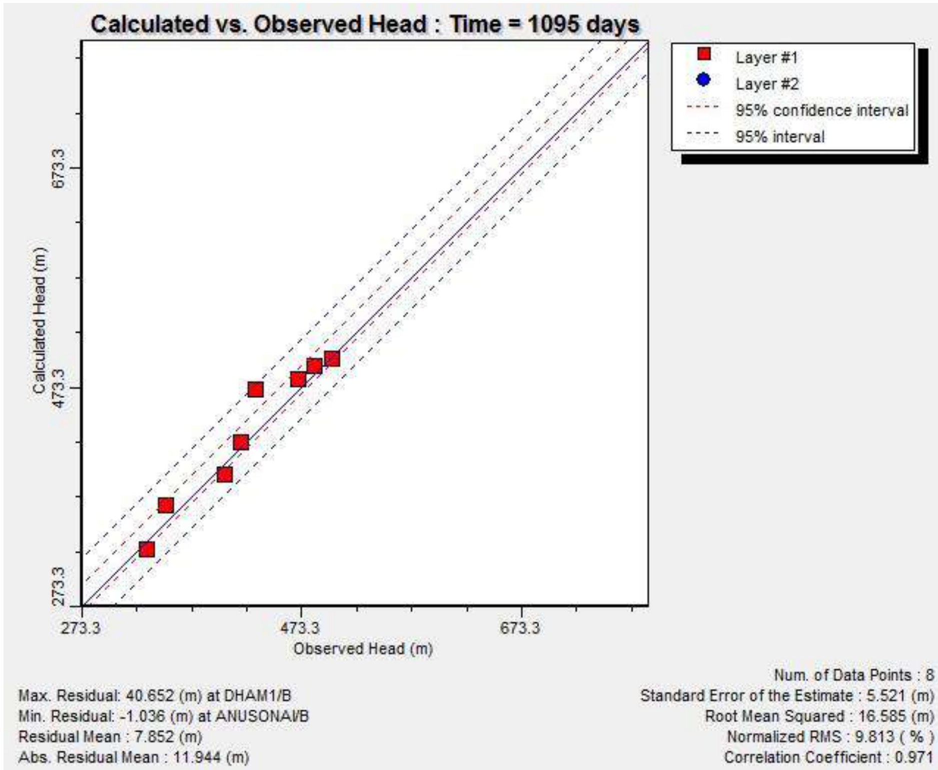


Figure 9.8 Comparison of computed and observed groundwater heads under steady state & Transient state conditions.

9.6 Simulation Results

The model was simulated in transient condition for a period of 5 years from year 2010-Dec 2014. There was fairly good agreement between the computed and observed heads (Figure.9.7). A study of the simulated potentiometric surface of the aquifer indicates that the highest heads are found on the Northern side of the study area, which is a general reflection of the topography. During the simulation period, it is observed that most of the cells in the first layer i.e., weathered zone gets dried up (Figure 9.9a). The number of dry cells gradually increases with the summer season and number of dry cells reduces with arrival of monsoon. The regional groundwater flow direction is from north to south till Kaveripattinam and after Kaveripattinam flow direction is west to east. The groundwater flow vectors for the month of May & December 2013 are given in Figures .9.10 a & b. The comparison of observed and computed heads are given in Figure 11 a to c.

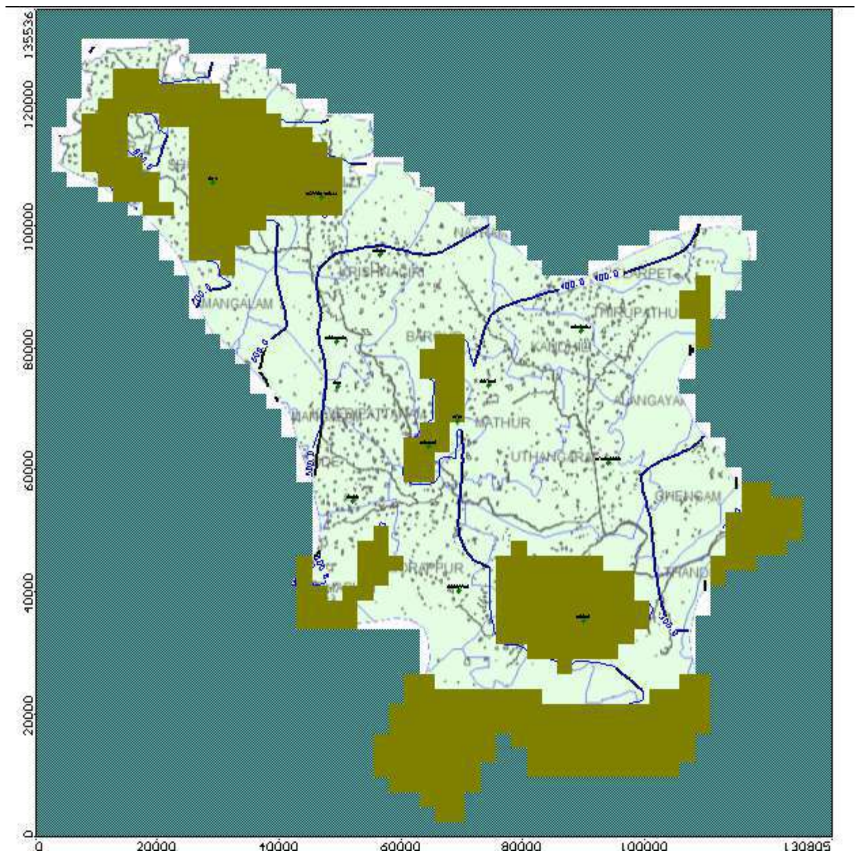


Figure 9.9a Simulated groundwater head during May 2012- Aquifer I

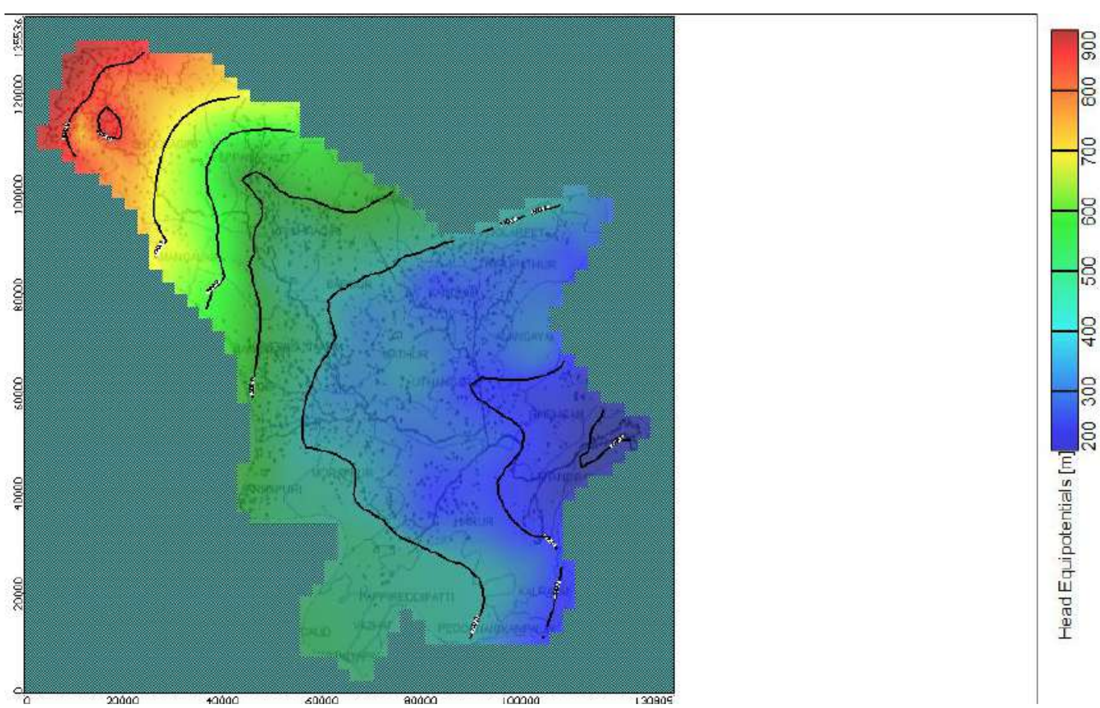


Figure 9.9b Simulated groundwater head during May 2012-Aquifer II

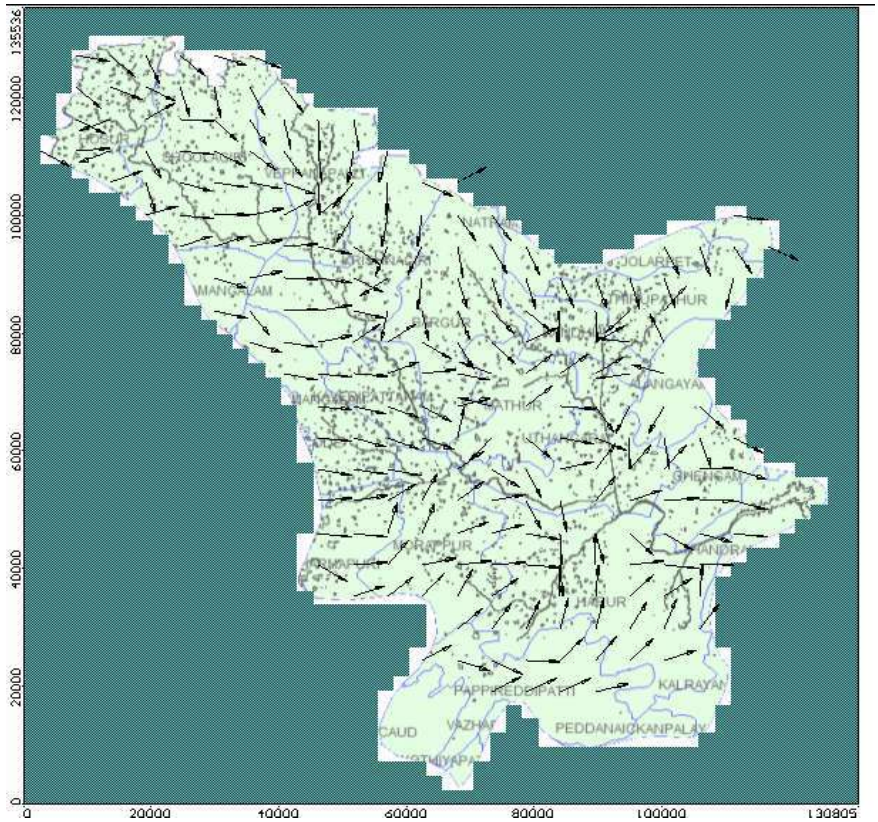


Figure 9.10a Groundwater flow vectors during May 2013

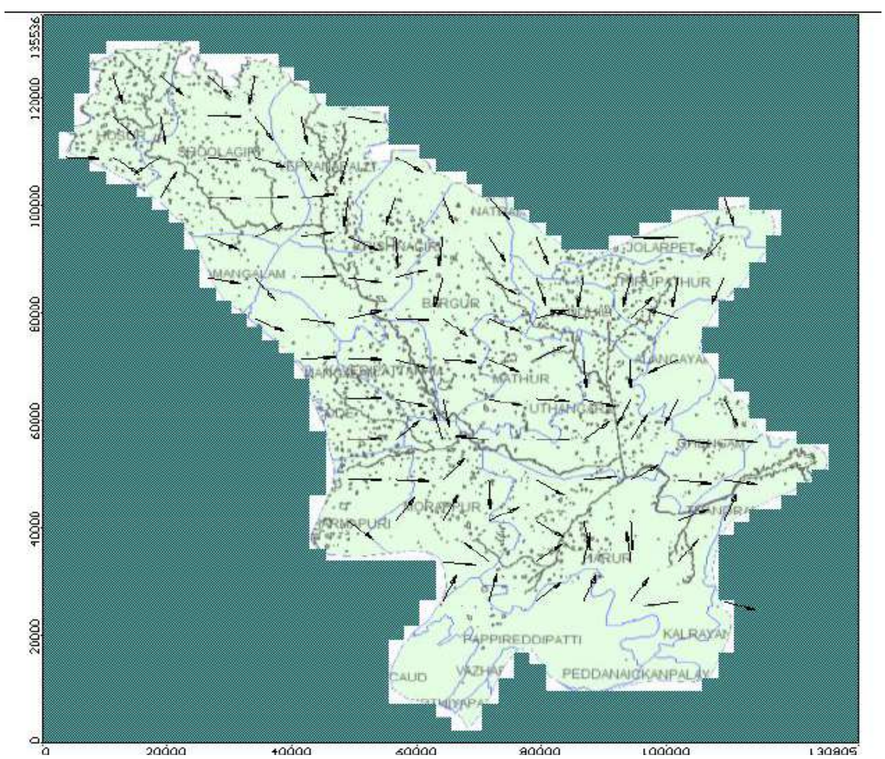


Figure 9.10b Groundwater flow vectors during December 2013

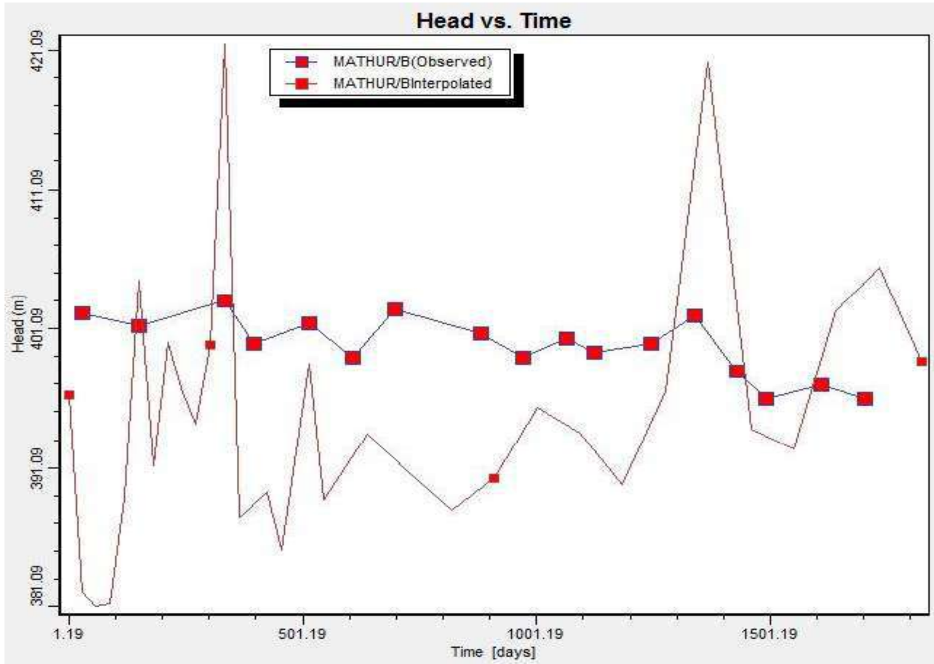


Figure 9.11a Times series analysis of Computed and observed at Mathur

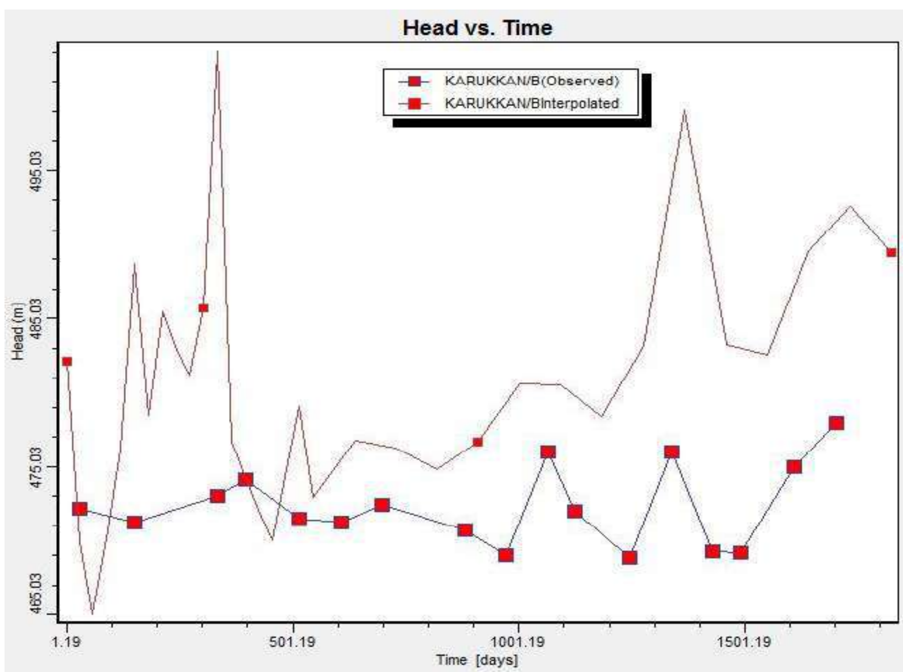


Figure 9.11b Times series analysis of Computed and observed at Karukkan

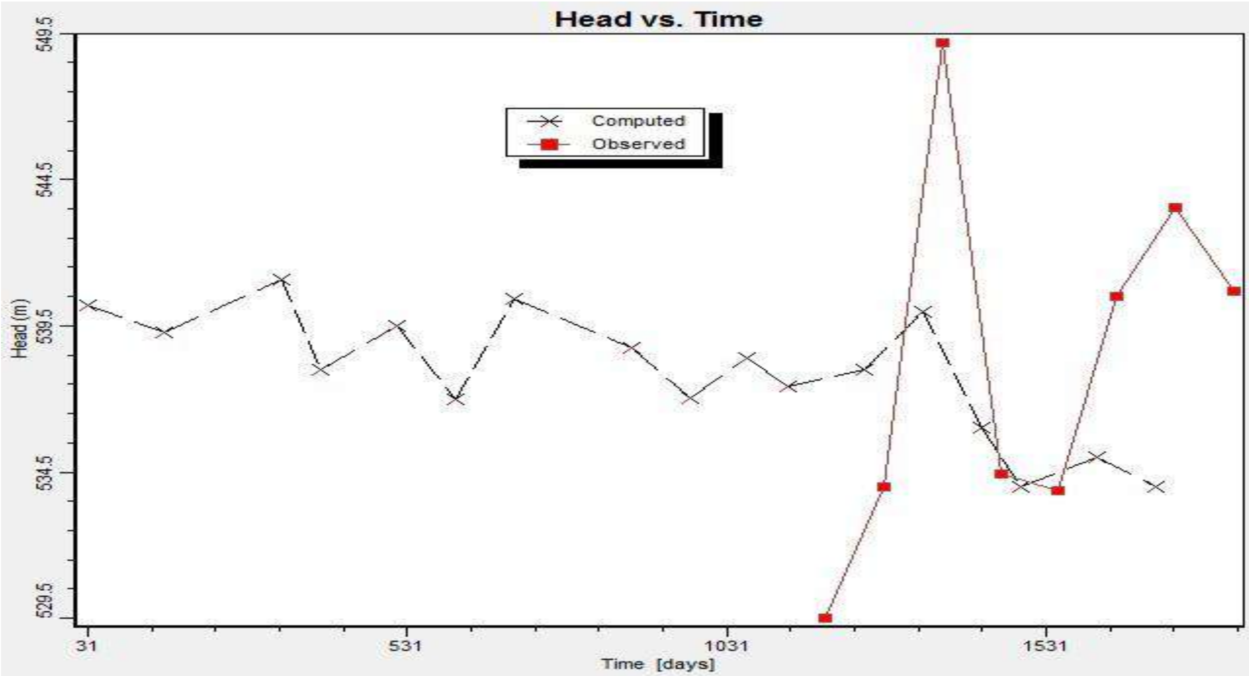


Figure 9.11c Times series analysis of Computed and observed at Veppanahalli

9.7 Model Forecast

The aquifer response for different input and output fluxes was studied in order to sustainably manage the aquifer system. The model was run for a further period of 06 years from 2014 to 2020. Before commencement of this simulation, the data of average rainfall (100 years), abstraction, river flow and recharge was provided to the model upto 2020.

Two prediction runs were planned to evolve optimal management schemes.

(1) Normal rainfall condition

The model was run to predict the regional groundwater head in this area until the year 2020. For these runs the monthly average rainfall calculated from 100 years rainfall data was used. The present level of groundwater abstraction was considered for this simulation. The simulated regional groundwater head for September 2020 is shown in Figure 9.12. There is not much increase or decrease in water level (Figure 9.12). Such observation is made in most of the locations.

(2) Drought year once in two years

Analysis of the past 100 years (1901-2000) rainfall data indicates that in 56 years, the rainfall was less than the average of 816 mm/year. The average of these low rainfall years (drought period) was found to be 696 mm/year. In order to study the effect of drought years in this area, the model was predicted by assuming deficit rainfall once in two years until 2020. The monthly average of deficit rainfall years was calculated and used for this purpose. The groundwater level declines during the assumed drought years. However, the groundwater level recovers to the level observed during the normal rainfall within the next year. One good flow in the rivers sees the groundwater levels attaining its normal levels. The contribution of the river to the aquifer system maintains the system in stable condition.

(3) Increase in pumping

The model was run to predict the regional groundwater head in area until the year 2020 with 10% increase in pumping (Figure 9.13). For these runs the monthly average rainfall calculated from 100 years rainfall data was used. The predicted model indicates that the major portion becomes dry and only central and south eastern portion have groundwater in aquifer - I. Model clearly indicates that the groundwater head will decline drastically with increase in pumping.

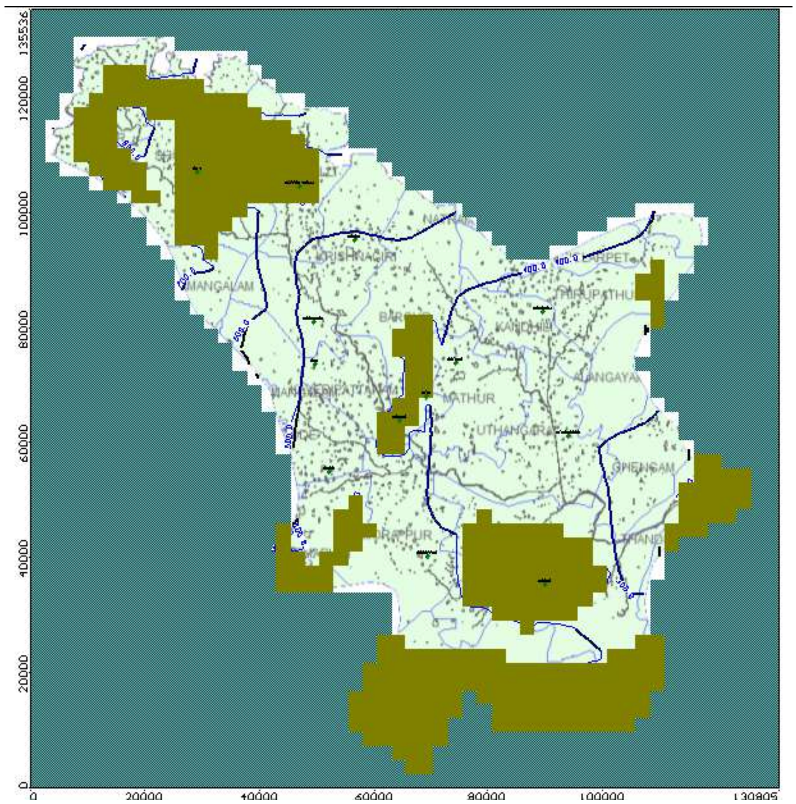


Figure 9.12. Predicted groundwater head 2020 under normal present conditions

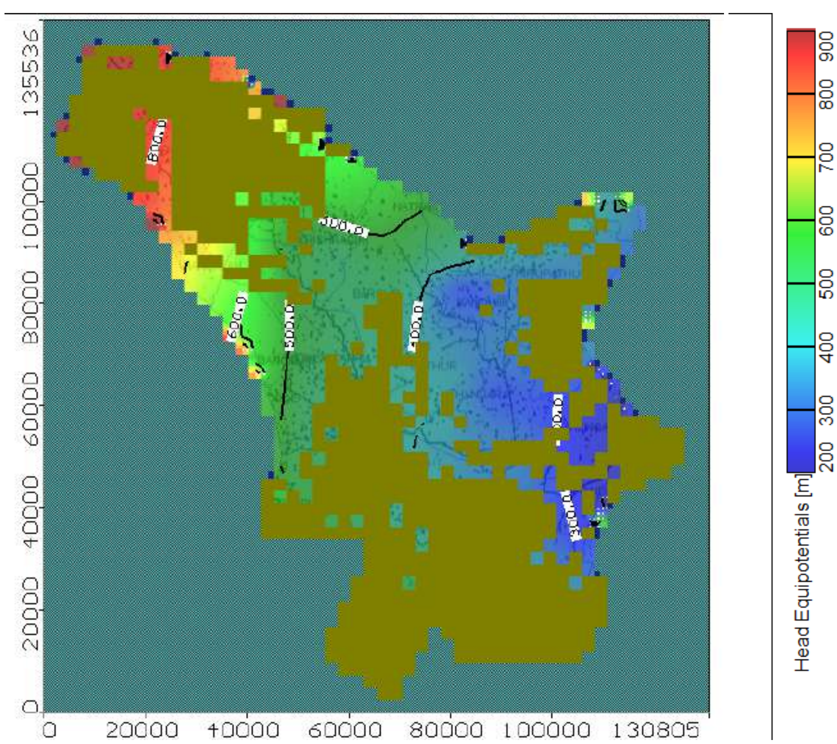


Figure 9.13. Predicted groundwater head 2020 with10%increase ion pumping

9.8 Conclusion

Three-layered finite-difference flow model was used to simulate the groundwater head in the parts of the upper Ponnaiyar aquifer system for a period of 5 years (Jan 2010-Dec 2014) for better understanding of the aquifer system. The simulated results indicate that this aquifer system gets dried up in many regions for the first layer i.e weathered layer in the present conditions. The spatial groundwater head follows the topography. The groundwater flows from the north to south untill Kaveripattinam and after flows towards the eastern. The computed groundwater head mimics the observed groundwater head in several locations. The model predicts the changes in ground water head with changes in hydrological conditions like drought occurring once in two years and normal run for another 06 years i.e upto 2020. With 10% increase in groundwater pumping the first layer gets dried up in major portion of the aquifer system. Declining groundwater head at a rate of 0.4 to 0.7 m/yr is observed in few locations in aquifer II with 10 % increase in pumping.

10**. GROUND WATER RELATED ISSUES**

10.1 Decline in groundwater levels

The Upper Ponnaiyar aquifer system is a drought prone aquifer syatem. The Groundwater development is more than the recharge, groundwater is extensively utilized for irrigation in the entire basin area for the past two decades, especially in the 38 over-exploited firkas out of the 58 firkas of the basin. Groundwater is the only source of irrigation in 80% of the basin area except in the central part where canal irrigation exists. Over exploitation of groundwater due to erratic rainfall, increase in number and depth of wells. Yield of the dug wells in Aquifer unit I reduced due to over development of aquifer unit II by bore wells. There is decline in groundwater level in the tune of 0.40 to 0.70 m/year in the basin, 70% of the dugwells in the basin become dry during summer season. The dug wells sustain only for 2 to 3 hours of pumping with drawdown of 2 to 5 m. The phreatic aquifer recharged during monsoon and the dug wells sustains for 3 to 4 months only.

10.2. Ground water quality issues

10.2.1 High Fluoride Concentrations

There is no anthropogenic contamination in the basin as there is no much urbanization. However, excess fluoride in ground water in some pockets causes health hazards by utilizing such ground waters for drinking purpose, villagers are affected with dental and skeletal fluorosis. More than 100 habitations in the basin affected by high fluoride concentration in groundwater used for drinking purpose. High fluoride content in groundwater is the major concern in some isolated pockets of the basin falling in Harur, Pappireddipatti, Morappur, Soolagiri, Bargur, Veppanahalli and Krishnagiri. Highest fluoride levels are recorded in the water samples of bore wells collected from aquifer II at Jeyavelkottai of Morappur block (3.8 mg/l), Dharmapuri district. Both aquifer units recorded fluoride concentration more than desirable concentration in groundwater.

10.2.2 High Salinity

Majority of samples fall C_3S_1 category for both aquifer I & II, which are high salinity and low sodium waters require good drainage. Crops with good salt tolerance should be selected. Gypsum amendments make feasible the use of these waters. Comparatively more number of samples falls in C_4S_1, C_4S_2 & C_4S_3, and category from aquifer-II, which are very high salinity and varying content of sodium. These waters are not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. They may produce harmful levels of exchangeable sodium wherever such waters are used. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected. Gypsum amendments make the use of these waters feasible.

10.3. Future Demand Scenario and Stress on Aquifer system

Future demand projected for domestic utilization will have a little stress on the aquifer system as the anticipated draft by 2025 and 2030 is not going to increase much in comparison to the present gross draft. However, draft can be regulated through increasing the water efficiency practices in irrigation sector. Already the dependency on ground water for domestic and drinking needs is decreasing in ground water contaminated areas as the alternative surface/ river sources are being harnessed.

10.4 Management Strategies

The ground water 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 ground water resource in a more rational and scientific way.

The study area is characterized by weathered and fractured system with very heavy abstraction of ground water for irrigation practices. Sustainable management plan for ground water is being proposed after a thorough understanding of the aquifer disposition down to a depth of 200m bgl.

10.5Augmentation Plan

Augmentation of groundwater can be achieved through construction of percolation ponds withrecharge 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 firkas of the basin through utilizing the uncommitted surface runoff of 855 MCM.

10.6 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. Artificial recharge and Water conservation plan is prepared for the over exploited and critical firkas of the basin area. 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 geomorphologic and drainage aspects are being given more weightage in selection of the Artificial Recharge structures.

10.7Demand 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.

10.8 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.

10.9Strategies to overcome the future stresses

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 Crop Change
- Increase are under micro irrigation system
- Agronomic Water Conservation
- Reducing Water use in Urban areas
- Increase use of waste water.

Lists of figures

Lists of table