केंद्रीय भूमि जल बोर्ड

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Central Ground Water Board

Department of Water Resources, River Development and Ganga Rejuvenation,
Ministry of Jal Shakti
Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

KOTTAYAM DISTRICT, KERALA

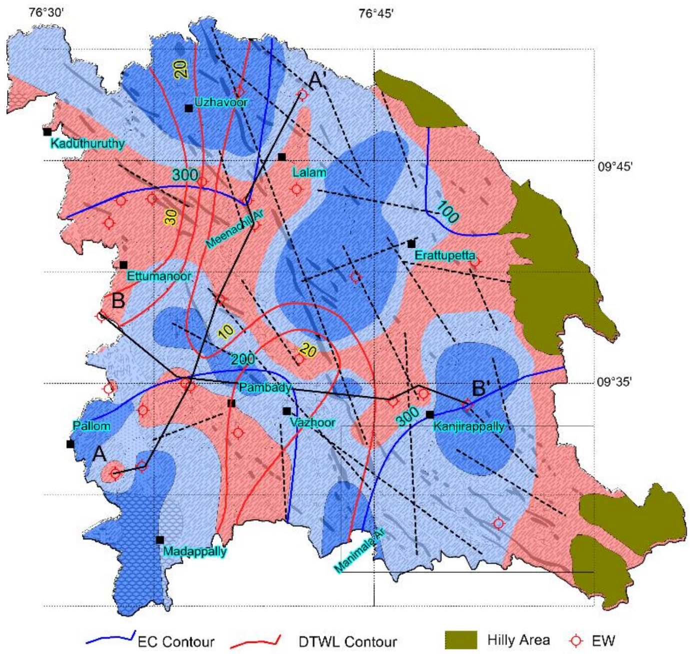
केरल क्षेत्र, तिरुवनंतपुरम

Kerala Region, Thiruvananthapuram

GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES, RIVER DEVELOPMENT AND GANGA REJUVENATION
CENTRAL GROUNDWATER BOARD

AQUIFER MAPPING AND GROUND WATER MANAGEMENT PLAN FOR HARD ROCK TERRAINS IN KOTTAYAM DISTRICT, KERALA

(AAP2018-19)



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KERALA REGION
Trivandrum
January 2020

TABLE OF CONTENTS

List of figures

List of tables

List of appendices

FOREWORD

The National Project on Aquifer Mapping (NAQUIM) is an initiative of the Ministry of Jal Shakti, Department of Water Resources, River Development & Ganga Rejuvenation, Government of India, for mapping and managing the entire aquifer systems in the country. The aquifer systems in Kerala are being mapped as part of this programme and this report pertains to aquifer mapping and its outcomes of the work carried out in the hard rock terrains of Kottayam district. The target scale of investigation is 1:50,000 and envisages detailed study of the aquifer systems up to 200 m depth, to ascertain their resource, water quality, sustainability, and finally evolve an aquifer management plan.

The report titled "Aquifer Mapping and Ground Water Management Plan for HardRock Terrains in Kottayam District, Kerala" gives a complete and detailed scientific account on the various aspects of the hard rock aquifers in the area including its vertical and horizontal dimensions, flow directions, quantum and quality of the resources, of both - the shallow and deeper zones of the hard rock aquifers. Voluminous data were generated consequent to hydrogeological, groundwater regime monitoring, groundwater quality, exploratory drilling, geophysical studies etc., in the district, and incorporated in the report. The information is further supplemented by various data collected from State departments. It portrays the various groundwater issues pertaining to the area along with recommendation for suitable interventions and remedial measures. Thus, it provides a total and holistic solution to the water security problems in Kottayam district.

This document has been prepared under the guidance ofDr. N. Vinayachandran, Scientist D & Nodal OfficerandSh. Santhanasubramani, Scientist C &Team leader. The painstaking efforts of the field hydrogeologist Sh. Vijesh V.K., Scientist-B in carrying out the aquifer mapping and preparation of this report are well appreciated. Dr V.S Joji, Scientist D deserves appreciation for his meticulous scrutiny of this report before printing. I am also thankful to the Chairman, Members and officers of CGWB, Trivandrum and CHQ, Faridabad for their valuable guidance in finalizing this document. Thanks, are also due to various organizations of Government of Kerala and Government of India for providing data required for the compilation of this document.

This report evolved in the present form through incorporations and modifications as suggested during the presentation of the report before the State Groundwater Coordination Committee (SGWCC), Chaired by the Water Resources Secretary, Kerala State, Sh. B. Ashok, IAS and before the District Collector & District Magistrate, Kottayam district, Sh. P.K. Sudheer Babu I.A.S. Their sincere efforts and encouragements for improvising the content of this report are acknowledged with gratitude.

I hope this compilation will be of much help to the planners, administrators and stakeholders in the water sector in Kerala and will serve as a useful guide for the optimal and sustainable management of groundwater resources in Kottayam district based on sound scientific foot.

Trivandrum,
January, 2019

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AQUIFER MAPPING AND GROUND WATER MANAGEMENT PLAN FOR THE HARD ROCK TERRAINSIN KOTTAYAM DISTRICT, KERALA (2018-19)

1. INTRODUCTION

In XII five-year plan, National Aquifer Mapping (NAQUIM) has been taken up by Central Groundwater Board (CGWB) to carry out detailed hydrogeological investigation on toposheet scale of 1:50,000. During the AAP 2018-19, CGWB, Kerala Region carried out aquifer mapping under NAQUIM in the hard rock terrains of Kottayam district. The aquifer mapping is a multi-disciplinary scientific process where data related to the aquifer systems and groundwater regime are integrated to characterize the quantity, quality and movement of groundwater in the aquifers. A better understanding of the hydrogeological processes that control the distribution and availability of groundwater in the weathered and fracture zones of the aquifer system is imperative for the sustainable resource management. The sustainable development and management of hard rock aquifer system involves development of strategies for balancing the water extraction and water availability. Integrated studies on various aspects of the groundwater regime have been carried out to know the disposition and productivity of the aquifer systems.

The hydrogeological environment of the study area has been conceptualized from the study of historical data on the groundwater regime and from the available technical reports and publications. The data gaps could be identified from the analysis of historical data which facilitated generation of new datain gap areas. The hydrogeological, hydrological, geophysical, hydrochemical and meteorological data were analysed for data gaps. Also, groundwater extraction/draft from the aquifer systems has been evaluated from detailed well inventory in the study area. In order to refine the aquifer geometry of the area integrated use of lithological and geophysical data were used.

1. 1 Approach and Methodology

The ongoing activities of NAQUIM include toposheet wise micro-level hydrogeological data acquisition supported by geophysical and hydro-chemical investigations along with groundwater exploration down to the depths of 200 meters. Considering the objectives of NAQUIM, the data on various components were segregated, collected and brought on GIS platform by geo-referencing the available information for its utilization for preparation of various thematic maps. The approach and methodology followed for Aquifer mapping is as given below:

Compilation of existing data (Central & State Govt.)

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Generation of different thematic layers

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Identification of theaquifer systems

↓

Identification of data gaps

↓

Data generation
(Water level, Exploration, Geophysical, Hydrochemical, Hydrogeological etc.)

↓

Preparation of robust aquifer maps with 3D disposition

↓

Preparation of aquifer management Plan

1.2 Study area

Kottayam district falls in the central part of Kerala state covering an area of 2208 sq.km. It accounts for 5.68% of the total area of the state and is bordered by Pathanamthitta on the south and Aleppey on the west, Ernakulam and Idukki districts on the north and east. District lies between 9^o 15’ and 10^o 21’ North Latitude and 76^o 22’ and 77^o 25’ East Longitude; falling in part of the Survey of India degree sheet 58 C. As per the Census of 2011, Kottayam districthad population of 1,974,551 of which male and female were 968,289 and 1,006,262 respectively. The district has two revenue divisions namely Kottayam and Pala and consists of five taluks viz; Changanacherry, Kanjirappally, Kottayam, Meenachil and Vaikom. Other administrative divisions include 11 blocks viz. Erattupetta, Ettumanoor, Kaduthuruthy, Kanjirappally, Lalam, Madappally, Pallom, Pampady, Uzhavoor, Vaikom and Vazhoor; 6 municipalities - Kottayam, Changanacherry, Vaikom, Pala, Erattupetta and Ettumanoor. There exists a total of 71 panchayths in Kottayam district. Kanjirappally is the biggest block in the district with an area of 342 sq.km. For the current work, out of the total study area of1657 Sq. km, about 1328 Sq. km (excluding hilly, forest and adjoining soft rock areas) of mappable hard rock area wasin detail studied. The administrative set-up of the study area is given in fig 1.1. In the current study 5 blocks viz; Pallom, Madappally, Ettumanoor, Uzhavoor and Kaduthuruthy were partly covered as the remaining part of these blocks being sedimentary and already covered under NAQUIM during the annual action plan of 2012-13.

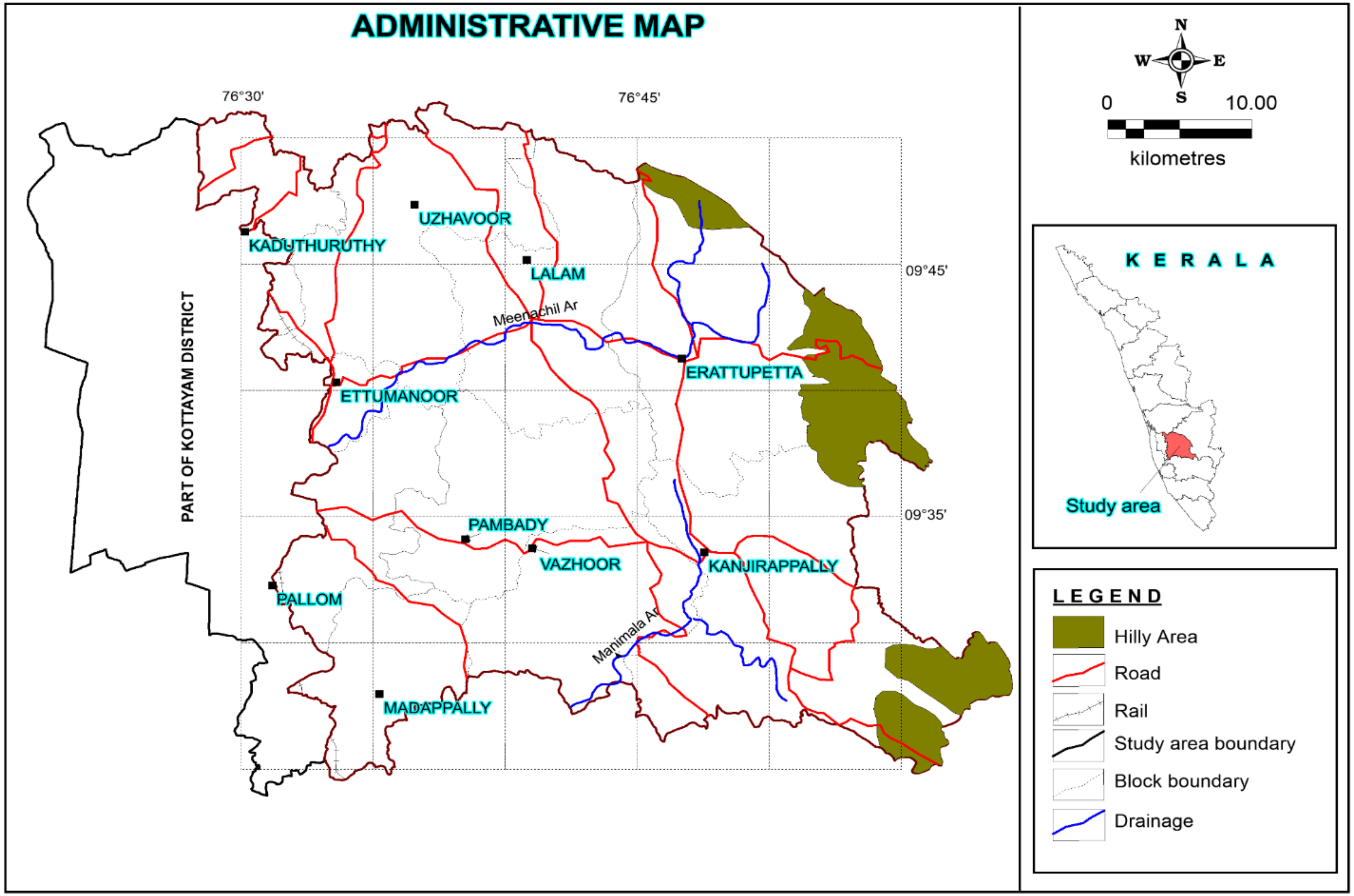


Fig.1.1: Location map of the study area

The district is blessed with both groundwater as well as surface water resources. Groundwater is mainly used for drinking and agricultural purposes. The groundwater in the shallow aquifer of the district is mostly developed through dug wells while, the deeper fractured crystalline aquifers are tapped through bore wells mainly for domestic, agricultural and industrial purposes. The lifting devices of water are rope and bucket, centrifugal pumps and jet pumps for dug wells and submersible and compressorpumps for bore wells.

1.3 Climate

The tropical type of climate in Kottayam, which is quite pleasant and moderate does not provide any distinctive seasons to the inhabitants characterized with high to moderate humidity levels. The average annual maximum temperature in this district ranges from 29.2 ^{o}C to 33.4 ^{o}C and the average annual minimum temperature between 19.7^{o}C to 25^{o}C. The months of March, April and May are the warmer months in the district. The period in between June and September is marked as the monsoon season in Kottayam, when the district receives the heaviest precipitation brought by the southwestern monsoon. However, the amount of rainfall decreases during the months of October, November and December (Northeast monsoon). The district normally gets an annual average rain fall of 3130.33mm. The annual Potential Evapotranspiration is 1424.1 mm based on Penman's method at Cochinmeteorological station which is close to the district boundary. Generally potential evapotranspiration is less during April to November while compared to other months. The monthly potential evapotranspiration (PE) ranges between 119.3 and 177.0 mm. The relative humidity is generally high during the morning hours and goes up to 79% and during evening hours it is around 76%. The general wind direction is from East to Northeast during morning hours and West to Northwest during evening hours. The wind speed ranges from 6.7 to 10.9 Km/hr. The India Meteorological Department maintains five observatories in the district namely Kanjirappally, Kottayam, Kumarakom, Vaikom and Kozha.

1.4 Soil

The soil types occurring in the study area can be broadly grouped into four types on the basis of their physico-chemical properties and morphological features. They are (a) Lateritic soil (b) Riverine alluvium (c) Brown hydromorphic and (d) Forest loams.

a) **The lateritic soil**: The lateritic soil is the predominant soil type, which covers almost the entire midland areas of the study area. The surface soil is mostly reddish brown to yellowish red in colour and the texture ranges from gravelly loam to gravelly clay loam. It is well drained and the presence of organic content is low.

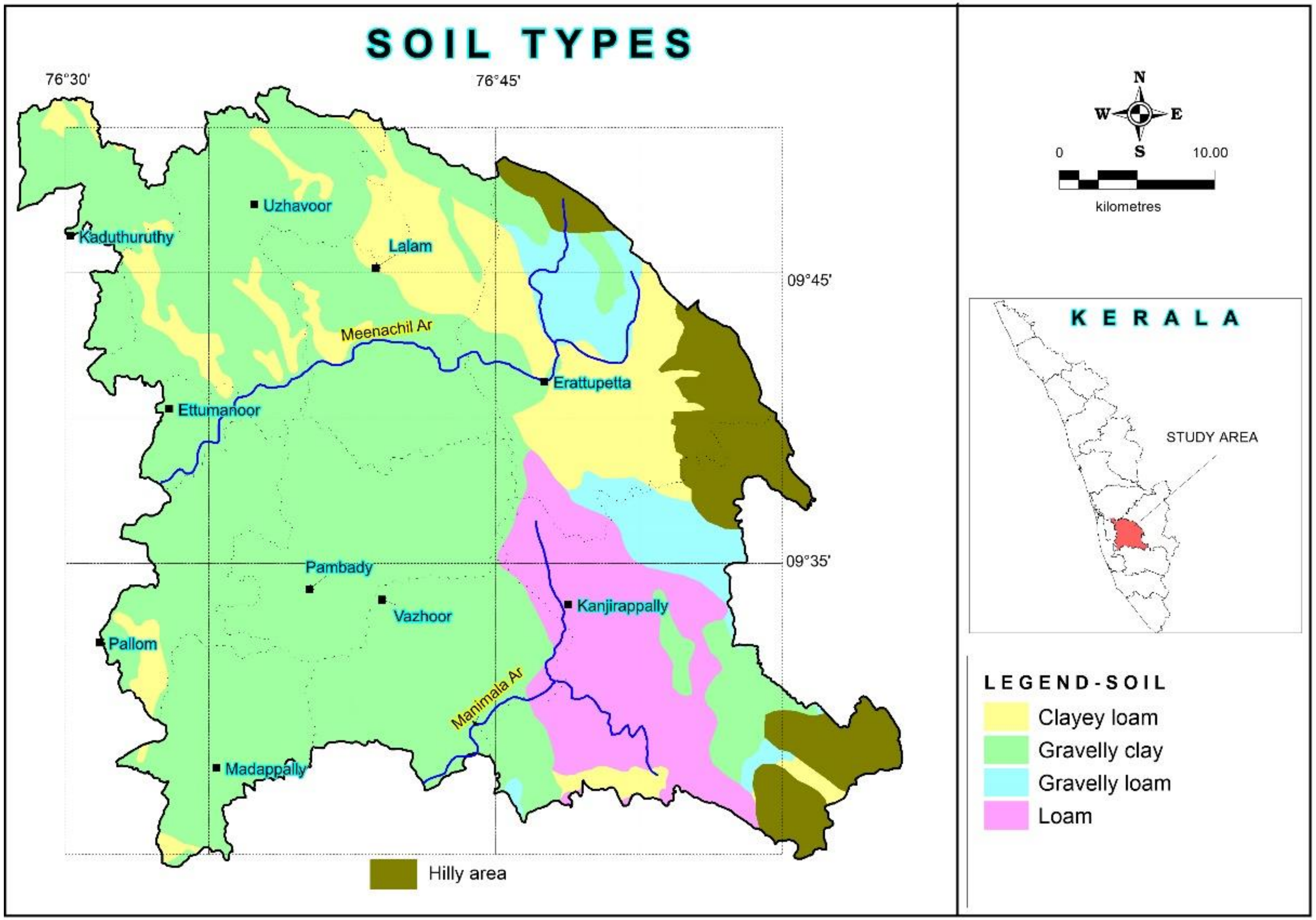


Fig.1.2: Soil map

b) **Riverine alluvium**: The occurrence of these soils is restricted along the river courses and their tributaries. These soils are characterised by moderate amount of organic matter, nitrogen and potassium. Presence of mica flakes has been observed in the alluvial soils. They are very deep soils with surface textures ranging from sandy loam to clayey loam.

c) **Brown hydromorphic soil**: These soils are mostly confined to valley bottoms between undulating topography in the midland and in low-lying areas. They have been formed as a result of transportation and sedimentation of material from adjoining hill slopes and also through deposition by local streams. These soils are very deep and brownish in colour and the surface soil texture varies from sandy loam to clay.

d) **Forest loam**: These soils are the products of weathering of crystalline rocks under forest cover. They are occurring in the eastern hilly areas. These are dark reddish brown to black in colour. The surface texture varies from loam to silt loam. They are characterised by a surface layer very rich in organic matter.

The soil map was prepared based on textural classification of the area (modified after the soil map published by Kerala State Land Use Board (KSLUB) is shown in fig 1.2.

1.5 Physiography and Geomorphology

Based on the physical features, the district can be divided into three regions as lowland, midland and highland. The Kanjirappally, Erattupetta, eastern parts of Uzhavoor and north-eastern part of Lalam block falls under the highland category (Elevation above 75 amsl); Vazhoor, Pampady, Madappally, Pallom, Ettumanoor, Kaduthuruthy and the remaining areas of Uzhavoor and Lalam falls under mid-land category (7.5 to 75 m amsl). About one percentage of the study area along the river courses and floodplains in Ettumanoor, Pallom, Madappally and Kaduthuruthy blocks falls in the low land category (<7.5 amsl). An elevation model (Source: Shuttle Radar Topography Mission-United States Geological Survey (SRTM-USGS)) of the study area depicting the elevation features is given in fig 1.3. This elevation data was downloaded in ".hgt" format from the directory "https://dds.cr.usgs.gov/srtm/".The maximum elevation in the study area is 1193 m amsl at Kurisumudi near Vagamon in Erattupetta Block.

The major geomorphologic features in the study area are the lateritic lower plateaus and it forms the potential phreatic aquifer in the study area. The piedmont zone is situated in between the lateritic lower plateaus and the denudational hills in the eastern boundary of the study area. A map detailing the geomorphology of the study area is given in fig. 1.4.

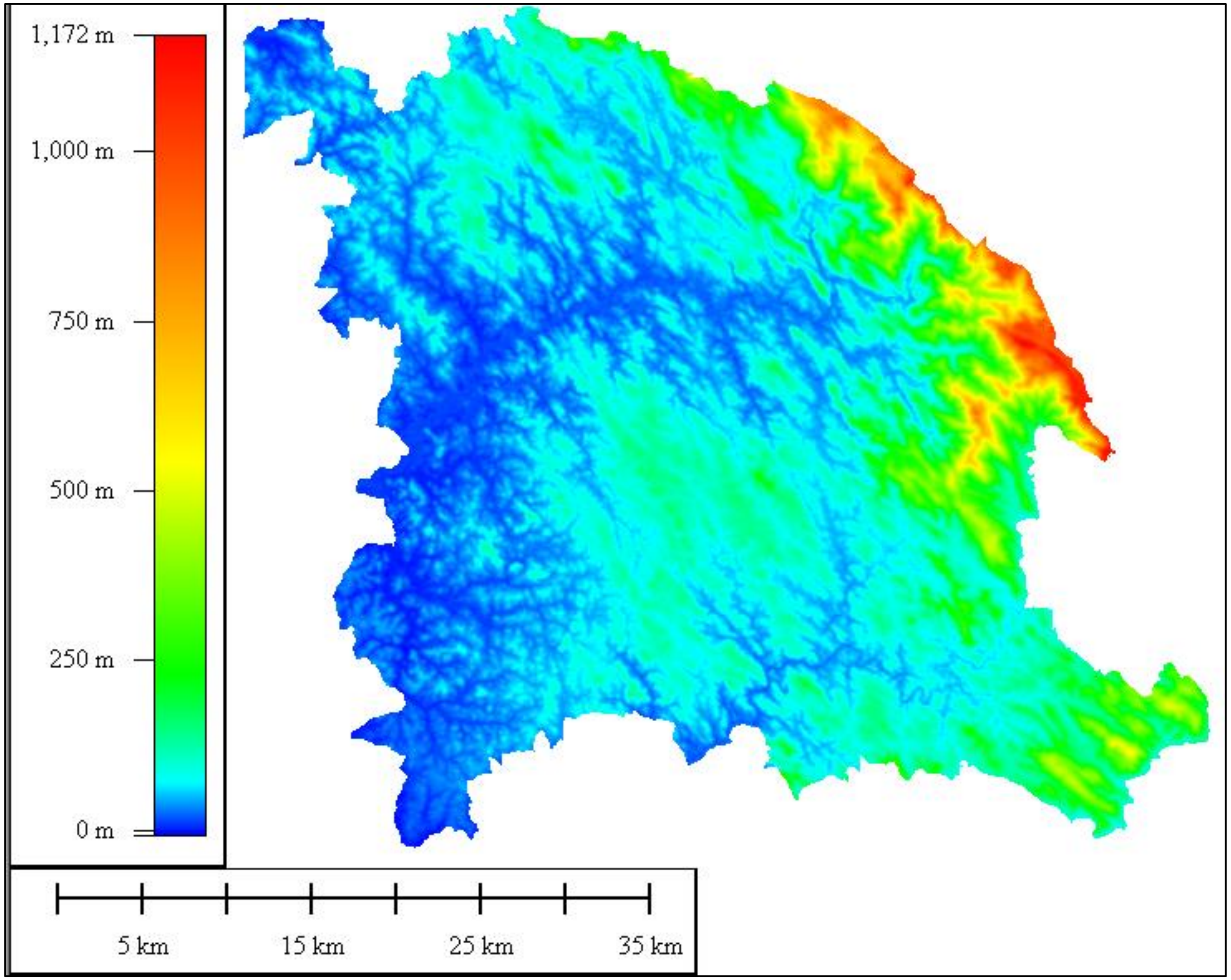


Fig.1.3: Digital Elevation Model of the study area (Source: SRTM data, USGS)

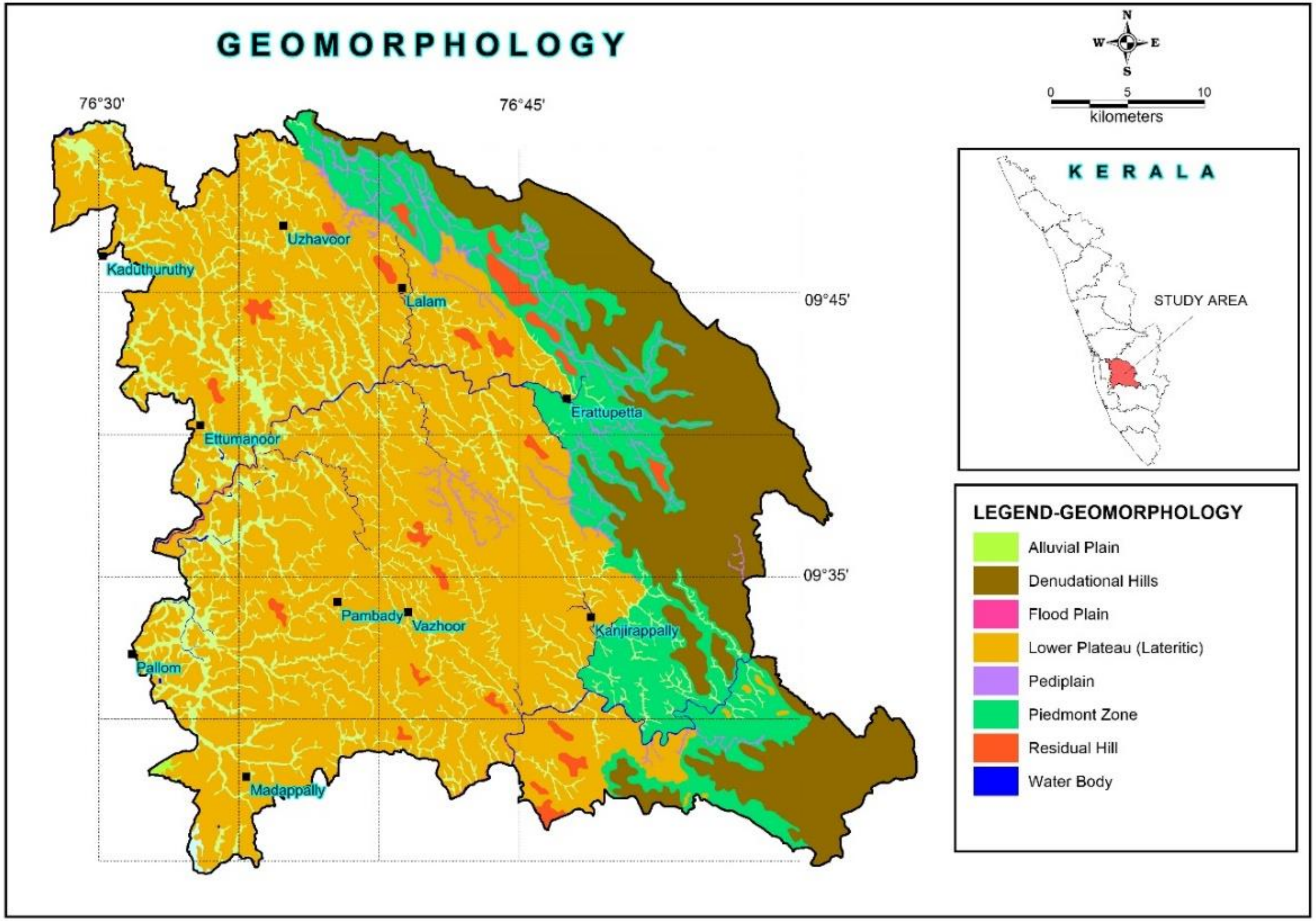


Fig.1.4: Geomorphology map

1.6 Agriculture & Land use

The spatial information on land use/land cover and their change in pattern through time is important for planning, utilization and management of the country's land resources. Land use/land cover inventories are assuming increasing importance in various resource sectors like agriculture planning, settlement and cadastral surveys, environmental studies and operational planning based on agro-climatic zones. For the current study the land use layers prepared by the KSLUB have been used. The major land use in the study area (out of 1657 Km^2) isrubber plantation comprising about 68 % of the study area. Other plantations (Tea, Cashew, Areca nut, Pepper etc.) comes around about 21%; only 4% comes under the category of crop lands and 3% of the study area is occupied by forests particularly along the eastern margin of the study area. About 1% of the study area is occupied by coconut plantations. Total forest area of the district is100.85 sq.km which accounts for about 4.6 percentage of the total geographical area of the district. Block wise detail of the land use pattern (2013) in the study area is given in Table 1.1.

Agriculture is the principal occupation in this district. The important crops cultivated in the district are rubber, pepper and paddy. Area under paddy cultivation in the district is 8.41 percentage of gross cropped area of the state during the year 2017-18. Rubber is the major plantation crop cultivated in the district. Total area under rubber cultivation in the district is 114440 Hectare, which is about 20.77 % of the total rubber cultivated area of the state. Production statistics of rubber shows Kottayam district's contribution to total production in the state is about 20.35 %. Block wise distribution of different crops in the district during 2017-18 is given in Table 1.2.

Groundwater is the main source of irrigation in the district and is primarily abstracted through dug wells followed by bore wells. Panchayath ponds and irrigation tanks are also available in the district and are often less used. The block wise details of area irrigated by different sources in the district are given in Table 1.3. Map depicting the land use pattern in the study area is given in fig 1.5.

The change in waste, fallow and current fallow lands in Kottayam district is given in table 1.4 and it is clearly evident that from 2005-06 to 2016-17, there is a drastic increase in the area of waste lands from 2712 Ha to 7273 Ha. The main reasons for this may be disinterest in agriculture, lack of availability of resources, particularly water and also unprofitability of agriculture.

Table 1.1: Block wise detail of land use pattern in the study area (Area in Ha)

#	LAND USE	VAZHUR	UZHAVOOR*	PAMBADY	PALLAM*	MADAPPALLY*	LALAM	KANJIRAPPALLY	ERATTUPETTA	ETTUMANUR*	KADUTHURUTHY*
1	Aquaculture	0	0	14.91	0	0	0	0	0	0	0
2	Agriculture plantation (Arecanut)	0	0	0	0	0	0.36	0	0	13.02	0
3	Agriculture plantation (Banana)	16.95	2.53	0	10.33	29.88	0	0	0	0	7.45
4	Agriculture plantation (Cashew)	0	0	0	0	0	0	50	0	0	0
5	Agriculture plantation (Coconut)	0	17.24	0	770.03	366.15	0	0	53.73	2796.55	1010.56
6	Agriculture plantation (Mixed)	5131.41	4512.96	5714.13	3409.25	3208.16	1846.84	3871.14	3800.68	2608.69	1703.05
7	Agriculture plantation (Pepper)	0	0	0	0	0	9.62	0	0	0	0
8	Agriculture plantation (Rubber)	11174.88	16005.64	13960.99	3593.43	3980.77	14574.42	24796.96	20454.8	2438.38	8454.52
9	Agriculture plantation (Tea)	0	0	0	0	0	0	1072.13	64.44	0	0
10	Barren rock/Stony waste/Sheetrock	0	22.63	0	0	0	1.83	47.07	198.79	0	0
11	Built-up (Cities/Town/Villages)	77.88	155.94	94.28	260.52	57.18	30.68	83.26	25.37	354.51	629.68
12	Cropland (Kharif)	0	0	0	0	0	0	0	63.59	0	0
13	Double crop (Kharif+Rabi)	0	1767.14	791.34	2229.09	2541.19	509.46	42.06	8.98	9124.58	3720.44
14	Fallow Land	0	3.55	11.24	41.91	108.28	24.06	0	0	4.9	151.28
15	Forest Deciduous (Dense)	0	8.43	0	0	0	0	3436.06	741.01	0	0
16	Forest Evergreen (Dense)	0	0	0	0	0	0	614.31	0	0	0
17	Forest Evergreen (Open)	0	0	0	0	0	0	588.9	0	0	0
18	Grass Land	0	0	0	0	0	0	15.94	554.61	0	0
19	Land with scrub	63.46	65.84	10.06	25.17	165.22	109.13	105.59	1313.42	2.4	0
20	Land without scrub	0	0	3.03	0	0	82.38	5.59	138.64	0	0
21	Mining/Industrial waste	0	2.47	0	0	5.78	0	0	0	0.78	0
22	River/Waterbodies	99.33	107.74	193.86	196.53	141.17	117.47	326.36	125.17	4152.95	436.45
23	Sandy Area	21.36	0	0	26	0	0	1.99	0	4.89	0
24	Wetlands (Waterlogged)	0	5.66	0	0	0	0	0	0	0	0
Total		**16585.27**	**22677.77**	**20793.84**	**10562.26**	**10603.78**	**17306.25**	**35057.36**	**27543.2**	**21501.7**	**16113.4**

*Partly covered blocks; Figures given for entire block area (Source: KSLUB, Govt. of Kerala)

Table 1.2: Block wise distribution of different crops in Kottayam district (Area in Ha)

Block	Paddy	Pepper	Aricanut	Nutmeg	Banana	Pineapple	Tapioca	Coconut	Vegetables	Tubers
Madappally*	2245.83	180.14	47.38	42.12	210.16	27.32	417.63	1242.27	274.7	55.1
Vazhoor	--	254.59	97.58	108.08	162.05	52.13	335.65	1325.22	150.76	107.49
Ettumanoor*	7402.17	70.2	58.33	74.16	62.41	10.19	144.74	2266.88	122.67	38.09
Pallom*	718.57	275.35	50.03	108.99	178.65	40.64	482.99	1673.81	220.44	115.71
Pampady	195.15	424.51	119.32	179.4	284.4	168.27	643.13	2089.38	195.67	106.99
Erattupetta	0.73	487.49	192.31	325.28	404.51	301.05	910.32	2281.83	247.91	86.96
Lalam	40.17	295.6	144.62	314.73	334.94	200.12	581.79	1840.77	211.58	57.29
Uzhavoor	414.25	331.88	128.27	285.07	574.37	362.85	1272.21	2690.92	456.7	125.99
Kaduthuruthy*	2592.2	183.42	114.48	270.92	352.09	219.85	276.95	2269.92	299.31	47.35
Kanjirappally	--	439.51	153	351.63	368.46	86.31	781.4	1982.48	265.94	268.55
Municipalities	1689.77	167.98	100.66	171.86	103.87	22.59	233.27	2423.8	198.68	63.24

*Partly covered blocks; Figures given for entire block area
(source: http://www.ecostat.kerala.gov.in)

Table 1.3: Block wise details of area irrigated (Ha) based on source of irrigation

Source of Irrigation	Surface Irrigation (1)					Groundwater (2)						Other sources including Traditional WHS (3)	Water extraction devices/lift			Total	
	Canal Based		Tanks/Ponds/reservoirs			Tube wells		Open wells		Bore wells			Electricity pump (4)	Diesel pump (5)	Petty & para/ Others (6)	Irrigation sources (1+2+3)	Water extracting units (4+5+6)
	Govt. Canal	Community/Pvt. Canal	Community ponds including small	Individual/Pvt. Ponds	Govt. Reservoir/ Dams	Govt.	Pvt.	Community/ Govt.	Pvt.	Govt.	Pvt.						
Erattupetta				60					100		60	475.86	320	250	125.86	695.6	695.86
Kanjirappally				10	2.6			5	200		130	307	400	164	98	692	692
Pallom*			12.6	60				8	240		30	2326.4	1100	120	1347	2647	2647
Ettumanoor*		400	295	68	0	0	0	0	480	0	14	8438	799	548	6438	9681	7681
Lalam				90					300		60	323					
Uzhavoor*	200			40			20		300		15	620	650	500	45	1195	1195
Kaduthuruthy*	2636			35					112		34	480.92	1297.8	1000	1500	3297.8	2797.8
Vazhoor				79			23		200			223.8	395	100.8	30	525.8	525.8
Pampady			28	35					500		30	396.99	500	321	168.99	989.99	989.99
Madappally*			50	56		5		10	1000	25	20	1778	1514	30	1200	2944	2744

*Partly covered blocks; Figures given for entire block area (Source: District Irrigation Plan, Kottayam)

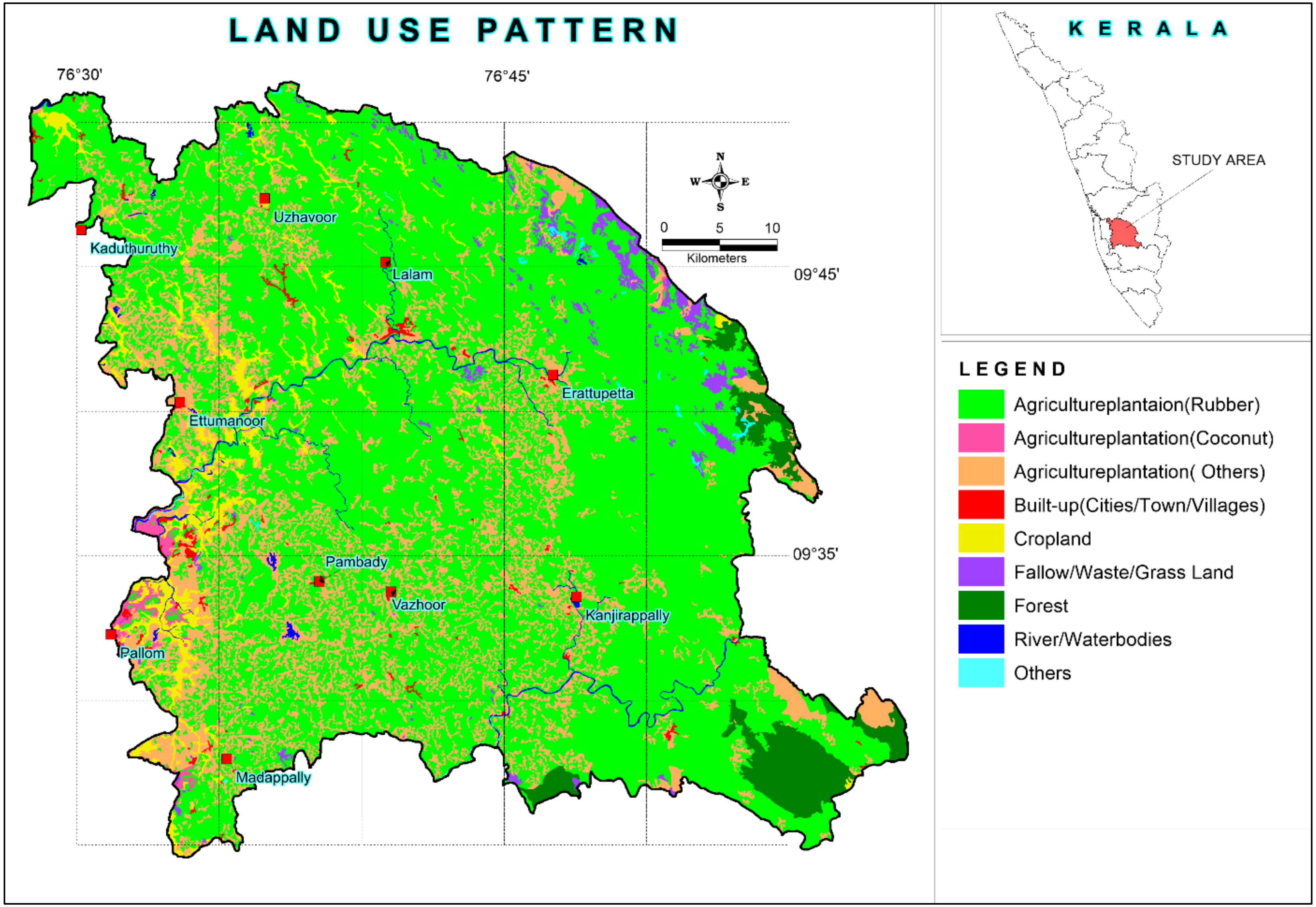


Fig.1.5: Land use pattern in the study area

Table 1.4: Change in waste, fallow and current fallow lands in Kottayam district

#	Year	Cultivable waste	Fallow other than current fallow	Current fallow
1	2005-06	2712	3011	5538
2	2006-07	7231	3595	4061
3	2007-08	6577	3372	3885
4	2008-09	5384	2839	3054
5	2009-10	4711	3173	5418
6	2010-11	4890	3046	5808
7	2011-12	8700	5186	6646
8	2012-13	5686	3305	5835
9	2013-14	6245	3108	6126
10	2014-15	6569	2610	5722
11	2016-17	7273	2518	4765

1.7 Drainage and Drainage Characteristics

The study area is occupied by 4 drainage basins viz. Meenachil,Manimala, Muvattupuzha and Pamba with the percentage of the total district area as 60%, 28%, 9% and 3% respectively. The important rivers in the study area are Meenachil and Manimala.

The Meenachil river originates from the Western Ghats and drains into the Vembanad lake. The total length of the river is 78 km and the drainage area 1272 sq.km. Meenachil river is a 6^{th} order stream with a stream gradient of 13.7m/km.The drainage pattern in general appears to be dendritic. There is one Central Water Commission (CWC) Hydrological Observation Station at Kidangoor on this river. Also there exists 4 gauge and discharge (G&D) stations maintained by Kerala state government at Cheripad, Palai, Peroor and Teekoy. The average annual stream flow in the river is about 1059 MM^3. There exists no major irrigation project in the basin.

The Manimala riveris a 90 km long river in south and central Kerala. Though the river is a tributary of Pamba River, it is considered a separate river for geographical purposes. It has its origin on the Muthavara Hills (2500 feet above main sea level) on the Western Ghats, in Idukki district. The drainage basin area is 847 sq.km. Manimala river is a 6^{th} order stream with a stream gradient of 12.84 m/km. There is oneCWC Hydrological Observation Station at Kallooppara on this river. Also there exist 3 G&D stations maintained by Kerala state government at Manimala, Mundakkayam and Thondra. The average annual stream flow in the river is about 1560.74 MM^3. There exists no major irrigation project in the basin. Map showing the drainage pattern of the study area is shown in fig. 1.6.

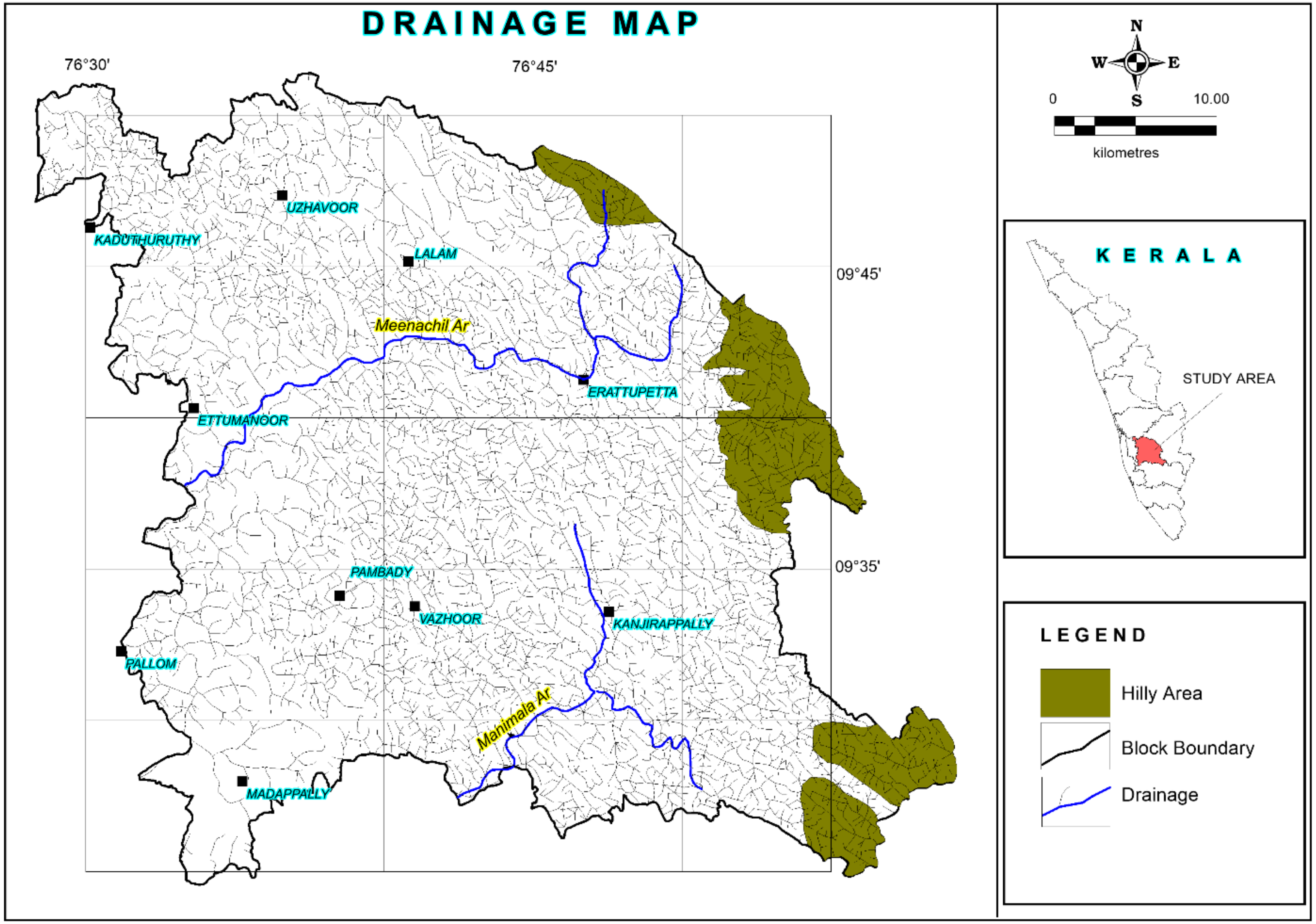


Fig.1.6: Drainage pattern in the study area

The Muvattupuzha Valley Irrigation Project (MVIP) is the main irrigation project having canal network in the district. The project envisages the utilization of the tail race discharge from the Moolamattam power house of the Idukki Hydro Electro Project by constructing a dam across Thodupuzha river at Malankara. The water from the reservoir is intended to irrigate the cultivable command area in Ernakulam, Idukki and Kottayam districts through its left and right bank canal system. The project was partially commissioned in 1994 and is yet to be completed. Dam and connected works are completed. In addition to irrigation purpose, the project envisages to supplement canal water for drinking water supply schemes, industrial benefit to the Hindustan News Print Factory, generation of hydel power at the toe of the dam with an installed capacity of 10.5MW. The project MVIP consists of two canal system on the right bank and the other on the left bank. The left bank main canal is 37.10km long and has five branches namely Murady, Ramamangalm, Piravom, Mulakkulam and Ettumanur. The left bank canal supplies water for irrigation in Kottayam district, particularly in the north-western part. The right bank main canal is 28.33km long has only one branch canal; Muvattupuzha branch. Total ayacut comes to 36129Ha. Since 1994, water distribution is being carried out in the completed stretches of canals. Out of the 36129 Ha potential envisaged through the project, 32308 Ha has been created till date. Since some intervening missing links could not be completed till date, the gross potential achieved through the project is 25959 Ha.

1. 8 Geology

Geologically major part of the study area comprises Precambrian metamorphic rocks and forms hilly grounds in the eastern part. The central to western part of the district is a low plateau, where Tertiary sediments containing lignite occurs. These are followed in the further west by a low plain, which is underlain by Quaternary Formations, fluvial or partly marine. The Charnockite Group dominates in areal distribution with charnockite, charnockite gneiss and diopside gneiss occupying the major part. Pyroxene granulite (with hornblende granulite), magnetite quartzite and cordierite gneiss occur as concordant bands within charnockite. The linear bands of quartzite (Khondalite Group) are the oldest rock of the area. Biotite gneiss (composite gneiss) representing the Migmatite Complex has a limited areal extent, west of Ettumanoor and along the eastern boundary. Three major granite bodies are emplaced in the district, two along the southwest and other in the east. Numerous dolerite and gabbro dykes trending NW-SE traverse the older basement rocks in the central and eastern parts. A prominent gabbro dyke extends from north to south with NNW-SSE trend. Tertiary sediments comprising sandstone, clay with lignite intercalations are confined to the west and they occur as small patches, especially as capping on hillocks. Both the Archaean and Tertiary rocks are lateritised. Quaternary alluvial deposits occur at the western part of the study area. The general stratigraphic succession of rocks in Kottayam district is given in table 1.5 and its spatial distribution is depicted in fig 1.7.

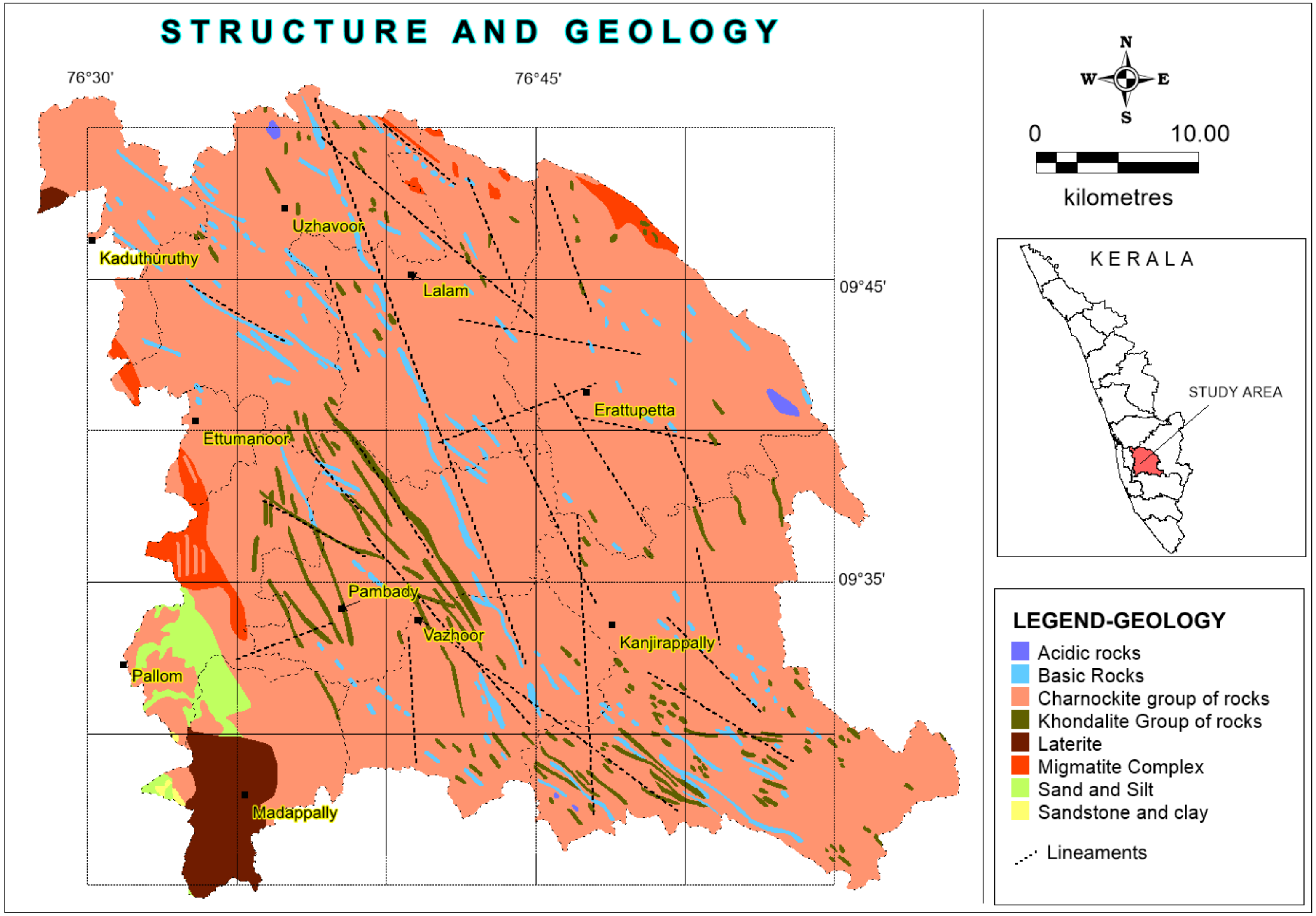


Fig.1.7: Geology of the area

Table 1.5: The Regional Geological Setting in Kottayam district

ERA	AGE	FORMATION	LITHOLOGY
QUATERNARY	Recent	Alluvium	Sands and clays along the coast, flood plain deposits, river alluvium and valley fill deposits.
	Sub-recent	Laterites	Laterites and lateritic clays derived from Tertiary sediments and crystalline rocks.
TERTIARY	Lower Miocene	Warkali beds	Sandstone and clay with thin bands of lignite.
-------------------------------------Unconformity--------------------------------------			
	Undated	Intrusives	Dolerite, gabbro, Pegmatites and Quartz veins.
PRE-CAMBRIAN	Archaean	Migmatite Group Charnockite Group Khondalite Group	Granite gneisses, charnockite, Biotite gneisses and Garnet Sillimanite gneiss, graphite gneiss.

1.9 Previous Work

A number of scientific studies have been carried out by various scientific agencies in this district. Central Ground Water Board has carried out systematic hydrogeological survey in the district during 1976-77 and 1978-79. The detailed groundwater balance studies were carried out during 1983-88 by SIDA assisted Coastal Kerala Groundwater Project (CKGWP). The groundwater exploration studies were carried out in western portion of district (in sedimentary formations) particularly at Kallara, Pyarattubhagm, Udayanapuram and Kuleseakaramangalam during the CKGWP project and ten numbers of bore well were drilled in the hard rock formation. After that during AAP 2011-12 eleven exploratory bore wells were drilled in Kottayam district. In addition to that, during AAP 2018-19 four exploratory wells were drilled in the hard rock terrain. The reappraisal hydrogeological studies were carried out in several phases and the recent study was carried out during 1996-97 and 2005-2006.Again, western part of Kottayam district falling in the Kuttanad Wetland System having an area of 553.44 sq.km was selected for the first National Aquifer Mapping (NAQUIM) studies in Kerala state along with other parts of Kuttanad in the year 2012-13. Part of Ettumanoor, Kaduthuruthy, Madappally, Pallom and Vaikom blocks were covered under this study.

2 DATA COLLECTION, GENERATION AND INTERPRETATION

2.1 Data collection and Data Gap Analysis

The historical or available data of the study area on Geology, Geophysics, Hydrogeology and Hydrochemistry generated under various studies carried out by the CGWB such as systematic hydrogeological studies, reappraisal hydrogeological studies, groundwater management studies, exploratory drilling and special studies have been utilized for data gap analysis in conjunction with the data collected from various State and Central government departments. The thematic layers on drainage, geomorphology, land use and land cover were reproduced from the data obtained from concerned State Government departments. The existing data on various themes are analysed for finding the data gaps is given in Table 2.1 and the results of the data gap analysis are described in detail in subsequent sections.

Table 2.1: The data availability for data gap analysis

#	Item	Data Available with State/Central Govt. Agencies	Data Available with CGWB	Total	Data Gap	Data Generated
1	GW level Data	21DW+25 PZ	66 DW+5 PZ	152	35	35
2	GW quality data	46	DW-14, BW-9	104	35	35
3	Bore hole Lithology Data	0	21	25	4	4
4	Geophysical Data (VES)	0	26	64	38	38
5	Pumping Test (EW)	0	8	9	1	Nil
6	Land use and Land cover	Kerala State Land Use Board				
7	Drainage	Kerala State Land Use Board				
8	Geology	Geological Survey of India				
9	Soil	NBSS &LUP				
10	RF and Meteorological Data	IMD and IDRB				

2.1.1 Water Level Monitoring

Water level monitoring wells maintained by CGWB and State Groundwater Department (SGWD) in the area have been made part of the monitoring network for the present study. A total of 66 dug wells are presently monitored by CGWB and 21 dug wells by SGWD for water levels in the phreatic aquifer system. Also there exists 30 piezometers in the study area (5 maintained by CGWB and 25 by SGWD, Kottayam). CGWB wells are being monitored four times (January, April, August and November) in a year whereas the wells of the State Groundwater Department (SGWD) are being monitored on monthly basis. The status of water level monitoring wells of CGWB in the area is listed in Table 2.2. The historical data from these stations have been used for data gap analysis and identified 35 new sites to fill up the data gaps. Measurements of water levels in wells are necessary for the evaluation of the quantity of groundwater and its interaction with surface water and rainfall. Water level is the vital indicator of the status of groundwater resource. The details of the GWMWs and KOWs are given in annexures I & II respectively.

Table 2.2: The status of water level monitoring wells of CGWB

Administrative block	Central Groundwater Board	
	Dug well	Piezometer
Erattupetta	9	1
Kanjirappally	10	--
Pallom	7	1
Ettumanoor	1	1
Lalam	4	--
Uzhavoor	11	1
Kaduthuruthy	1	--
Vazhoor	10	--
Pampady	6	--
Madappally	7	1
Total	66	5

2.1.2GroundwaterExploration

Information on aquifer geometry, groundwater potential of fracture aquifer systems and their characterization are primarily inferred from exploratory drilling data. The basic data from 21 exploratory drillings in the area is used for data gap analysis and based on this study data gaps were identified for 4 more exploratory wells. The lithologs of these wells are given in annexure-III. Information on weathered thickness and depth of occurrence of fractures are also deduced from geophysical data such as vertical electrical sounding (VES) and profiling. However exploratory drilling is inevitable in deciphering the lithology and the depth of occurrence of deeper fractures as the depth of penetration of VES being comparatively less. The consolidated lithologs of all the EWS drilled in the study area are given in Annexure -III and a concise of the outcomes of exploration are given in Annexure-VI.

2.1.3 Vertical Electric Soundings (VES)

Geophysical data on VES are used to extract information on the weathered thickness, depth of occurrence of fractures etc. The aquifer geometry could be refined from the interpretation of geophysical data in conjunction with the available lithological logs from exploratory drillings. Geophysical methods are normally employed as a reconnaissance study before exploratory drilling as the cost of geophysical investigation is much less when compared to exploratory drilling. VES data for 26 locations are used for data gap analysis. Based on the study data gap of 38 additional VES sites were identified. The details of VES carried out in the study area are given in annexure IV.

2.1.4 Water Quality Monitoring

The historical data on water quality in the area is available from the water level monitoring stations maintained by CGWB. Water sampling is being done every year from these wells during pre-monsoon period (April). CGWB maintains 14 water quality monitoring stations in the hard rock terrain of Kottayam district to monitor the quality changes in the shallow aquifer. Also, SGWD maintains 46 water quality monitoring stations in the area. The data gap analysis has been carried out to find out the adequacy of information on water quality and identified 35 new locations for additional sampling.Water quality data of 57 samples collected from GWMWs, KOWs and exploratory wells in the study are given in Annexure-V.

2.1.5 Rainfall

Rainfall pattern of the district is in such a way that it receives rainfall in almost all months of the year. The study area receives both southwest and northeast monsoon. The district normally gets an annual average rain fall of 3130.33 mm. The average number of rainy days in the district is 117. The Southwest monsoon contributes 62% of rainfall from June to September and the northeast monsoon contributes about 19%, remaining 19 % is received in the remaining months. The graph showing average annual rainfall in the district for the last 12 years is shown in the fig 2.1.

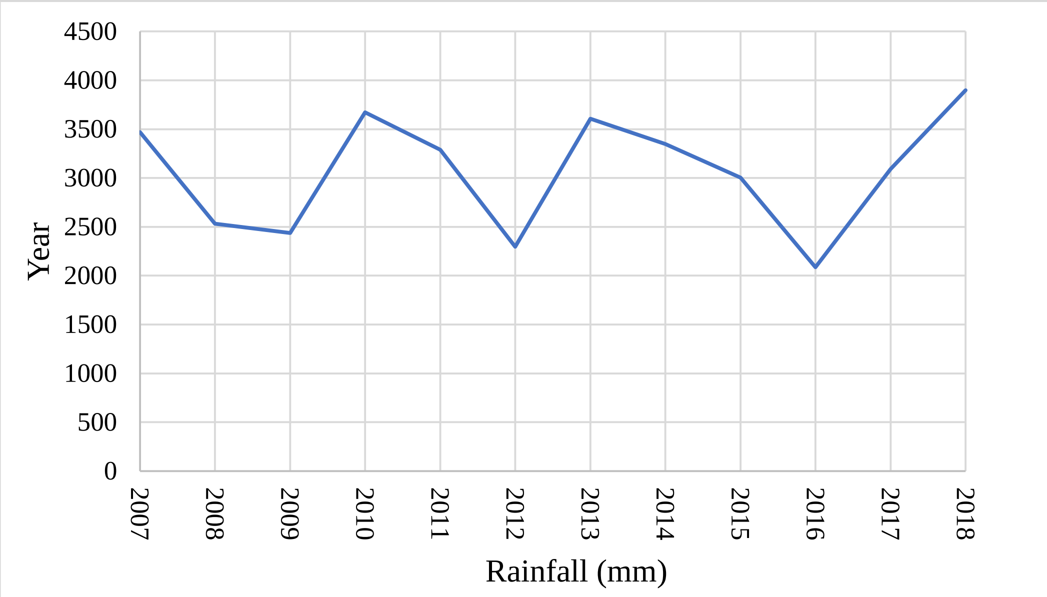


Fig.2.1: Graph showing average annual rainfall versus year

The spatial variation in rainfall over the area is best represented by isohyets and is shown in fig. 2.2. Towards the eastern part of the study area normal annual rainfall increases due to altitude effect (up to 3600 mm at Kanjirappally). Lowest normal annual rainfall is reported at Ettumanoor in the western part of the study area (around 2300 mm). The mean monthly rainfall of Kottayam district for the last five years is shown in Table 2.3 and graphic representation of monthly rain fall for the last five years (2014-18) is given in fig 2.3.

Table 2.3: Mean Monthly rainfall of Kottayam district

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL
2014	11.1	18.7	45.2	145.3	303.6	496.8	490.9	805.1	313.4	468.4	156.5	94.8	**3349.8**
2015	9.1	4.4	131.7	301.7	239.9	615.5	306.8	293.1	374.1	402.9	203	122	**3004.2**
2016	11.5	43.7	72.5	56.5	318.7	630.6	431.1	198.6	70.4	154	90.7	7.7	**2086.0**
2017	27.8	0.2	128.3	58.2	315.9	654	342.3	450.3	482.4	287.3	267.4	79.1	**3093.2**
2018	0.2	5.1	38.3	245.1	403.1	814.3	921.6	617.1	54.1	389.5	344.2	65.2	**3897.8**

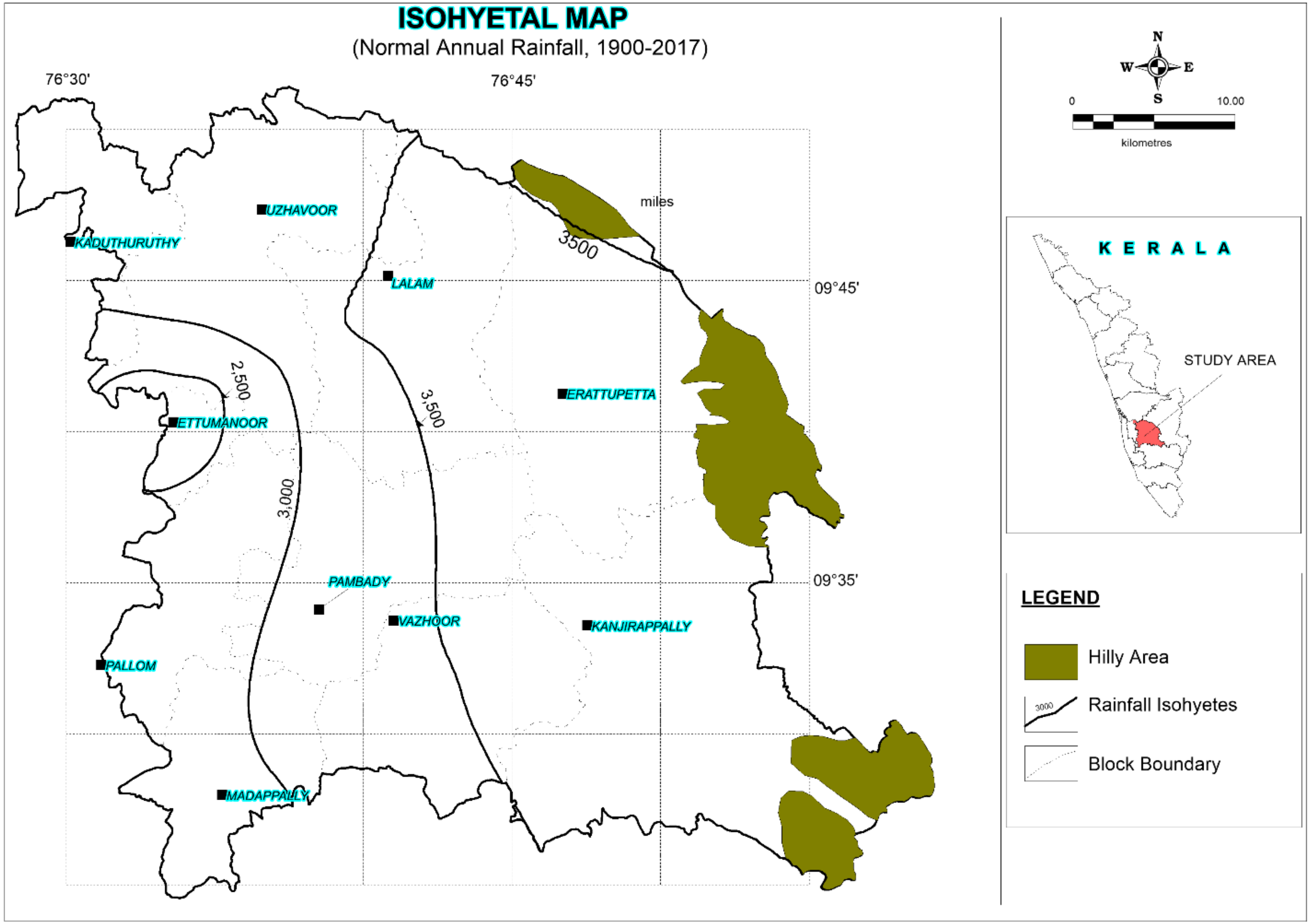


Fig.2.2: Rainfall isohyets in the area

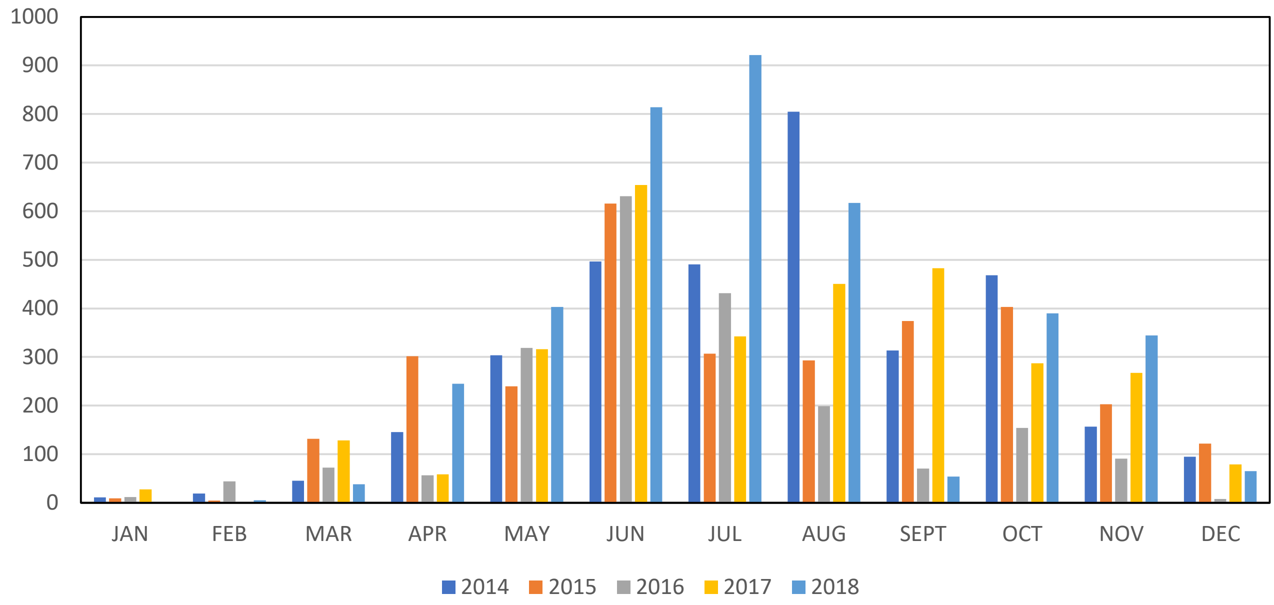


Fig.2.3: Graphical Representation of Mean Monthly Rainfall in Kottayam district

2.1.6 Soil Infiltration Tests

To estimate the infiltration rate of soil in the study area 2 double ring infiltration tests were conducted; one at Chengalam in Pampady block and another at Kozha in Uzhavoor block. A double ring infiltrometer requires two rings: an inner and outer ring. The purpose is to create a one-dimensional flow of water from the inner ring so that the analysis of data is simplified. If water is flowing in one-dimension at steady state condition, and a unit gradient is present in the underlying soil, the infiltration rate is approximately equal to the saturated hydraulic conductivity. An inner ring is driven into the ground, and a second bigger ring around that to help control the flow of water through the first ring. Water is supplied either with a constant or falling head condition, and the operator records how much water infiltrates from the inner ring into the soil over a given time period. The ASTM standard methodspecifies inner and outer rings of 30 and 60 cm diameters, respectively. Details of the tests are given in annexure-VIII.The infiltration rates are worked out to be 13.2 cm/hour at Chengalam (Akalakunnam Panchayath, Pampady block) and 15.06 cm/hour at Kozha (Kuravilangad Panchayath, Uzhavoor block).

2.1.7 Determination of storage parameter of phreatic aquifer

To estimate the storage parameter (Specific yield) of shallow/phreatic aquifer, data of a large diameter pumping test conducted by State Ground Water Department, Kottayam at Purappanthanam village in Erattupetta block of Kottayam district was used. As per the analysis by using Papadopoulos-Cooper curve matching (1963) method the specific yield has been worked out to be 2.6%. The details of the pump test analysis are given in annexure-VII.

2.2 Data Generation and Integration

The data gaps were identified from detailed analysis of existing data and based on the finding new data generated for the gaps. The activities include establishment of key wells, water quality monitoring wells, geophysical survey and aquifer evaluation (pumping tests). The data gaps identified and the new data generated under various themes are given in Table.2.4. The value addition made after data generation and integration of various components of the groundwater regime are described in the following sections.

Table 2.4: Data requirement and data generated under aquifer mapping

Themes	Existing data	Data Gap	Data generated	Total
Groundwater Monitoring Wells (GWMWs)	117	35	35	152
Exploratory wells (EWs)	21	4	4	25
Vertical Electric Soundings (VES)	26	38	38	64
Water quality	69	35	35	104
Pumping tests	8	--	--	9

Based on data gap analysis carried out in the area 4 additional exploratory wells, 38 vertical electric soundings (VES), 35 new key observation wells (KOWs), 35 additional water quality monitoring stations were established. The details of groundwater level monitoring wells are given in Annexure I (GWMWs) &II (KOWs). The combined (existing and new data generated) location maps of the water level monitoring wells (GWMWs and KOWs), VESs, EWs and water quality monitoring stations are given in figures 2.4, 2.5, 2.6 and 2.7 respectively.

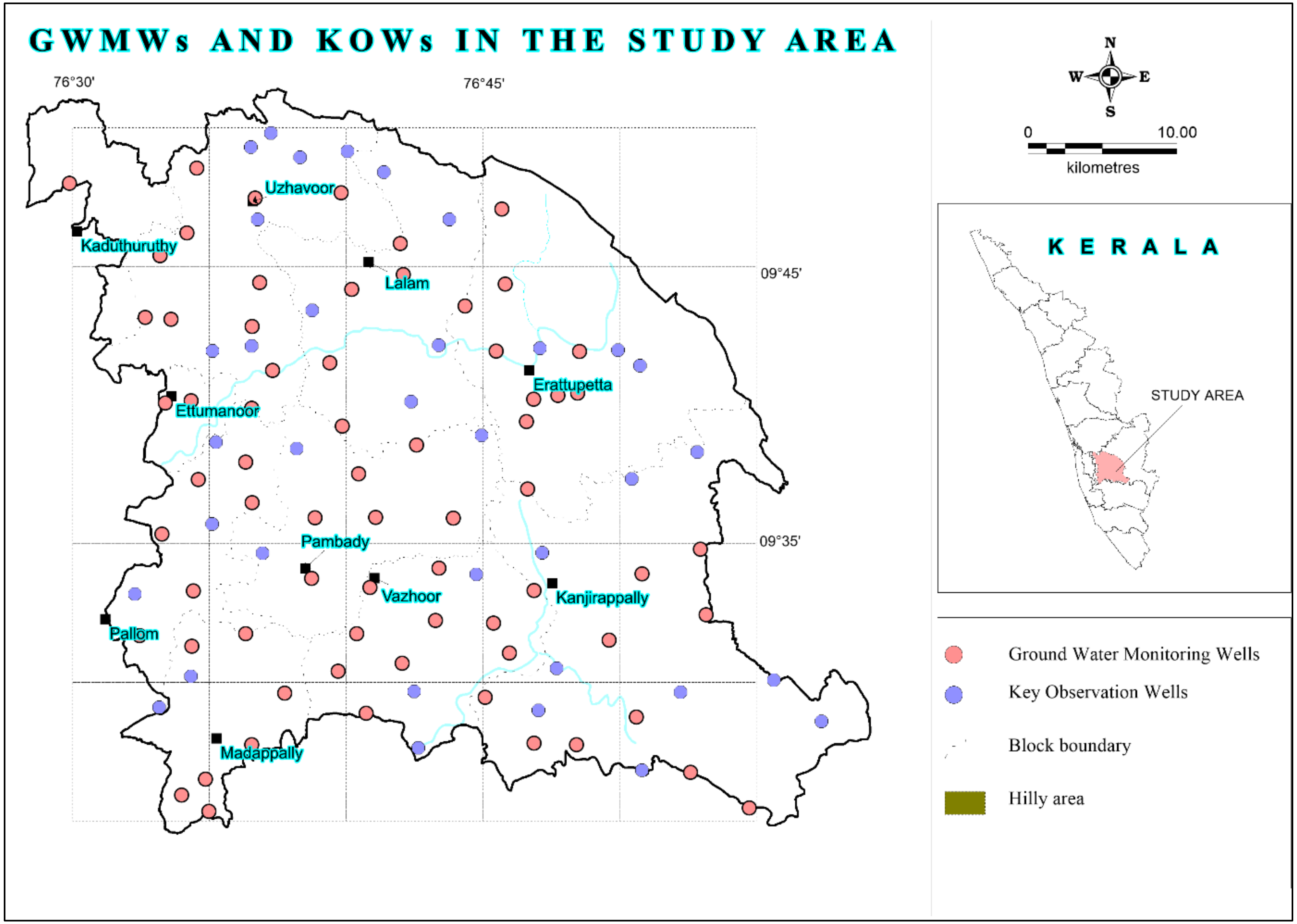


Fig.2.4: Location of water level monitoring wells (GWMWs and new KOWs established) in the study area

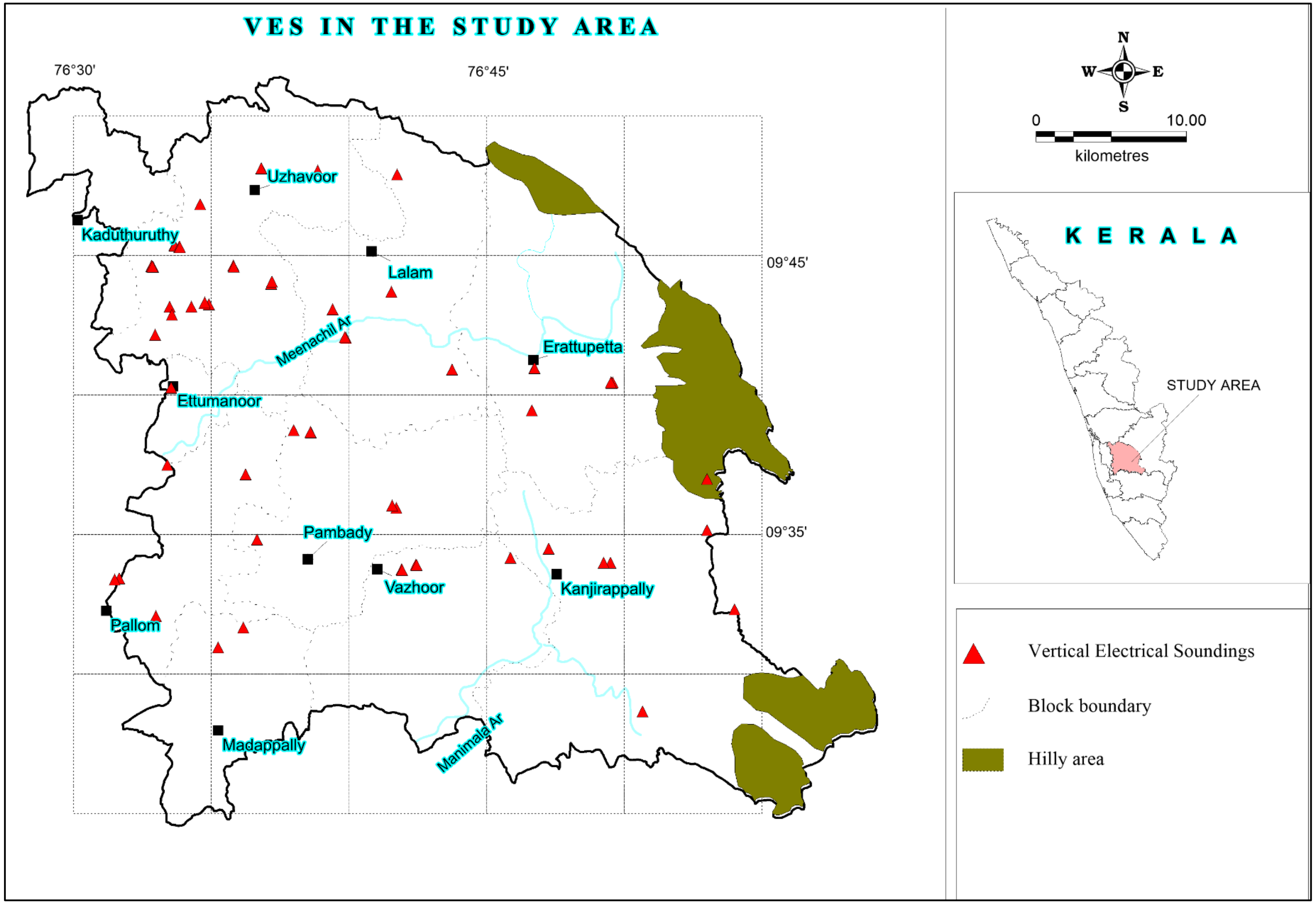


Fig.2.5: Location of vertical electric soundings (existing and new) in the study area

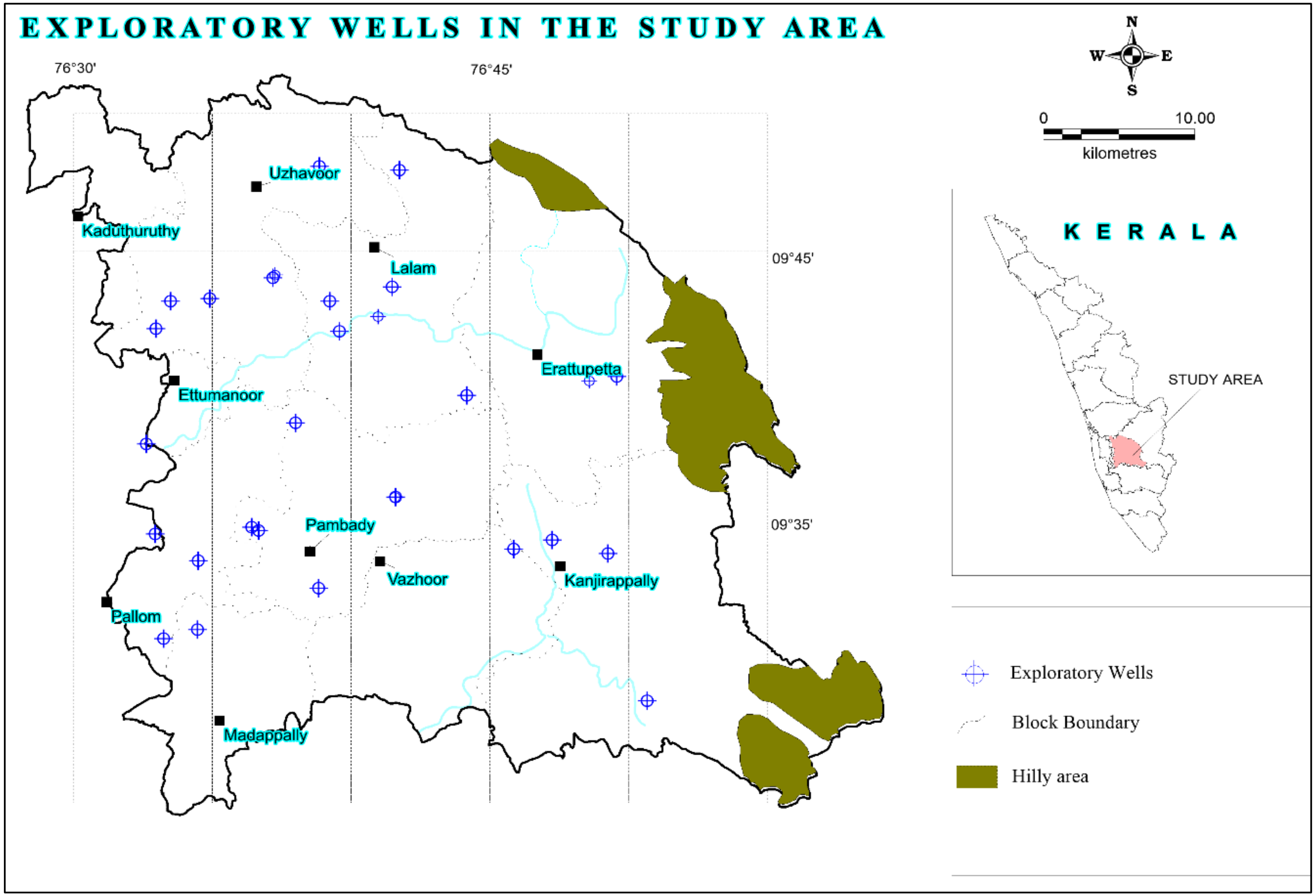


Fig.23.6: Location of exploratory wells (existing and newly constructed) in the study area

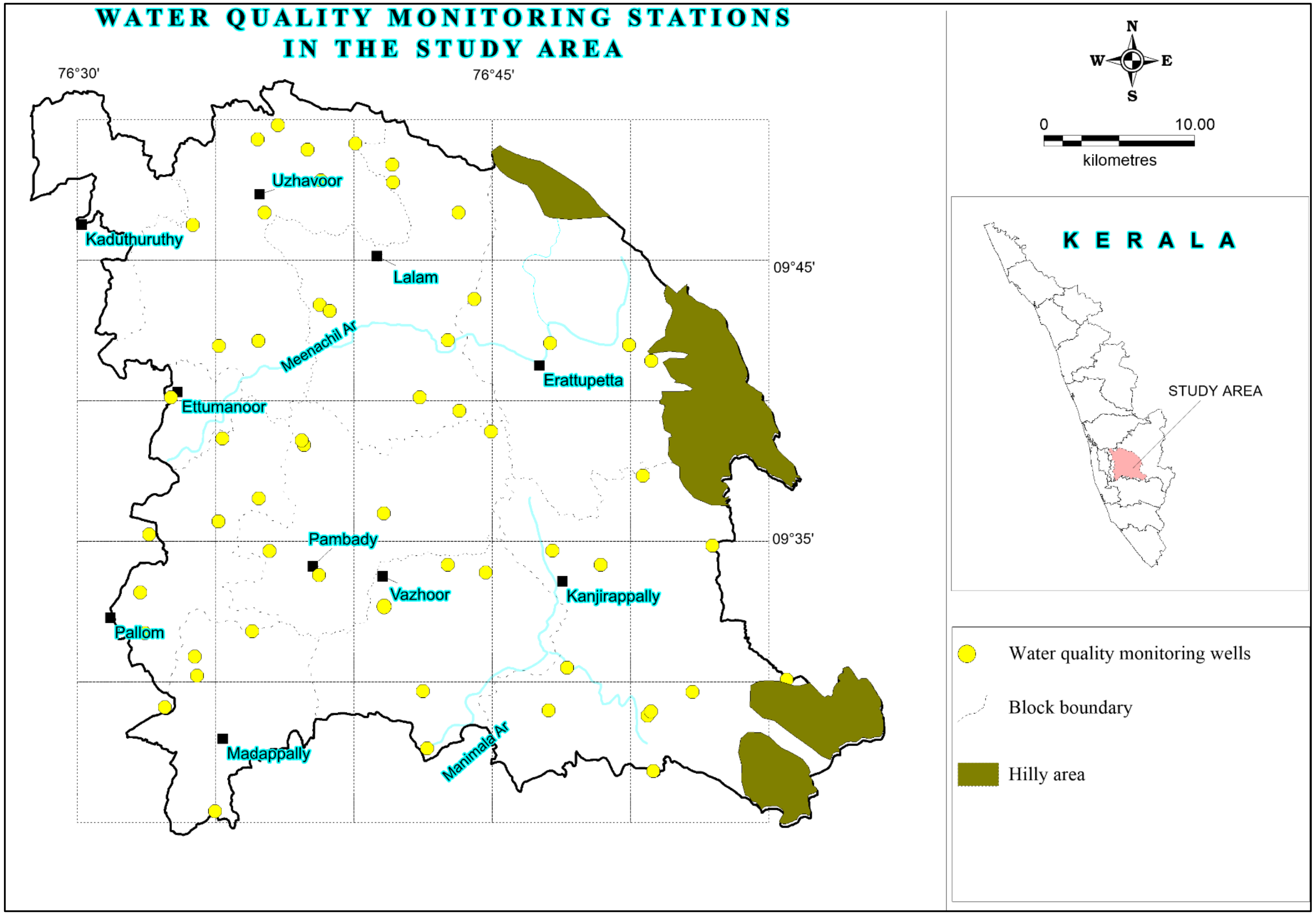


Fig.2.7: Location of water quality monitoring stations (existing and newly established) in the study area

3. AQUIFER MAPPING

The weathered zone (mainly laterites and fractured weathered Charnockite) and fractures in crystalline rocks form the repositories of groundwater in the area. Groundwater exists under phreatic condition in the weathered zone and shallow fractures and under semi-confined conditions in fracture systems. The weathered zone and the underlying deeper fractured zone are interconnected and groundwater extraction from the fracture system affects the groundwater levels in the weathered zone. Hence, the area is considered to have two aquifer systems which are interconnected but have different hydraulic properties. Thus, the aquifer systems are mapped as;

1. Phreatic Aquifer System (Aquifer I)

2. The Deeper Fracture system (Aquifer II)

3.1 Phreatic aquifer system (Aquifer I)

The laterites and weathered Charnockites associated with shallow fractures form the phreatic aquifer system in the study area. The laterites of Sub-Recent age occur as a residual deposit due to weathering of crystalline rocks. The typical laterite profile seen in crystalline terrain consists of lateritic soil at the top followed by soft laterite, lithomargic clay and weathered zone. The occurrence and movement of groundwater in the weathered zone is mainly influenced by the depth of weathering gradient and topography. Groundwater abstraction structures in this zone include dug wells mainly and through shallow bore wells. The depth of dug wells in phreatic aquifer system ranges from 3.59 to 15.40 m bgl and that of bore wells up to the depth of 30-40m bgl. The water level ranges from 1.2 to 16.25 m bgl during the pre-monsoon period. During post monsoon period the water level ranges from 1.0 to 12.05 m bgl. The yielding capacity of phreatic aquifers varies spatially and temporally and is related to the aquifer characteristics, rainfall, surface water availability and thickness of weathered residuum.

3.1.1 Thickness of weathered zone

From the exploratory drilling data two aquifer zones were identified viz. the weathered zone (aquifer - I) and the fracture zone (Aquifer-II) below it. Weathered zone includes the weathered formation and the underlying shallow fractures and its thickness varies in the range of 2 to 29 m. Generally, the thickness of weathered formation is controlled by the degree of structural deformation happened in the terrain and the gradient. The more the structural deformation the more will be the degree of weathering. Also, as the gradient of the terrain increase, the thickness of weathering decreases. The weathered thickness in the area vary highly as observed from exploratory drillings and the data have been used to elucidate the lateral and vertical changes in weathered zone. The information from 25 bore wells and 64 VESs has been analysed for understanding the spatial variations in the thickness of weathered zone. The thickness of the weathered zone generally decreases towards the eastern part of the study area, where it becomes less than 5m on an average mostly. In the western and central parts, the thickness is relatively more and goes up to 20 m at places. The Spatial variations of weathered zone thickness in the area are given in Fig 3.1.

3.1.2. Water levels

Water level is a direct indicator of the availability of groundwater resources in an area. Measurements of water levels in wells are necessary for the evaluation of the quantity of groundwaterand its interaction with surface water and rainfall. The water levels of 71 GWMWs of CGWB (66 dug wells and 6 Piezometers) were taken four times in a year (April, August, November and January). The water levels of the 35 newly established KOWs were taken during pre- and post-monsoon periods, i.e. during April and November. The water level data of GWMWs and KOWs are given in annexure I & II respectively.

The water levels in the phreatic aquifer were analysed for pre-monsoon (Fig. 3.2) and post-monsoon (Fig. 3.3) seasons and the depth to water level maps were prepared. Analysis of the pre-monsoon water level map shows that major part of the study area shows water levels in the range of 5 to 10 m bgl followed by 2-5 m bgl. But during post-monsoon the scenario reverses, i.e. major part came under 2-5 mbgl followed by 5-10 m bgl levels. Deeper water levels (> 10 m bgl) are found as isolated patches during both the seasons. The shallow water levels during post monsoon indicate the effect of rainfall recharge to the groundwater regime.

Water level fluctuation in the wells in an area between pre- and post-monsoon period is indicative of the net changes in the groundwater storage in response to the recharge and discharge components and is an important parameter for planning sustainable groundwater development and management. Major part of the study are experiences rise in water level in the range of 0-2 m. Fall in water levels in the range of 0-2 m is observed along the eastern, north-eastern parts of the study area. Even though the area receives an average annual rainfall of 3130 mm, major part of the study area has got water level fluctuation in the range of 0-2 m due to limited aquifer storage space. Hence, a major part of the district is not suitable for artificial recharge and all artificial recharge interventions should be site specific and on need basis. However, the watershed interventions for prolonged soil moisture retention and soil conservation are effective for the region as significant part of the terrain is undulating with high gradients. The lower plateau regions (see fig 1.4) where, water level is >5 m during both the seasons have ideal sites for artificial recharge.The study area shows a fall in water level from 2.7 to 0.04 m and rise in water level from 0.01 to 6 m; the fluctuation map is given in Fig.3.4. The water table elevation contour map (Fig 3.5) shows that the general flow of groundwater is towards the west. Also, the gaining nature of the streams (Influent) are also evident from the nature of the water table contours.

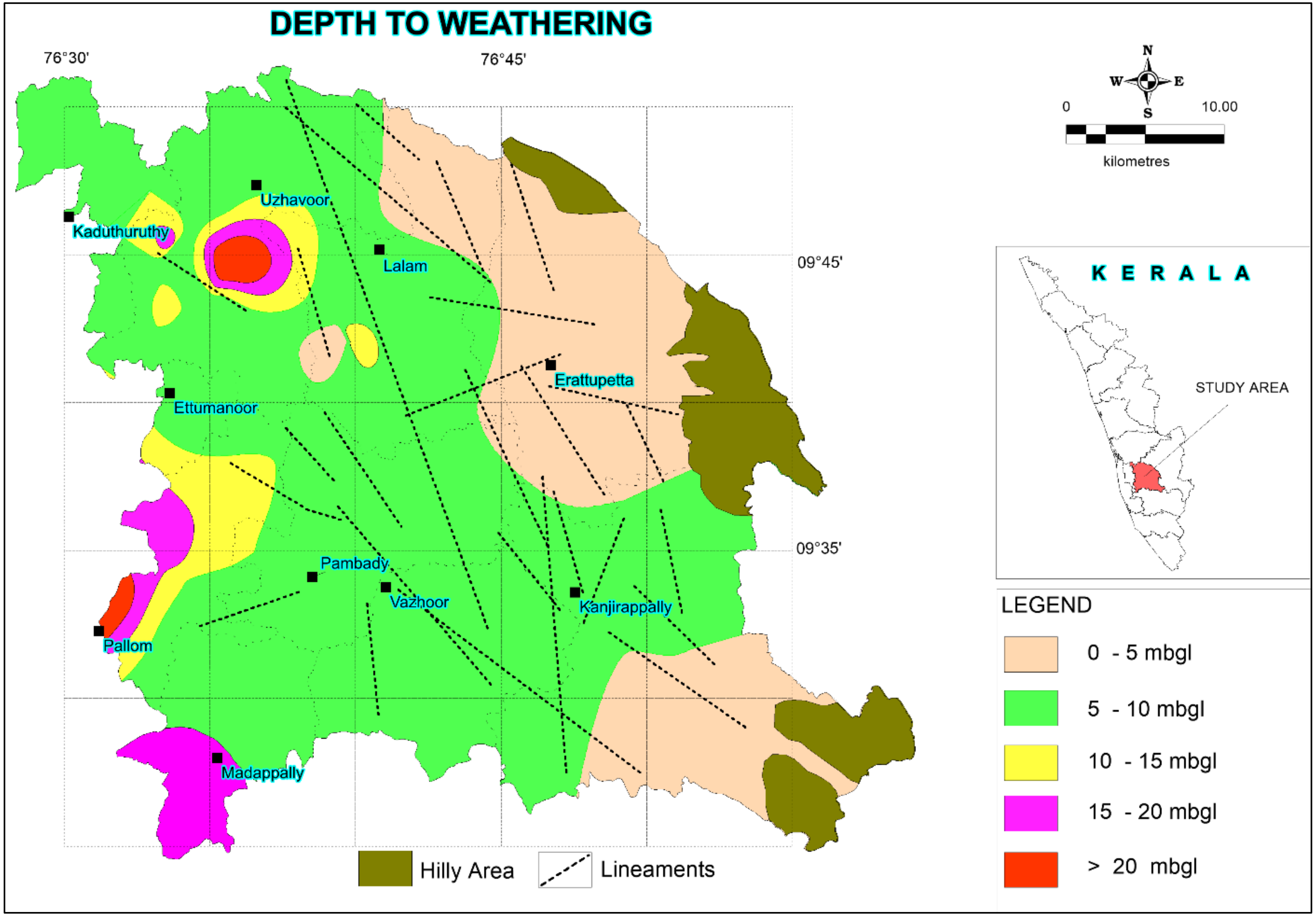


Fig3.1: Spatial variation of weathered zone thickness in the area

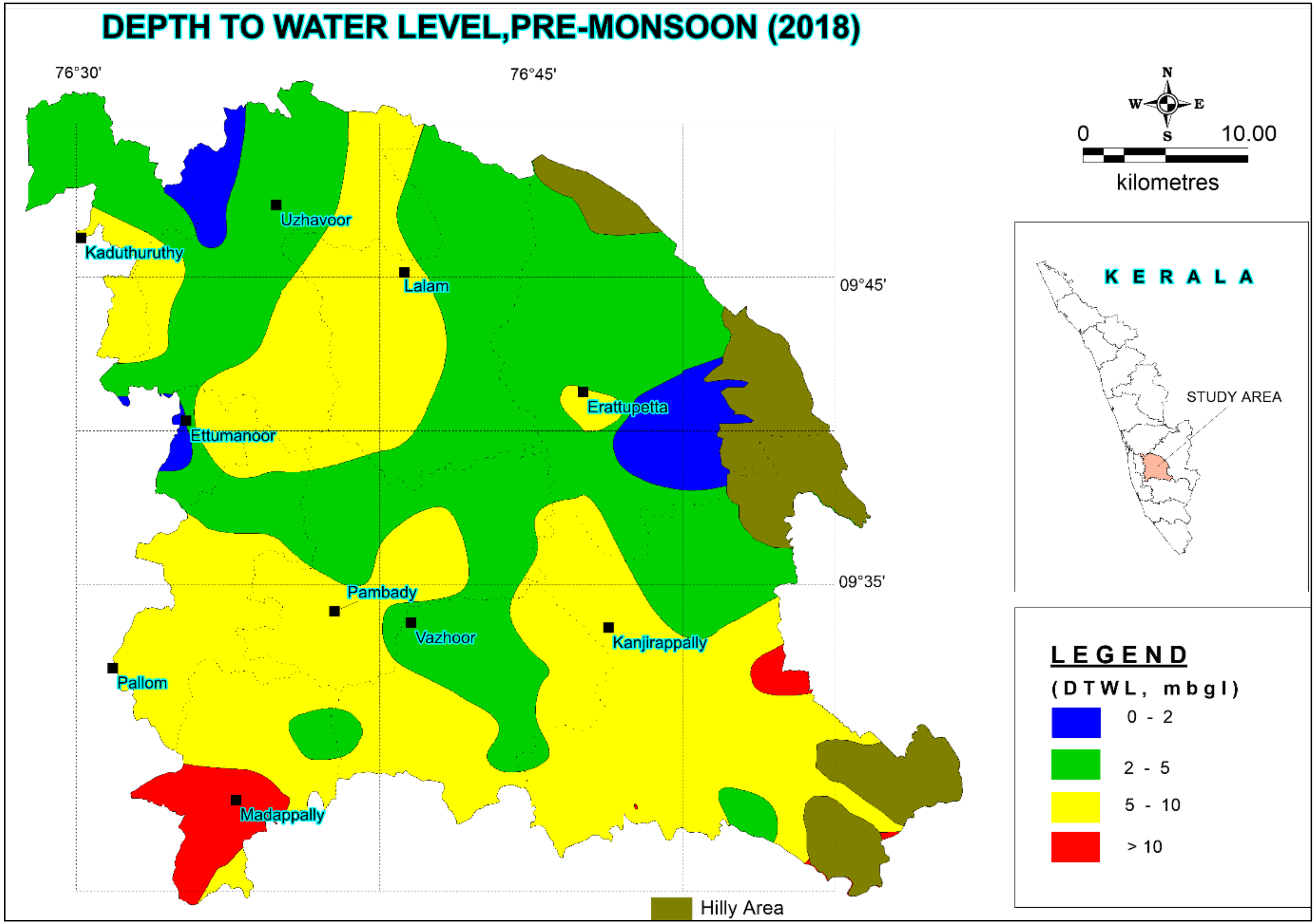


Fig.3.2: Pre-monsoon Water level map of Phreatic aquifer

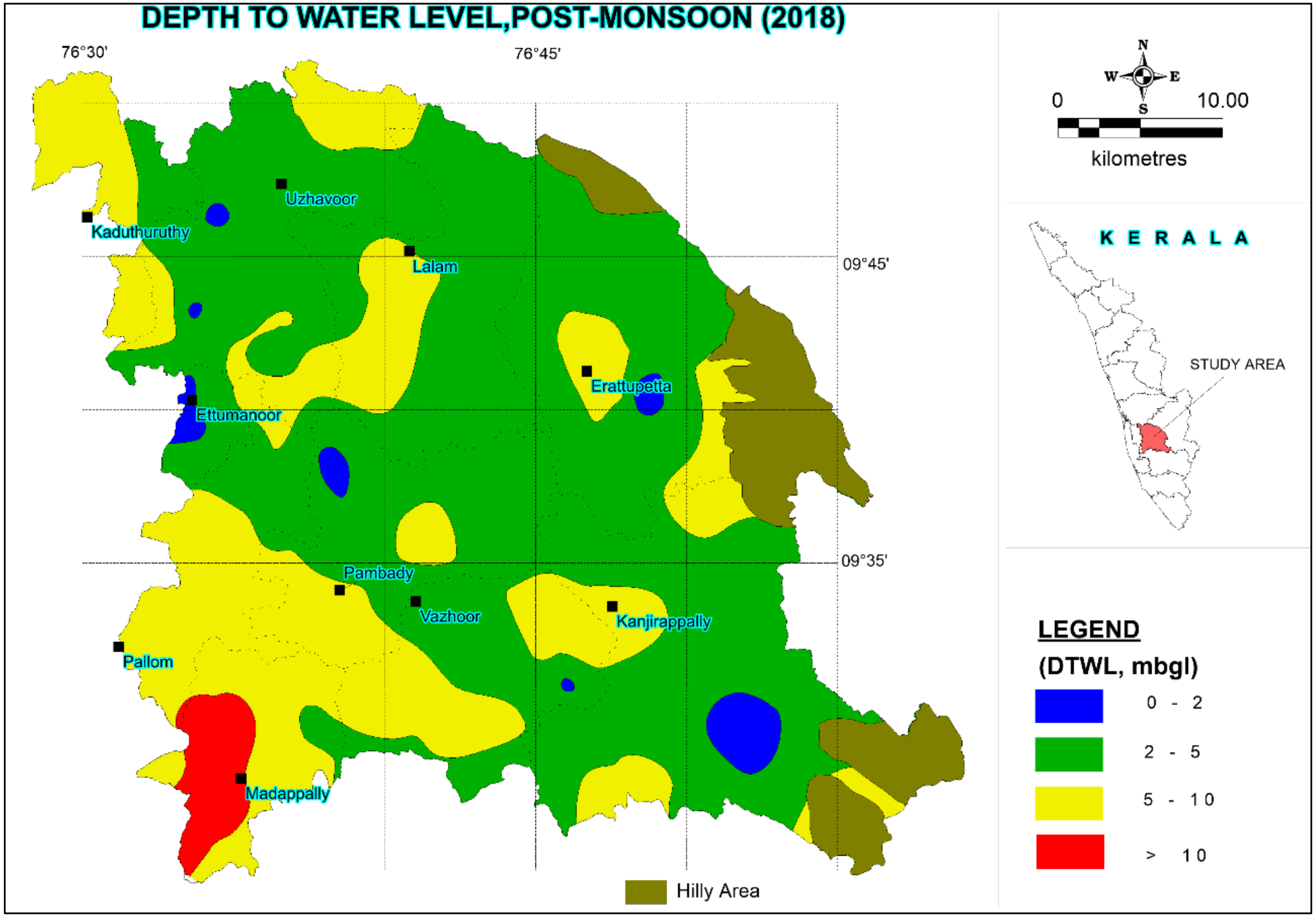


Fig.3.3: Post-monsoon Water level map of Phreatic aquifer

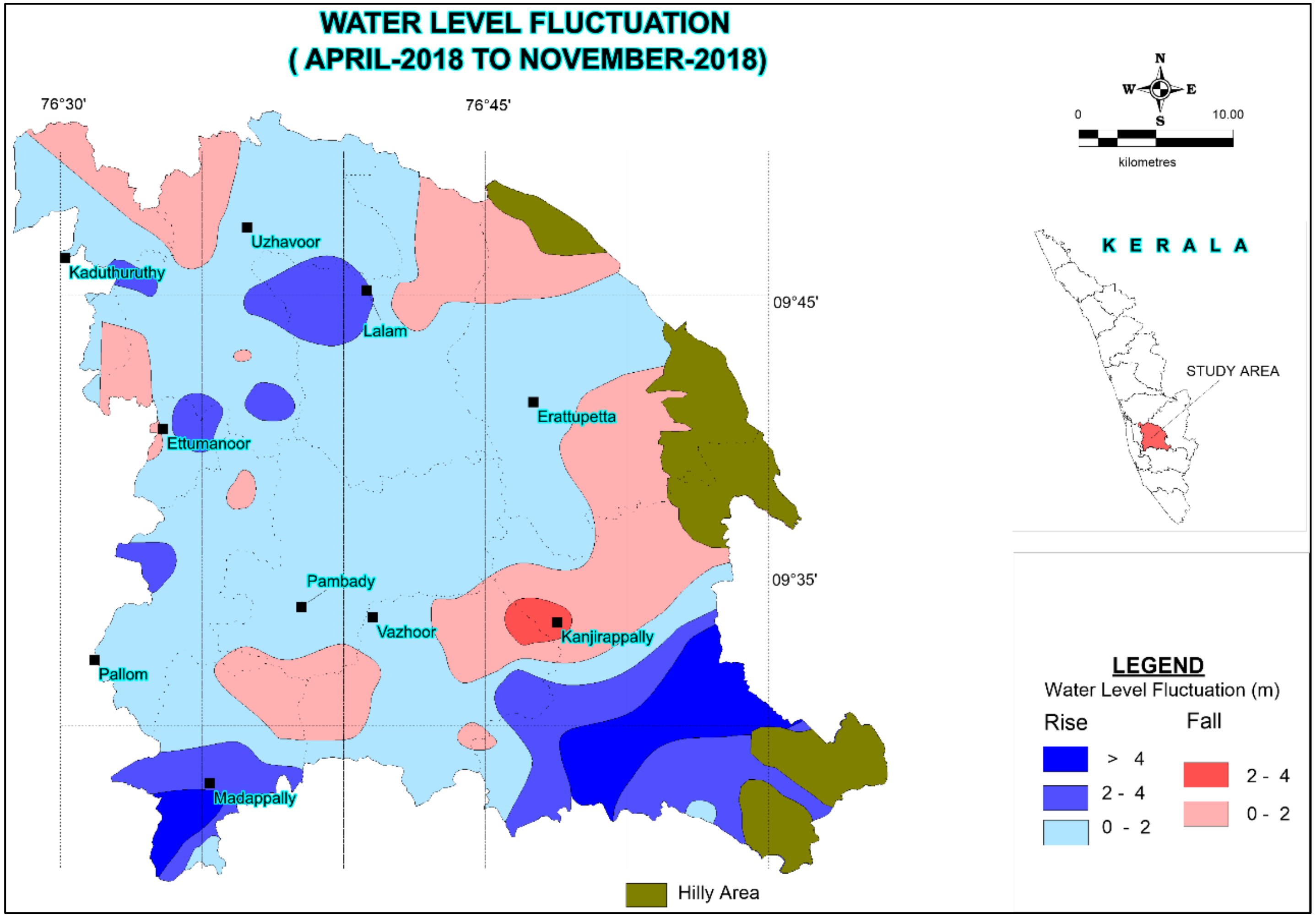


Fig.3.4: Water level Fluctuation map of Phreatic aquifer

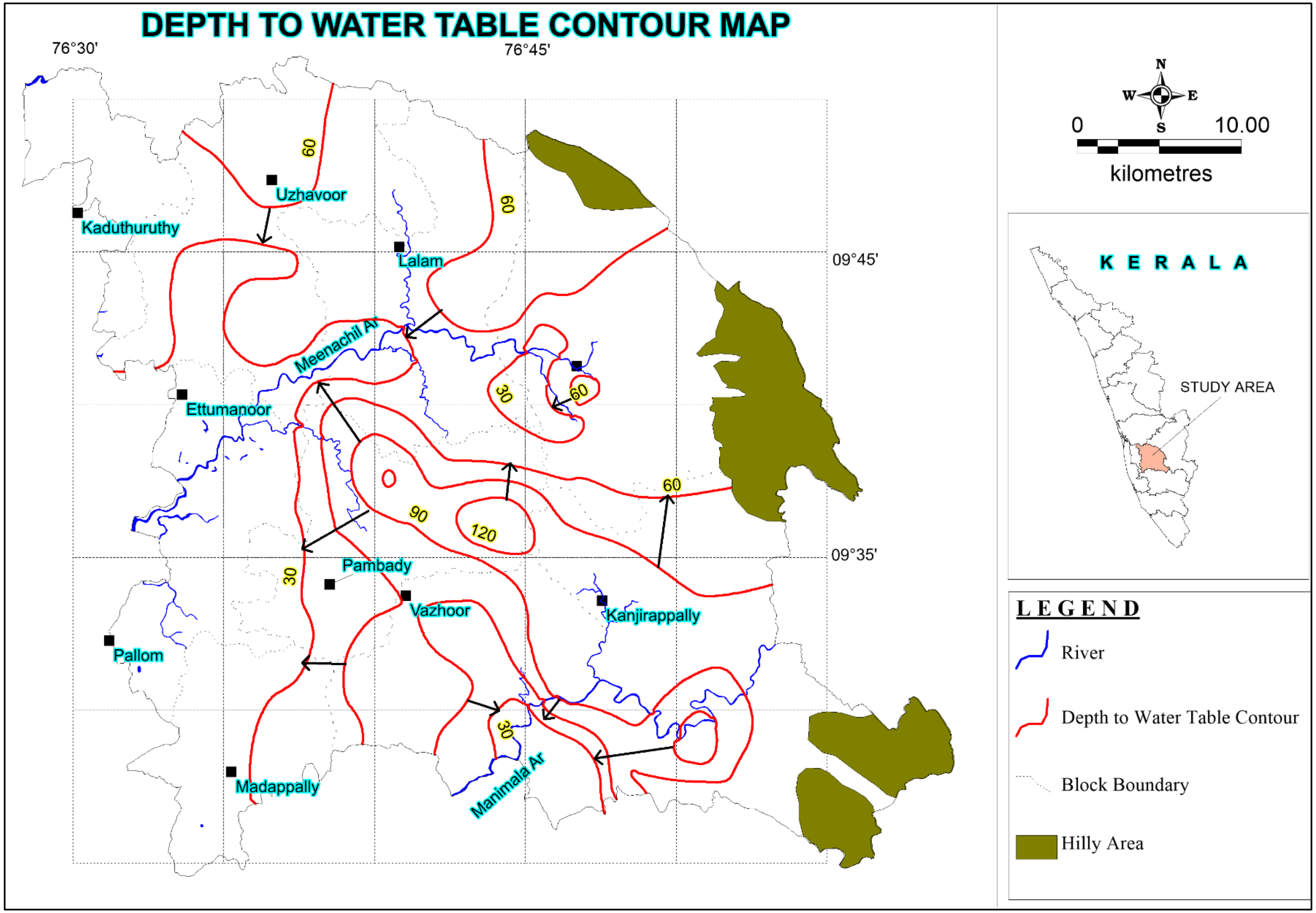


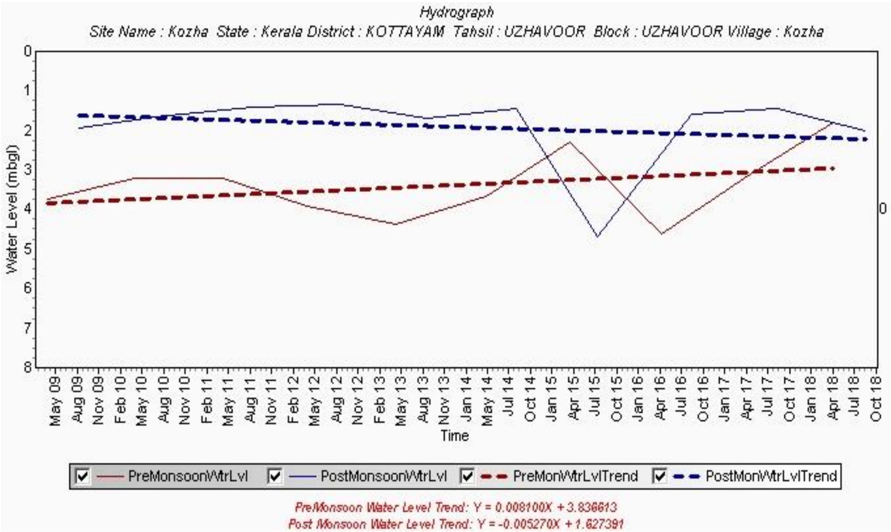
Fig.3.5: Water table elevation contour map of phreatic aquifer.

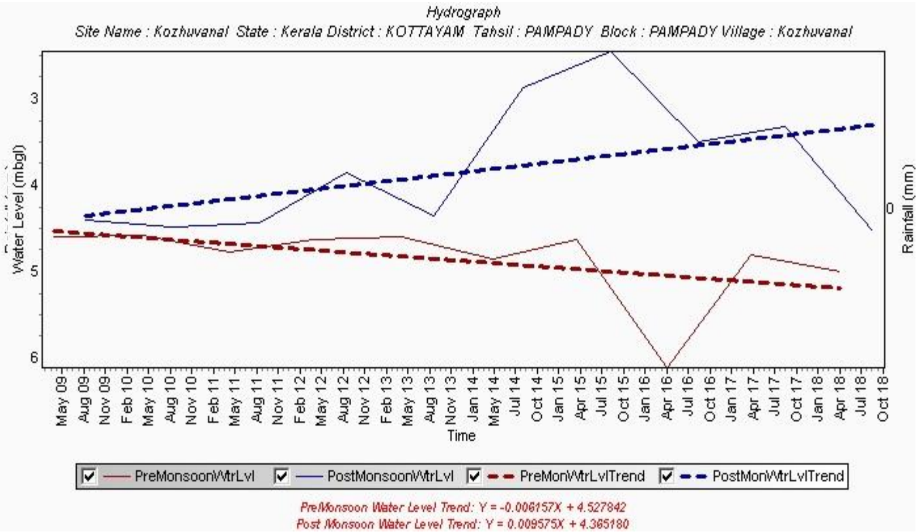
3.1.3. Water level trend

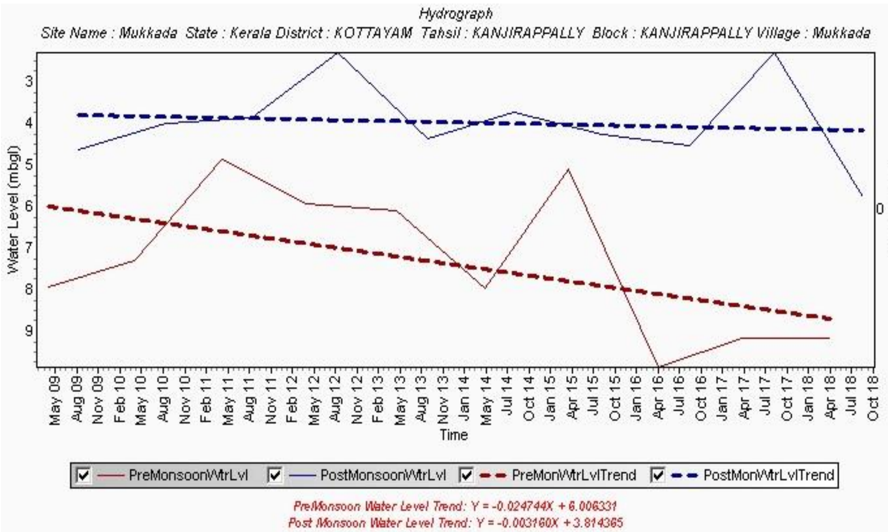
The variation in water level with reference to time and space is the net result of groundwater development and recharge. The long-term change in water level is apparent from the trend of water levels over a period of time and is best reflected in a hydrograph. The decadal trend (2009-2018) of groundwater levels, for pre-monsoon and post-monsoon periods is given below in table 3.1. Analysis of decadal trend shows that there is no major rise or fall in water level trends during both the seasons. Some of the hydrographs of representing the area are given in Fig. 3.6.

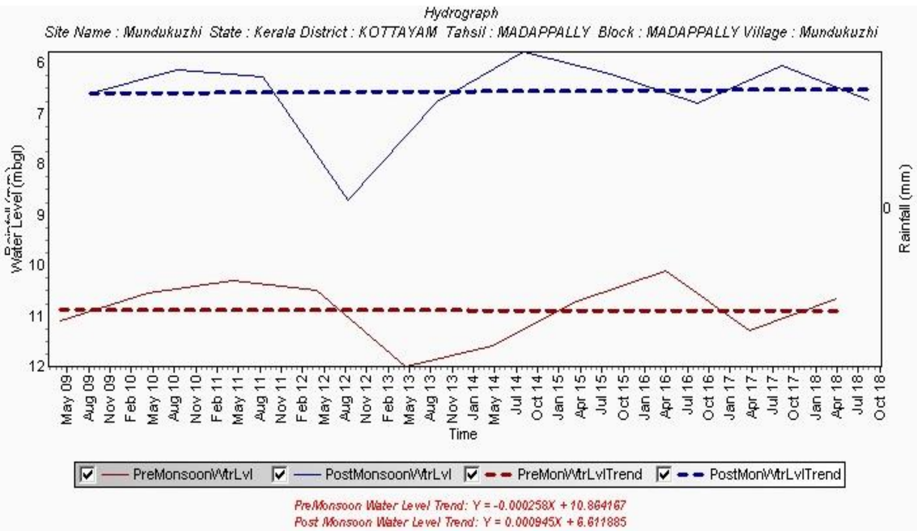
Table 3.1 Table Showing trend of the water level

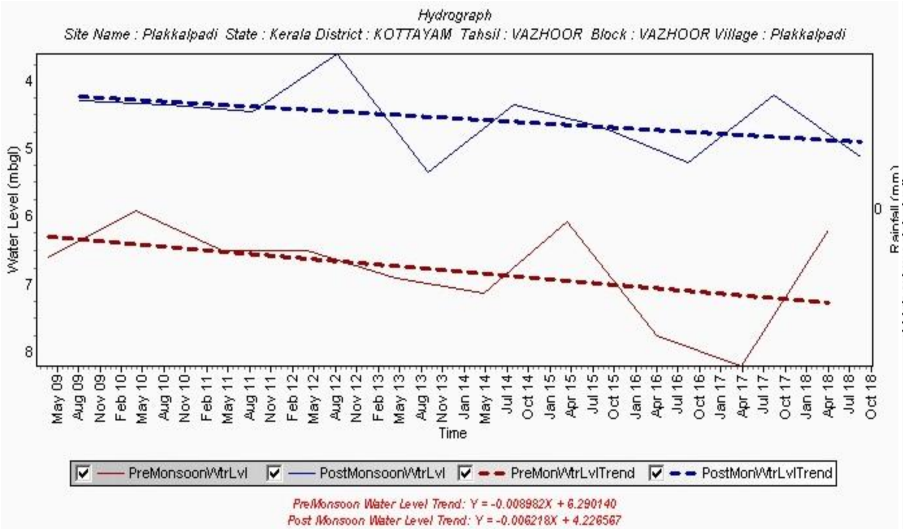
#	Location	Pre-monsoon			Post monsoon		
		Data points	Rise (m/year)	Fall (m/year)	Data points	Rise (m/year)	Fall (m/year)
1	Mundukuzhi	10	--	0.0030	11	0.0112	--
2	Mukkada	10	--	0.2926	11	--	0.0374
3	Erumeli	9	--	0.2010	8	--	0.1823
4	Plakkalpadi	10	--	0.1062	11	--	0.0735
5	Kangazha	10	0.0492	--	10	0.0258	--
6	Thottakkad	10	0.0928	--	11	--	0.1415
7	Thekethukavala	9	0.1766	--	11	0.0244	--
8	Kuvapalli	9	--	0.3315	10	--	0.2086
9	Mundakayam	9	--	0.4373	11	0.0193	--
10	Kanjirapally	10	0.1133	--	9	--	0.1076
11	Pambadi	8		0.2540	10	--	0.4609
12	Vazhur	9	0.0068	--	10	--	0.0694
13	Kottayam	10	--	0.0159	11	0.0584	--
14	Kalakatty	10	--	0.0482	11	--	0.0363
15	Urulikunnam	10	--	0.0885	11	0.2371	--
16	Kozhuvanal	10	--	0.0728	11	0.1132	--
17	Iykarakunnam	9	--	0.0033	11	--	0.0222
18	Ettumannur	7	0.0625	--	8	0.0592	--
19	Kidangur	10	--	0.1192	11	0.0919	--
21	Kidangoor	10	--	0.0461	11	--	0.0992
22	Poonjar	10	--	0.1573	10	--	0.1078
23	Palai	10	0.1872	--	11	--	0.0653
24	Vempally	10	0.0107	--	11	--	0.0053
25	Kalathur	10	0.0162	--	11	--	0.0339
26	Narianganam	9	--	0.0087	11	--	0.0844
27	Marangattupalli	10	--	0.0917	11	--	0.0217
28	Kuravilangad	10	--	0.0100	11	--	0.0890
29	Kozha	10	0.0958	--	11	--	0.0624
30	Ramapuram	7	--	0.2959	7	--	0.2870
31	Arunuttimangalam	7	--	0.0765	11	--	0.1231
32	Monipalli	10	--	0.0193	11	--	0.0645

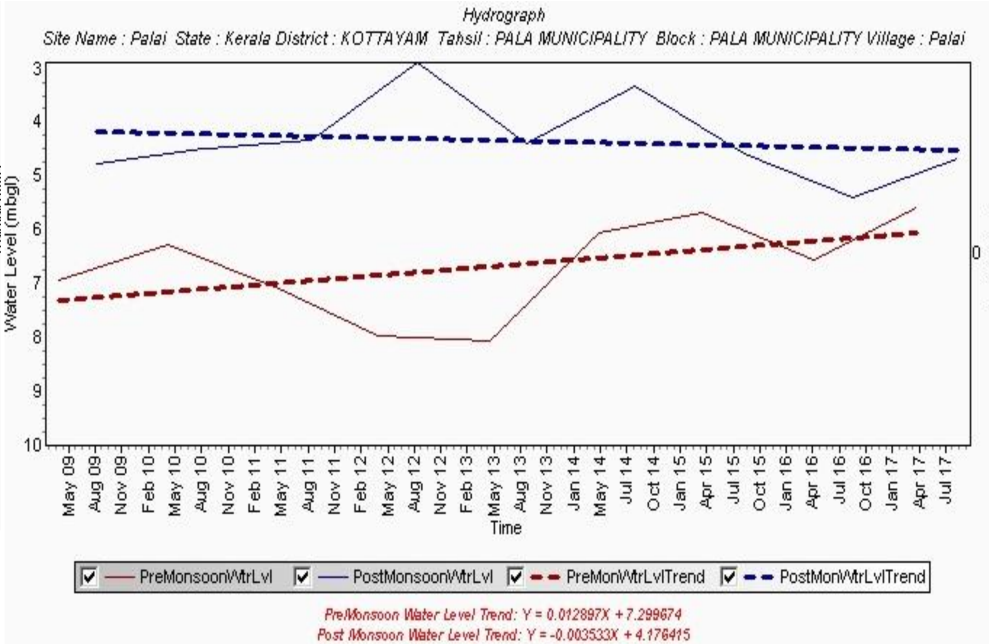

Hydrograph
Site Name : Kozha State : Kerala District : KOTTAYAM Tahsil : UZHAVOOR Block : UZHAVOOR Village : Kozha
Water Level (mbgl)
Time
PreMonsoonWtrLvl
PostMonsoonWtrLvl
PreMonWtrLvlTrend
PostMonWtrLvlTrend
PreMonsoon Water Level Trend: Y = 0.008100X + 3.836613
Post Monsoon Water Level Trend: Y = -0.005270X + 1.627391


Hydrograph
Site Name : Kozhuvanal State : Kerala District : KOTTAYAM Tahsil : PAMPADY Block : PAMPADY Village : Kozhuvanal
Water Level (mbgl)
Rainfall (mm)
Time
PreMonsoonWtrLvl
PostMonsoonWtrLvl
PreMonWtrLvlTrend
PostMonWtrLvlTrend
PreMonsoon Water Level Trend: Y = -0.006157X + 4.527842
Post Monsoon Water Level Trend: Y = 0.009575X + 4.365180


Hydrograph
Site Name : Mukkada State : Kerala District : KOTTAYAM Tahsil : KANJIRAPPALLY Block : KANJIRAPPALLY Village : Mukkada
Water Level (mbgl)
Time
PreMonsoonWtrLvl
PostMonsoonWtrLvl
PreMonWtrLvlTrend
PostMonWtrLvlTrend
PreMonsoon Water Level Trend: Y = -0.024744X + 6.006331
Post Monsoon Water Level Trend: Y = -0.003160X + 3.814365


Hydrograph
Site Name : Mundukuzhi State : Kerala District : KOTTAYAM Tahsil : MADAPPALLY Block : MADAPPALLY Village : Mundukuzhi
Water Level (mbgl)
Rainfall (mm)
Time
PreMonsoonWtrLvl
PostMonsoonWtrLvl
PreMonWtrLvlTrend
PostMonWtrLvlTrend
PreMonsoon Water Level Trend: Y = -0.000258X + 10.864167
Post Monsoon Water Level Trend: Y = 0.000945X + 6.611885


Hydrograph
Site Name : Plakkalpadi State : Kerala District : KOTTAYAM Tahsil : VAZHOOR Block : VAZHOOR Village : Plakkalpadi
Water Level (mbgl)
Time
PreMonsoonWtrLvl
PostMonsoonWtrLvl
PreMonWtrLvlTrend
PostMonWtrLvlTrend
PreMonsoon Water Level Trend: Y = -0.008982X + 6.290140
Post Monsoon Water Level Trend: Y = -0.006218X + 4.226567


Hydrograph
Site Name : Palai State : Kerala District : KOTTAYAM Tahsil : PALA MUNICIPALITY Block : PALA MUNICIPALITY Village : Palai
Water Level (mbgl)
Time
PreMonsoonWtrLvl
PostMonsoonWtrLvl
PreMonWtrLvlTrend
PostMonWtrLvlTrend
PreMonsoon Water Level Trend: Y = 0.012897X + 7.299674
Post Monsoon Water Level Trend: Y = -0.003533X + 4.176415

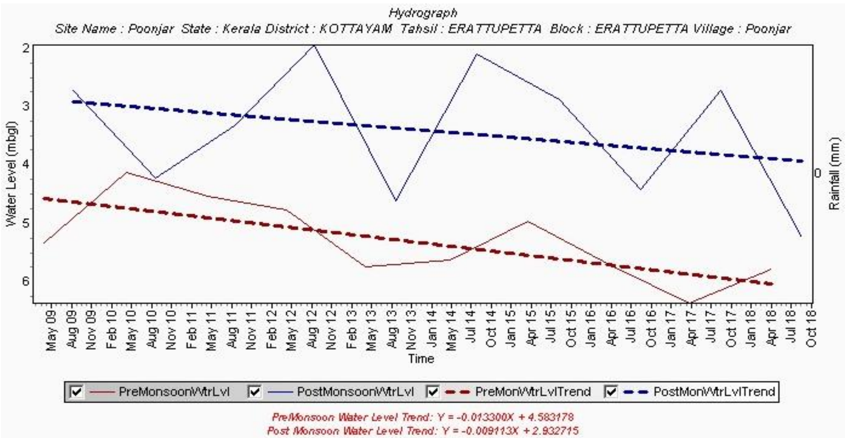

Hydrograph
Site Name : Poonjar State : Kerala District : KOTTAYAM Tahsil : ERATTUPETTA Block : ERATTUPETTA Village : Poonjar
Water Level (mbgl)
Rainfall (mm)
Time
PreMonsoonWtrLvl
PostMonsoonWtrLvl
PreMonWtrLvlTrend
PostMonWtrLvlTrend
PreMonsoon Water Level Trend: Y = -0.013300X + 4.583178
Post Monsoon Water Level Trend: Y = -0.009113X + 2.932715

Fig.3.6: Hydrographs of some of the wells in the study area

3.2 The fracture aquifer system (Aquifer II)

The geology of the area in conjunction with lithological log of bore wells drilled has been used to study the disposition of fracture aquifer system. In hard rocks groundwater potential is controlled by lineaments and fractures. The availability of water in the fracture zones depends on presence of secondary porosity (interconnected fracture zones or lineaments). The information on weathered thickness and fracture zones from exploratory wells have been used for the preparation of various diagrams like fence, 3D model etc., to represent the sub-surface aquifer disposition of the area. A total of 25 bore wells have been drilled in the hard rock area, tapping fractured crystallines. The depth of the exploratory wells ranges from 80.5 to 215.77 mbgl and these bore wells were located along NNE, NNW, NS and WNW lineaments. Fracture zones in these bore wells were encountered at various depths starting from 9 m bgl to a maximum depth of 196 m bgl with a maximum drill time discharge of 1302 lpm. Groundwater in the deeper fractured aquifer system exists under semi-confined state, in general. The depth to water level ranges from 1.54 (Vallichira) to 25. 40 (Pallikkathodu) mbgl. to Most of the bore wells in the area tap the fracture zones within the depth range of 40 to 80m bgl and rarelyextend up to 110m bgl. In general, the chances for getting potential fractures below 150 m bgl are relatively less. The transmissivity values of the wells drilled range between 0.5 to 122 m^2/day. It has been observed that wells falling along NE and NW lineaments have got relatively higher discharges when compared to others.

The depth of weathering in the area varies widely and in the eastern parts it is relatively less (<5 m) and towards the central and western parts of the study area the thickness increases and goes up to 25m at places. In the eastern parts of the study area, the depth of weathering is less than 5 m (in the major part of Erattupetta, eastern part of Pala and south-eastern part of Kanjirappally blocks), whereas weathering thickness is more than 15 m in the south-western part of Madappally, eastern part of Pallom and in the central part of Uzhavoor blocks. In the rest of the area (major part of the study area) the weathering thickness is in the range of 5-10 m. The cross sections of the sub surface aquifer disposition prepared from the lithologs of EWs drilled by CGWB is shown in fig. 3.7 and fence diagram and 3D view of the area is shown in fig. 3.8. Only 24 percentage of the wells drilled in the hard rock area yielded discharge more than 3 lps (180 lpm).

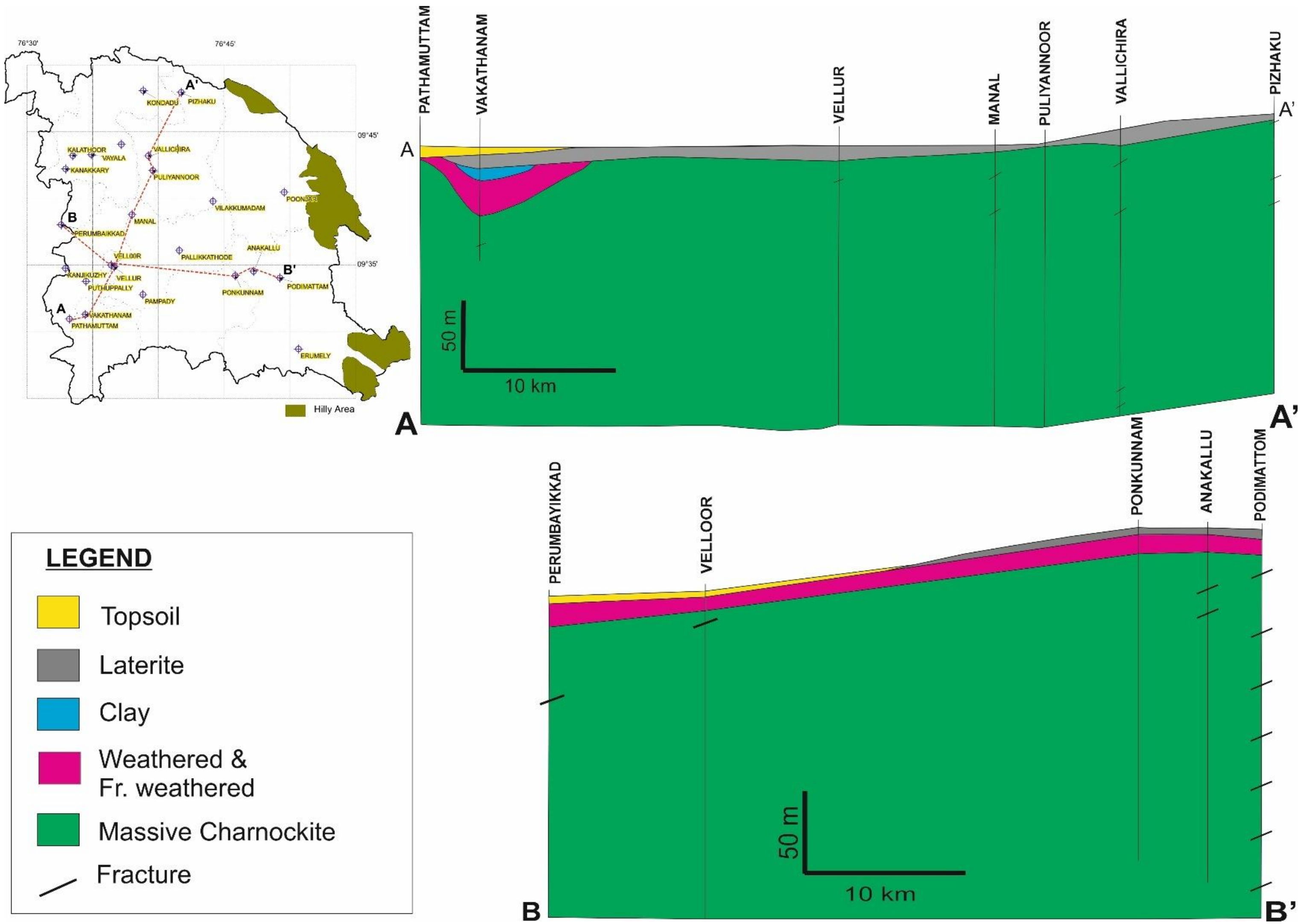


Fig.3.7: Cross section along AA' and B-B'

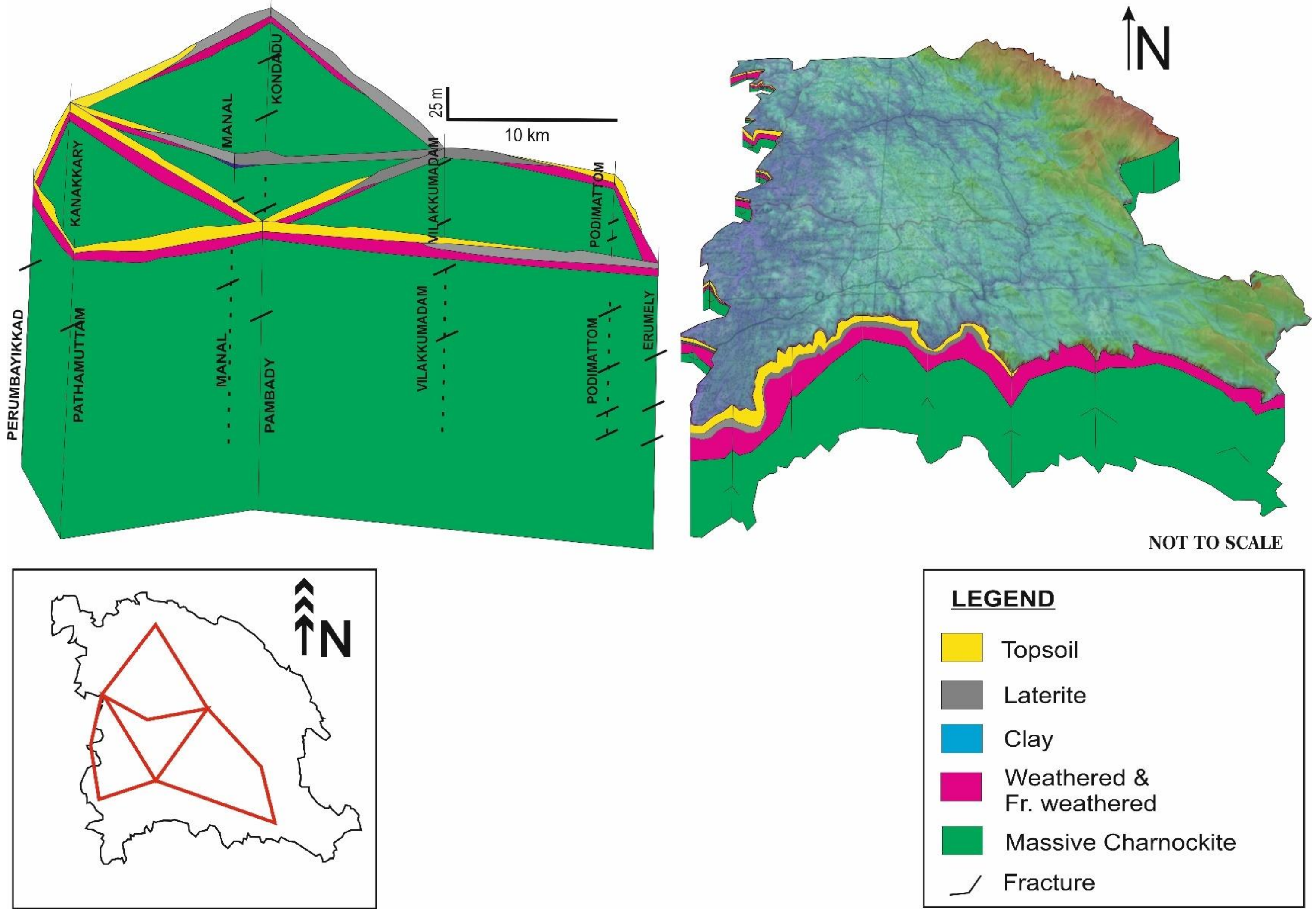


Fig.3.8: Fence and conceptual 3D aquifer disposition of the study area

3.2.1 Geophysical investigations

Geophysical surveys consisting of Vertical Electrical Soundings (VES) were carried out to explore the subsurface conditions and to recommend sites for exploratory drilling and also to extract additional information on the data gaps for aquifer mapping. In the study area, VES were carried out in 43 locations by employing the Schlumberger & Half Schlumberger electrode configuration. The obtained VES data was interpreted by using the computer interpretational techniques. The interpreted results obtained are presented in annexure -IV.

The interpreted results have given rise to a maximum of 6 layered geoelectric sections. The first layer resistivity value was varying in the range of 49-3603 ohm.m, with thickness in the range of 0.5-8.5 m which represents the topsoil. The second layer resistivity value was varying in the range of 19-13611ohm-m. Within this range, at some sites the resistivity was encountered <200 ohm-m which was considered as weathered formation and at some sites the resistivity was varying in the range of 200–13611ohm-m which was considered as hard laterite formation. The thickness of this layer was varying in the range of 1.2-76 m. The third layer resistivity was varying in the range of 52-2252 ohm-m which represents fractured to massive formation. The thickness of this layer was varying in the range of 3.7-148 m and at some sites this layer was extending in nature. The fourth layer resistivity was varying in the range of 69-VH ohm-m. The thickness of this layer was varying in the range of 4.8-48 m and at some sites this layer was extending in nature. The fifth layer resistivity was varying in the range of 25-9257ohm-m. The thickness of this layer was varying in the range of 12.7-60 m and at some sites this layer was extending in nature. The last layer (sixth layer) was encountered in the few of sites with resistivity range of 200-3679ohm-m. The representation of different field curves in Kottayam district has been presented in fig.3. 9.

Based on the results of Geophysical Surveys (VES), locations for exploratory borewells have been recommended at some of the sites. Eg: Poonjar, Pallickathodu, Uzhavoor, Nattakom, Pala, Marangattupally, Kuruvilangad and Thottuva etc.Theexploratorydrillings in some of these sites yielded meagre discharge. Eg: Pallickathodu (0.7 lps) andPoonjar (0.5 lps).

3.2.2 Groundwater and its relation to Geological Structures

Geological structures like fractures, lineaments, faults, joints, intrusive rocks like dykes etc. influence the occurrence and movement of groundwater. Such information can be extracted from field investigations as well as from the study of topo-sheets and remote sensing imageries. For the current study, the lineament map from ISRO's geoportal "Bhuvan" (National Remote Sensing Centre) was used. The lineaments identified in the basin trend various directions such as NNW, NNE, NS and WNW. The rose diagram of thelineamentsis given in the Fig. 3.10.

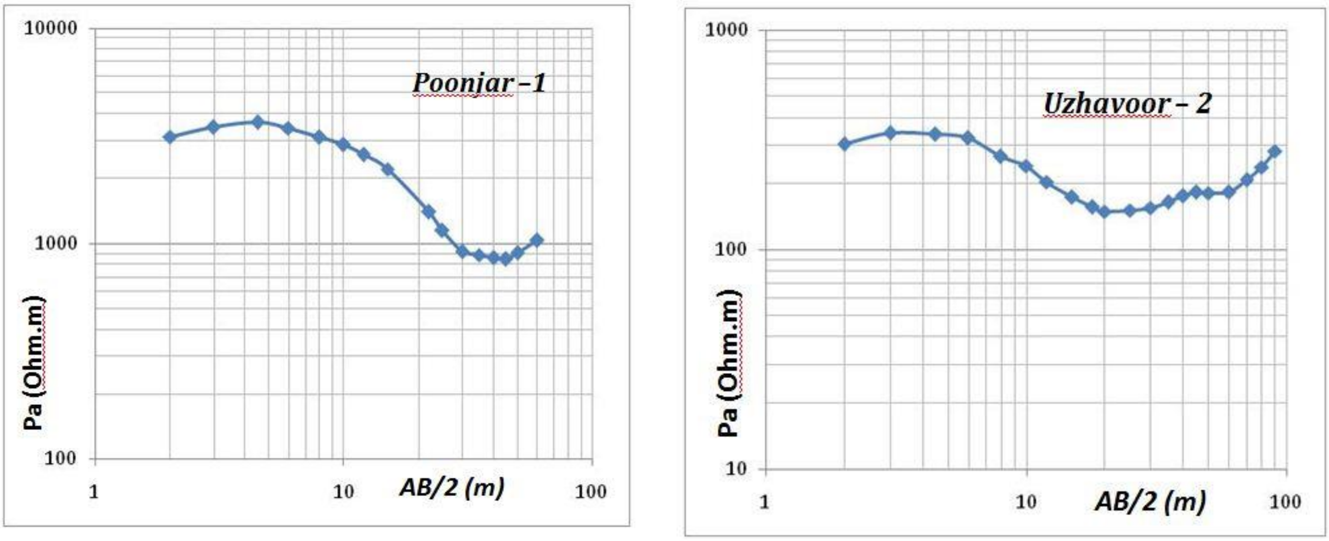


Fig 3.9: Representation of different field curves in Kottayam district

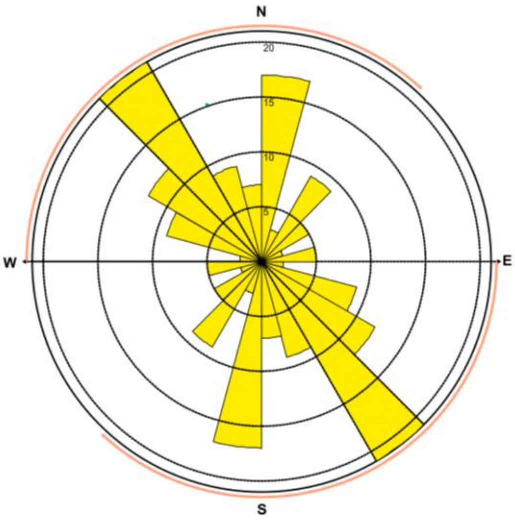


Fig.3.10: Rose diagram of lineaments

The yield of the boreholes had a direct bearing on the tectonic history and the rock types. The yield from bore wells varies in the area. Within the same geological formation, the spatial variation in yield is very common in hard rocks. The comparative study of the yield of the wells with lineaments indicates that the NNE-SSW and NNW-SSE lineaments are relatively morepotential. The number of wells having varying yield ranges and details of high yielding wells and lineaments are given in Table.3.2. The relationship of the high yielding wells with lineament direction in the study area is given in table 3.3.

Table 3.2: Frequency of bore wells in different Yield ranges

Yield of Exploratory Wells	No of wells /Percentage
>3 lps	6 / 24 %
Between 1 to 3lps	2/ 8%
Up to 1 lps	17/ 68%

Table 3.3: Details of high yielding wells and lineaments

#	Location of Exploratory well	Yield (lps)	Formation	Lineament
1	Kondadu	8	Charnockite	NNW
2	Pizhaku	3.3	Charnockite	WNW
3	Vilakkumadam	20	Charnockite	NNW
4	Vakathanam	3.5	Charnockite	NNE
5	Podimattom	13.7	Charnockite	NNE
6	Manal	3	Charnockite	NNW

3.2.3 Aquifer characteristics

The hydraulic properties of fracture systems are evaluated from pumping tests and the results of which are annexure-VI. The Transmissivity value varies from 0.5 to 122 m^2/day and the Storativity values varies from 0.0006 to0.003. The details of exploratory wells are given annexure-VI.

In the present study 2 soil infiltration tests were carried out at Chengalam (Akalakunnam panchayath, Pampady block) and Kozha (Kuravilangad Panchayath, Uzhavoor block). The tests were conducted during February,2019 using double ring infiltrometer. The measurement of the water volume is done on the inner ring only. The experiment is carried out till a constant infiltration rate is obtained. Based on the steady state infiltration capacity, soils can be divided into four categories (K. Subramanya, 2015) and is detailed in table 3.4. The summarized outcomes of the tests are given in table 3.5. The curves of Infiltration and cumulative depth of infiltration versus time in minutes are given in fig. 3.11 and 3.12.

Table 3.4 Classification of Infiltration capacities (K. Subramanya,2015)

Classification of Infiltration capacities		
Infiltration Class	**Infiltration Capacity (mm/hr)**	**Remarks**
Very Low	< 2.5	Highly clayey soils
Low	2.5 to 12.5	Shallow soils, Clay soils, Soils low in organic matter
Medium	12.5 to 25	Sandy loam, Silt
High	>25	Deep sands, well drained aggregated soils

Table 3.5: Summarised Results of Soil infiltration tests

#	Location details	Date	Soil Type	Duration (min.)	Cumulative depth of infiltration (cm)	Final Infiltration rate (cm/hr)
1	Sacred Heart Convent School, Chengalam	27.2.19	Sandy loam, Silt	180	50.7	13.2
2	District Agricultural Farm, Kozha	28.2.19	Sandy loam, Silt	230	115.01	15.06

It is observed from the results that the soil infiltration rate varies from 13.2 cm/hr to 15.06 cm/hr. The total cumulative depth of infiltration varies from 50.7 cm to 115.06 cm.It is observed that the infiltration capacities in the study area falls in class of deep sands, well drained and aggregated having relatively high infiltration rates.

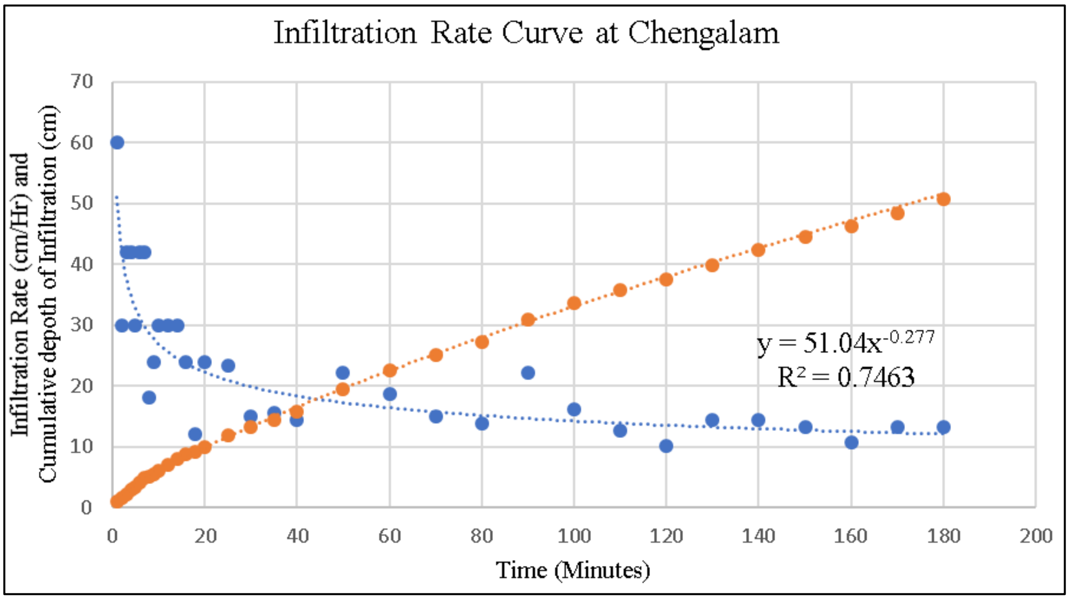


Fig. 3.11: Curves of infiltration and cumulative depth of infiltration at Chengalam

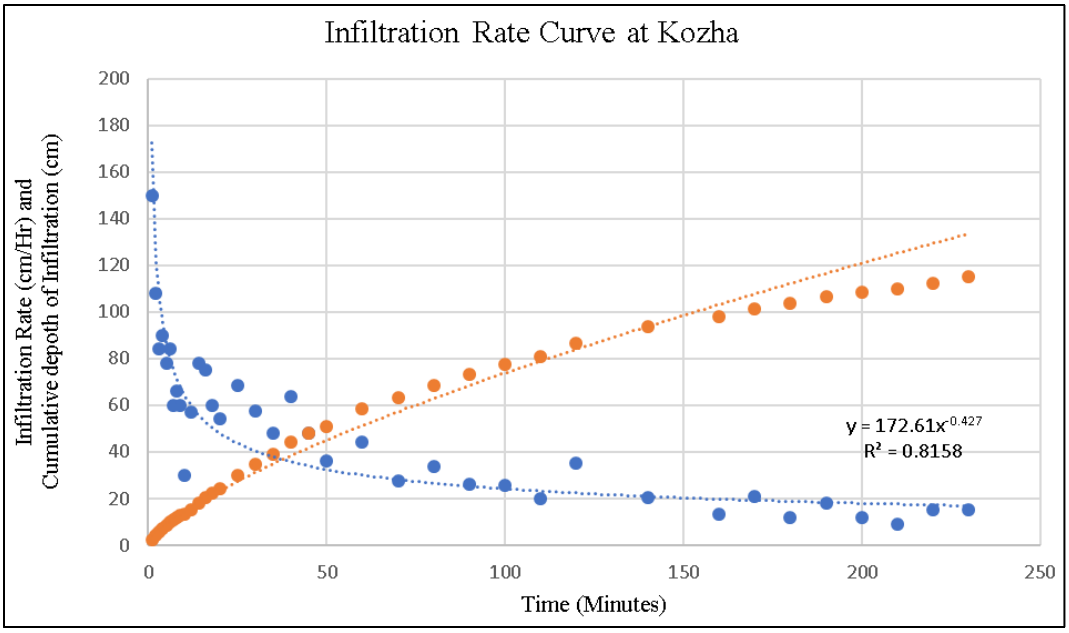


Fig. 3.12: Curves of infiltration and cumulative depth of infiltration at Kozha

Also, to estimate the specific yield of phreatic aquifer, data of a dug well test conducted by State Groundwater Department was used. The test was conducted at Purappanthanam village in Erattupetta block and the result came out to be 2.6%.

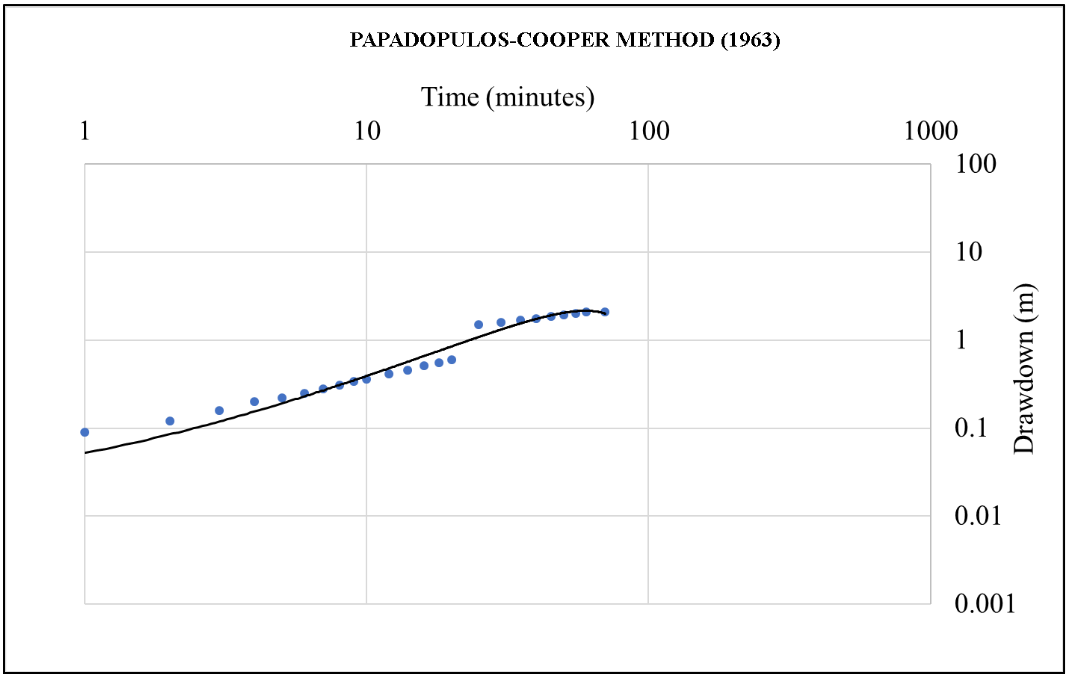


Figure 3.13: Time versus drawdown data of the large diameter pump test

By curve matching technique, identified $1/U_w$as 90, F (U_w, α) as 1.5, drawdown (s) as 2 m and time as 50 minutes. Then substituting values in equation, T=(Q/4πs) *F (U_w, α), got transmissivity as 48.50 m^2/day. Again, by substituting values in $S=4TtUw/r_w^2$, calculated specific yield as 2.6% (r_w=radius of well). The time versus drawdown plot is given in figure 3.13.

3.2.4 Chemical quality ofgroundwater

In a groundwater flow regime water chemistry constantly undergoes modification due to various processes such as dissolution of minerals, precipitation of dissolved ions under unstable conditions, cation exchange and anthropogenic addition etc. The chemical composition of subsurface water is controlled by various factors such as the amount of dissolved CO_2 in rain water and soil, the composition of the rocks through which the water percolates and the duration of contact between the water and the soil/rock. Further,low hydraulic conductivity of aquifers provides more residence time for rock-water interactions. Thus, with the decrease in hydraulic conductivity there is general increase in chemical concentration of various ions in groundwater.

The hydrochemical evolution along the flow paths are significantly altered under anthropogenic interferences and consequent pollution of aquifer systems (Drever, 1982; Langmuir, 1997; Abu-Jabeer, 2001; Singh et al, 2007). The effects of pollution in the flow system can easily be identified from a comparison of dissolved ions and ion ratio studies in simple terms (Hem, 1985).

3.2.4(a). Groundwater quality in phreatic aquifer system: The existing water quality data from 48 dug wells (13 GWMWs and 35 KOWs) for the month of April-2017 have been analysed for extracting information on regional distribution of water quality and their suitability for various uses (Annexure-V).

The groundwater quality in the area is generally good for all purposes. In most of the location pH is acidic in nature and varies between 4 and 7.42. The electrical conductivity (in µS/cm at 25° C) of groundwater in phreatic zone is in the range of 29 to 310 and Chloride in the range of 2.8-37 mg/l. Fluoride content in the observation wells monitored is in the range of 0 to 0.37 mg/l in the study area. Nitrate above the permissible is noted in two locations at Kadapoor and Paippad.

The percentage of the epm values of cations and anions in the samples from phreatic zone were plotted in Hill- Piper diagram (Fig. 3.14) for classifyingthe water types and the same is given in table 3.6.

Gibbs (1970) found that the three mechanism - atmospheric precipitation, rock dominance and evaporation-crystallization process are the major factors controlling, the composition of the dissolved salts of the world's water. Other second order factors, such as relief, vegetation and composition of material in the basin cause only minor deviations within the zones dominated by the three above prime factors.

The diagram of Gibbs (1970) forms an excellent tool in understanding the chemical evolution of the surface water and groundwater hence the chemical analysis data of groundwater samples collected from phreatic aquifer have been plotted on the Gibbs diagram – (TDS vs Cl^-/Cl^-+HCO^{3-}) and is shown in Fig. 3.15. The samples fall in the precipitation dominance zone. From the diagram it is very well evident that the samples from phreatic aquifer falls in precipitation dominance zone and it undergoes seasonal flushing due to the heavy rainfall spells prevailing in the area.

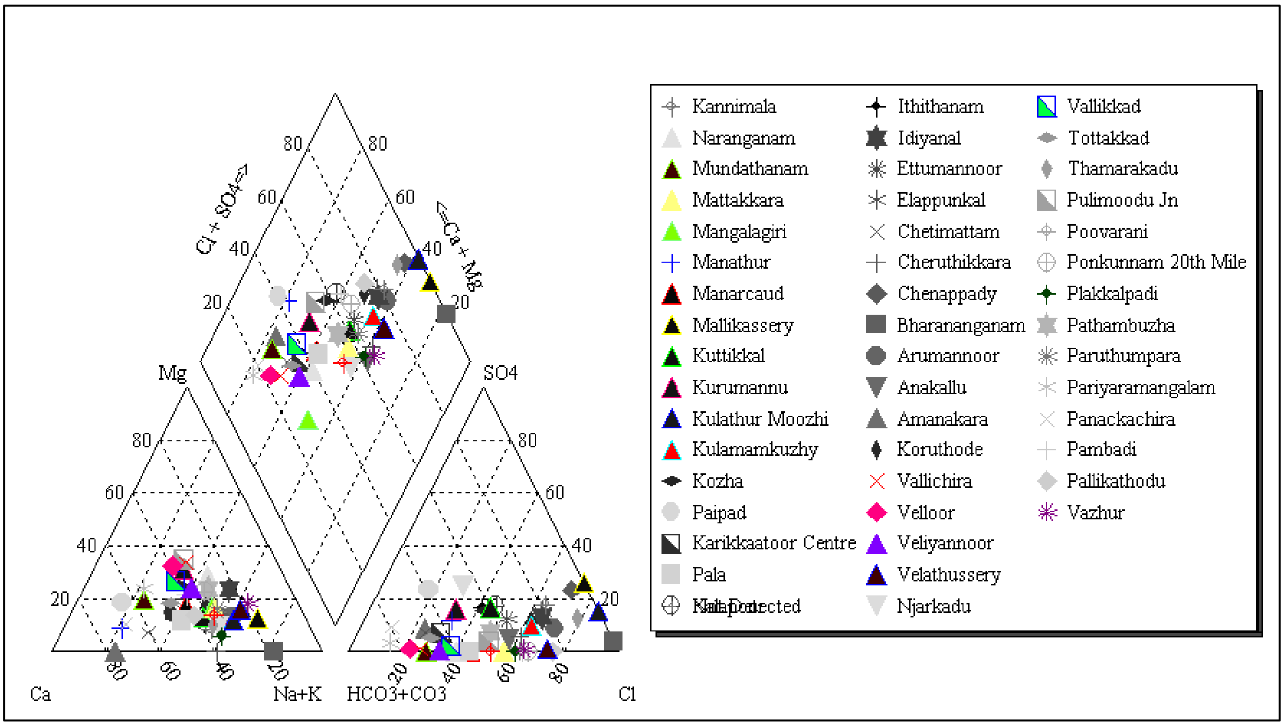


Fig.3.14: Hill-Piper Diagram (Phreatic aquifer)

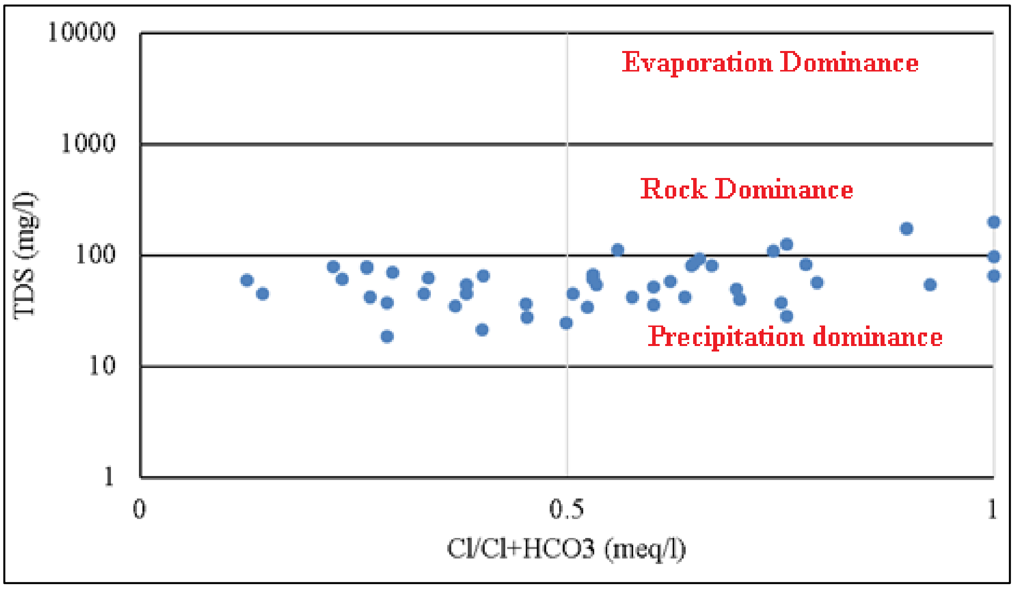


Fig.3.15: Gibbs Diagram of phreatic aquifer

Table 3.6: Water types in phreatic aquifer system

#	**Location**	**Water Type**
1	Amanakara	Ca-Na-NO3-Cl
2	Anakallu	Ca-Na-NO3-Cl-HCO3
3	Arumannoor	Ca-HCO3-Cl
4	Bharananganam	Ca-Na-HCO3-Cl
5	Chenappady	Na-Ca-NO3-HCO3-Cl
6	Cheruthikkara	Na-Ca-Mg-Cl-HCO3-NO3
7	Chetimattam	Ca-Mg-HCO3
8	Elappunkal	Na-Mg-Ca-HCO3-NO3-Cl
9	Ettumannoor	Na-Ca-Cl-HCO3
10	Idiyanal	Ca-Na-HCO3-Cl
11	Ithithanam	Na-Ca-Cl-SO4
12	Kalapoor	Na-K-Cl-NO3
13	Kannimala	Ca-Na-Mg-NO3-Cl-HCO3
14	Karikkaatoor Centre	Na-Mg-Ca-Cl-NO3
15	Koruthode	Ca-Mg-Na-HCO3-NO3-Cl
16	Kozha	Na-Ca-Mg-Cl-NO3-HCO3
17	Kulamamkuzhy	Na-Ca-Cl-HCO3
18	Kulathur Moozhi	Na-Ca-Cl-HCO3-NO3
19	Kurumannu	Ca-Na-K-HCO3-Cl-SO4
20	Kuttikkal	Na-Ca-Cl-HCO3-NO3
21	Mallikassery	Na-Ca-Cl-NO3-HCO3
22	Manarcaud	Na-Ca-Cl-NO3
23	Manathur	Ca-HCO3-SO4
24	Mangalagiri	Ca-NO3-HCO3
25	Mattakkara	Na-Ca-Cl-HCO3
26	Mundathanam	Ca-Na-Cl-NO3
27	Naranganam	Mg-Ca-Na-Cl-HCO3
28	Njarkadu	Na-Ca-HCO3-Cl
29	Paipad	Na-Ca-Cl-NO3
30	Pala	Ca-Na-HCO3-Cl
31	Pallikathodu	Mg-Ca-Na-HCO3-Cl
32	Pambadi	Ca-Mg-Na-HCO3-Cl
33	Panackachira	Na-Ca-NO3-Cl

34	Pariyaramangalam	Na-Ca-Cl-HCO3
35	Paruthumpara	Na-Cl-HCO3
36	Pathambuzha	Ca-HCO3-Cl
37	Plakkalpadi	Na-Ca-Cl-HCO3-NO3
38	Ponkunnam 20th Mile	Na-Ca-Cl-NO3
39	Poovarani	Ca-Na-HCO3-Cl
40	Pulimoodu Jn	Na-Cl-NO3
41	Thamarakadu	Ca-Na-Mg-Cl-NO3-HCO3
42	Tottakkad	Ca-Na-Mg-HCO3-Cl
43	Vallichira	Na-Ca-Cl-NO3-HCO3
44	Vallikkad	Na-Ca-Cl-HCO3-NO3
45	Vazhur	Ca-Mg-HCO3-Cl
46	Velathussery	Na-Ca-NO3-Cl-HCO3
47	Veliyannoor	Ca-HCO3
48	Velloor	Ca-HCO3-Cl

3.2.4(b). Groundwater quality in deeper aquifer system: Water samples were collected from fractured aquifers through bore wells (9 EWs) during their construction were analysed for EC, pH, major cations, anions and Fluoride. The EC values of the analysed samples ranges from 130- 400 µS/cm. Chloride values ranges between 4.3-9.9 mg/l and fluoride in the range of 0-0.24 mg/l. The details of the samples are given in annexure-V. The analysis of the data shows that water in the fractured zones is of alkaline nature and quality of water is generally good for all uses. The water type classification of the samples from deeper aquifer based on the plotting in Hill-Piper diagram (fig.3.16) is given in table 3.7. To Know the origin of water in fractured aquifer system, the chemical analysis data of groundwater samples collected from fractured aquifers has been plotted on the Gibbs diagram and is shown in fig. 3.17. Majority of the samples from deeper aquifer falls in rock dominance zone/near rock dominance zone, indicating that the major source of chemical species in groundwater is from mineral dissolution through rock-water interaction.

Table 3.7: Water types in deeper aquifer system

#	Location	Water Type
1	Erumely	Na-HCO3
2	Kanjikuzhy	Na-Mg-Ca-HCO3
3	Kondadu	Ca-Mg-HCO3
4	Manal	Ca-Mg-Na-HCO3
5	Pizhaku	Ca-Mg-HCO3
6	Podimattom	Ca-Mg-HCO3
7	Vakathanam	Na-Ca-HCO3
8	Vallichira	Na-HCO3
9	Vilakkumadam	Ca-Mg-HCO3

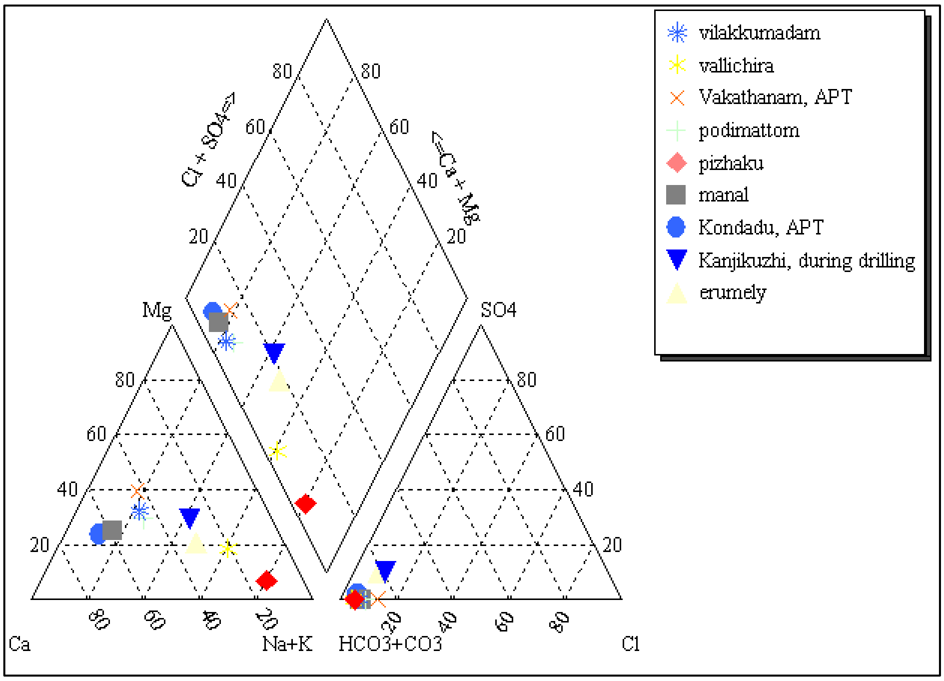


Fig.3.16: Hill-Piper Diagram (Deeper aquifer)

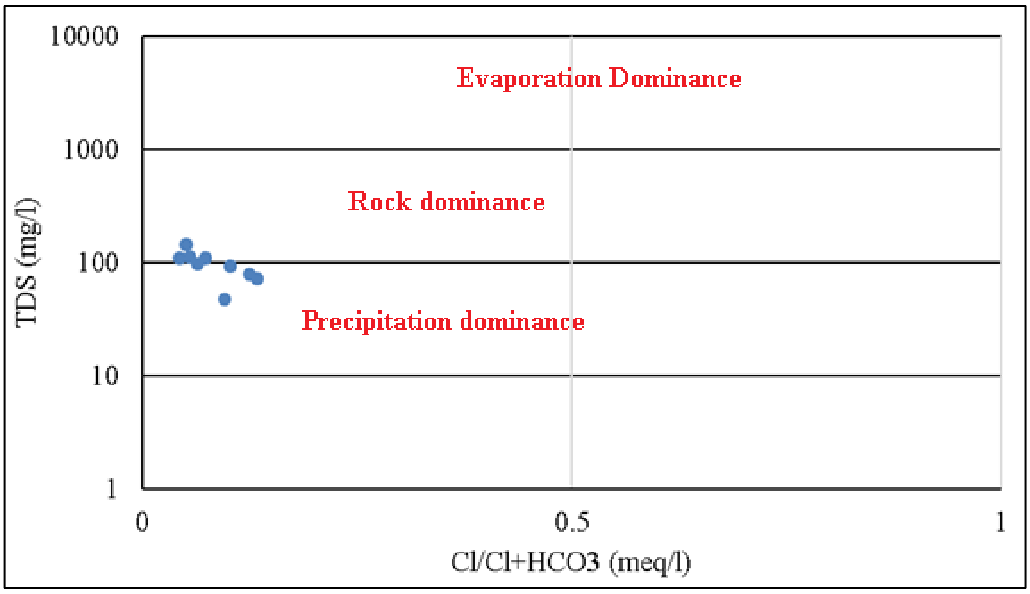


Fig.3.17: GibbsDiagram of deeper aquifer

3.3. Groundwater Resource Estimation

The occurrence of groundwater availability varies from place to place. Increasing population, rapid urbanization and industrialization has resulted in increasing use of groundwater resources. Judicious and planned development of groundwater and its scientific management have become necessary to ensure long-term sustainability of this precious natural resource. Phreatic aquifers are the major source of groundwater in the area in the study area. Any decision about future utilizations should be made after having a clear understanding of the status of the resource, the amount that has already been extracted, the amount remaining, and the impact of further depletion. The groundwater resources in the area are estimated based on the Groundwater Estimation Methodology (GEC) 2015. The data pertaining to command and non-command area are not available hence, the entire area is considered as non-command area. The block wise groundwater resources in the area is calculated for both phreatic (Aquifer-1) and deeper fractured aquifer system (Aquifer-II). The storage parameter values used in the estimation for phreatic aquifer vary from 0.003 to 0.08, whereas as for the deeper fractured aquifer, it varies from 0.0015 to 0.002.

Groundwater extraction in the study area is mainly for meeting the domestic and irrigation requirements. In view of the non-availability of data on the number of wells being used for domestic purposes, the groundwater extraction for domestic uses has been computed block-wise on the basis of 2011 population, projected to the year of assessment (2017). Domestic requirement of water in the study area has been computed as the product of the population and the per-capita water requirement (assumed as 150 L/day/person). The groundwater extraction for irrigation use has been computed from the data on the block-wise number of irrigation wells collected by the State Groundwater Department, Government of Kerala. The groundwaterextractionfigures are arrived at by multiplying the number of wells with the corresponding unit extraction/draft. The annual extractable groundwater recharge to unconfined aquifer is 229.66 MCM and the stage of groundwater extraction is 37.5 %. The net groundwater availability for future use is 135.19 MCM. Groundwater extraction for irrigation is very low (33.27 MCM) and extraction for domestic and industrial use together comes about 52.89 MCM.All the blocks in the study area falls under “Safe” category. Block-wise groundwater resources in the study area is given in table 3.8.

In-storage volume in the phreatic aquifer below the zone fluctuation is worked out as 150.68 MCM. In-storage in the weathered zone is calculated as the product of area, weathered zone thickness and specific yield. Also, the groundwater resource in the fractured zone is worked out to be 187.11 MCM, based on the common depth of occurrence of fracture, area and storativity and is shown in table 3.9.

The total groundwater resources in the phreatic aquifer system has been calculated to 380.38 MCM (combining dynamic and static resources). And the total resources in the fractured crystalline (deeper aquifer) has been worked out to be 187.11 MCM.

Table 3.8: Block-wise dynamic groundwater resources in the study area

#	Assessment Unit/ District	Command / Non-Command area / Total (Sq. Km)	Annual Extractable Groundwater Recharge (mcm)	Current Annual Ground Water Extraction for irrigation(mcm)	Current Annual Ground Water Extraction for domestic and industrial water supply (mcm)	Existing Gross Groundwater Extraction for All uses (mcm)	Annual Groundwater Allocation for Domestic use as on 2025 (mcm)	Net Groundwater Availability for future use (mcm)	Stage of Groundwater Extraction (%)
1	Erattupetta	152.51	23.61	4.68	5.86	10.53	5.97	12.97	44.6
2	Ettumanoor	27.69	5.54	0.65	1.79	2.43	1.82	3.07	44
3	Kaduthuruthy	65.53	15.3	2.28	2.51	4.79	2.56	10.47	31.3
4	Kanjirappally	222	38.89	6.06	9.28	15.34	9.46	23.37	39.4
5	Lalam	189.39	28.05	3.11	5.61	8.71	5.72	19.22	31.1
6	Madappally	44.38	13.25	1.76	3.37	5.13	3.44	8.05	38.7
7	Pallom	94.56	21.52	2.3	5.67	7.97	5.77	13.45	37
8	Pampady	166.3	25.41	2.82	6.04	8.86	10.46	12.13	34.9
9	Uzhavoor	223.3	36.78	5.69	7.45	13.13	10.57	20.52	35.7
10	Vazhoor	142.24	21.31	3.94	5.33	9.27	5.43	11.94	43.5
11	**Total (mcm)**	**1328**	**229.66**	**33.27**	**52.89**	**86.17**	**61.19**	**135.19**	**37.5**

Table:3.9. Aquifer wise groundwater resources in the study area

#	Assessment Unit	Total Area (Sq. Km)	Annual Extractable Dynamic Groundwater Recharge of unconfined Aquifer (mcm)	In storage Groundwater Resources of Unconfined Aquifer (mcm)	Groundwater Resources – Phreatic Aquifer-I (mcm) (2+3)	Groundwater Resources- Fracture Aquifer-II (mcm)	Total Groundwater Resources (mcm)
1	Erattupetta	152.51	23.61	12.81	36.42	17.16	53.58
2	Ettumanoor	27.69	5.54	7.09	12.63	8.03	20.66
3	Kaduthuruthy	65.53	15.3	8.39	23.69	9.83	33.52
4	Kanjirappally	222	38.89	23.98	62.87	33.3	96.17
5	Lalam	189.39	28.05	14.2	42.25	21.31	63.56
6	Madappally	44.38	13.25	10.65	23.9	12.43	36.32
7	Pallom	94.56	21.52	27.99	49.51	26.48	75.98
8	Pampady	166.3	25.41	15.96	41.37	17.46	58.84
9	Uzhavoor	223.3	36.78	18.09	54.87	25.12	79.99
10	Vazhoor	142.24	21.31	11.52	32.83	16	48.83
11	**TOTAL (MCM)**	**1328**	**229.66**	**150.68**	**380.34**	**187.11**	**567.45**

3.4 Groundwater related problems

The main groundwater related problems in the study area are as follows:

1. **Water Scarcity:** As per the estimation of groundwater resources in the study area all the blocks fall under safe category. However, the study area experiences drying up of wells during summer season especially during rain deficient periods. In the study area groundwater is developed mostly through dug wells. Now a days, in highland terrains alsobore wells are common, as most of the dug wells in this area usually dries up in summer. The problem of summer scarcity is more evident in Mundakkayam, Kanjirappally, Erattupetta, Teekoy, Melukavu, Erumely, Poonjar, Koottikkal, Koruthode, Manimala and Chirakkadavu panchayaths. The main reason is the limited thickness of aquifer in the eastern parts (high lands); mostly, less than 5 m, hence there exists no sufficient storage space in the aquifer to store water. Also, the physiography and geomorphologic settings of the area allows fast run-off coupled with high rates of baseflow. The Meenachil river which is the main drainage in the area has got a gradient of 13.7 m/Km and the mean annual base flow is calculated to be 220.24 MCM. The percentage of base flow with respect to the annual run-off ranges between 8.6 to 16.5%. In case of Manimala the gradient is 12.84 m/Km and the mean annual base flow contribution worked out to be 226.8 MCM. The annual quantities of baseflow in Manimala river varies between 16.3 to 24% of total run-off.
2. **Quality issues:** Water quality contamination affecting potability, staining and rusting of water supply lines is also noticed in the study area. Microbial contamination of groundwater in open wells and shallow bore wells is a major quality issue in the area and is primarily attributed from soak pits. High iron concentration in groundwater more than the permissible limit (0.3 mg/l) is reportedin many parts of the area and is mainly caused by the dissolution of iron in groundwater due to low pH values of groundwater. Also, Nitrate in groundwater is reported above permissible limit (<45 mg/l) from few isolated pockets. Drinking water quality data (2017) from Department of Drinking Water and Sanitation, Ministry of Jal Shakti (see table 3.10) shows that bacteriological contamination (mainly coliforms) is a main concern in the study area.
3. **Anthropogenic activities:** Rapid urbanization and lack of facility for waste disposal in municipalities, change in land-use and cropping pattern, indiscriminate dumping of bio-degradable and non-biodegradable waste into abandoned wells and surface water bodies, wet land filling, cultivable land encroachments, illegal sand mining along river beds and conversion of paddy fields have adverse effects on the quantity and quality of the water.
4. **Quarrying:** Charnockite group of rocks occupying the highland and midland region of the study area are good sources of building materials. Quarrying of these rocks creates localized groundwater problems.

Table3.10: Block wise number of sources contaminated in Kottayam district.

#	Block	No. of Sources (Shallow + Deeper) contaminated (above permissible limit)	
		Fe	Bacteriological
1	Erattupetta	13	973

2	Ettumanoor*	2	1379
3	Kaduthuruthy*	1	1325
4	Kanjirappally	49	1351
5	Lalam	11	774
6	Madappally*	1	1550
7	Pallom*	81	989
8	Pampady	36	902
9	Uzhavoor*	12	1088
10	Vazhoor	9	722

*Partly covered blocks, figures given for entire block

5. **Lack of awareness:** Also, conducting awareness programmes to maintain hygienic conditions around drinking water sources by the concerned government, non-government organisations, and local institutions would lead to safer drinking water provisions. An ideal groundwater management approach will be one that will not only construct structures but also make an effort to sensitize and involve the community to work on the issue. There is an urgent need for a concerted effort to integrate science and community participation for groundwater management.

3.5 Aquifer map

An aquifer map of the area is evolved out of various studies on aquifer geometry, aquifer characteristics and water resources in the aquifer systems, yield characteristics and water quality described above. The aquifer map of the phreatic (weathered zone) and fracture aquifer systems are shown in fig. 3.18 and 3.19 respectively.

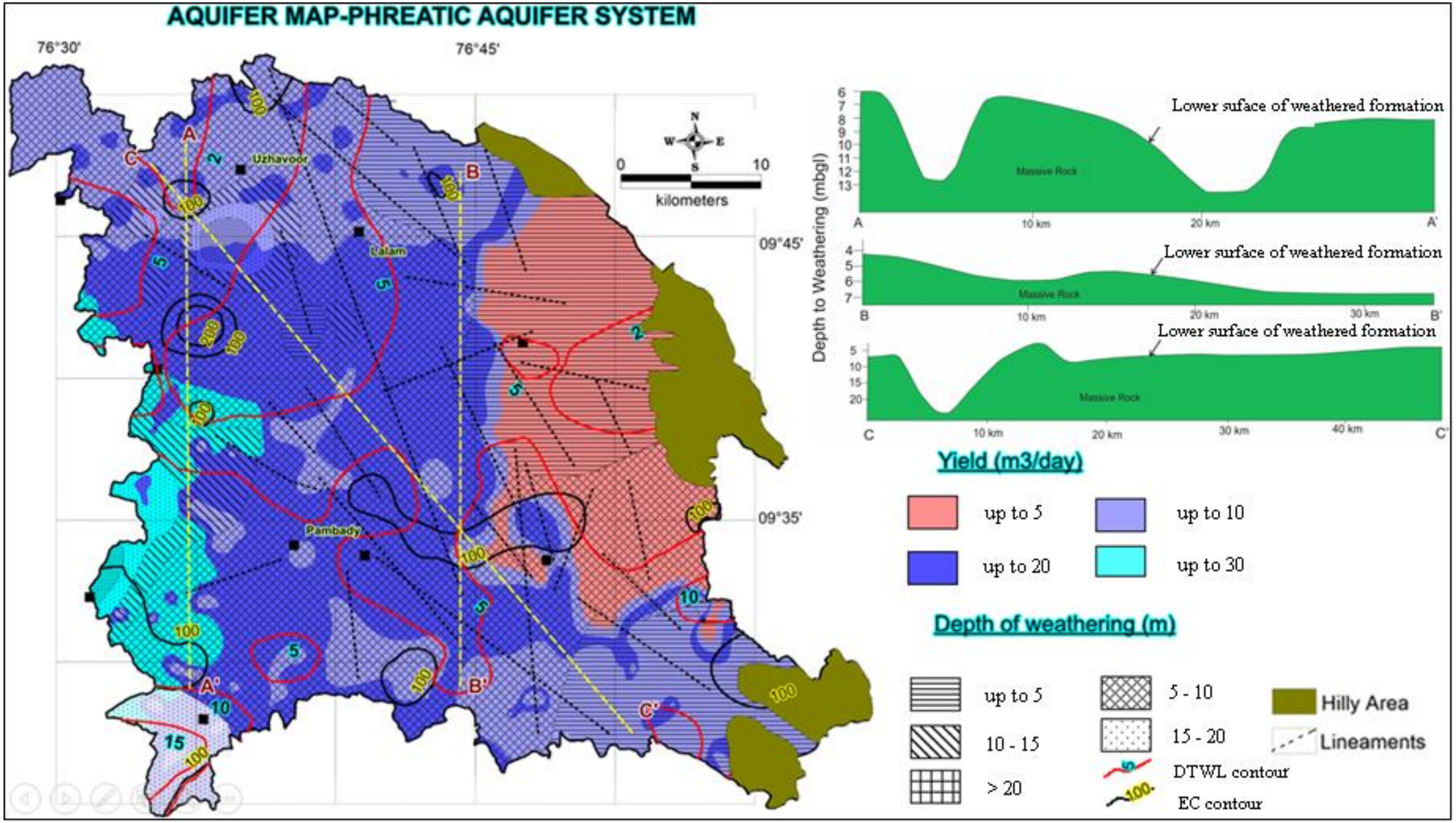
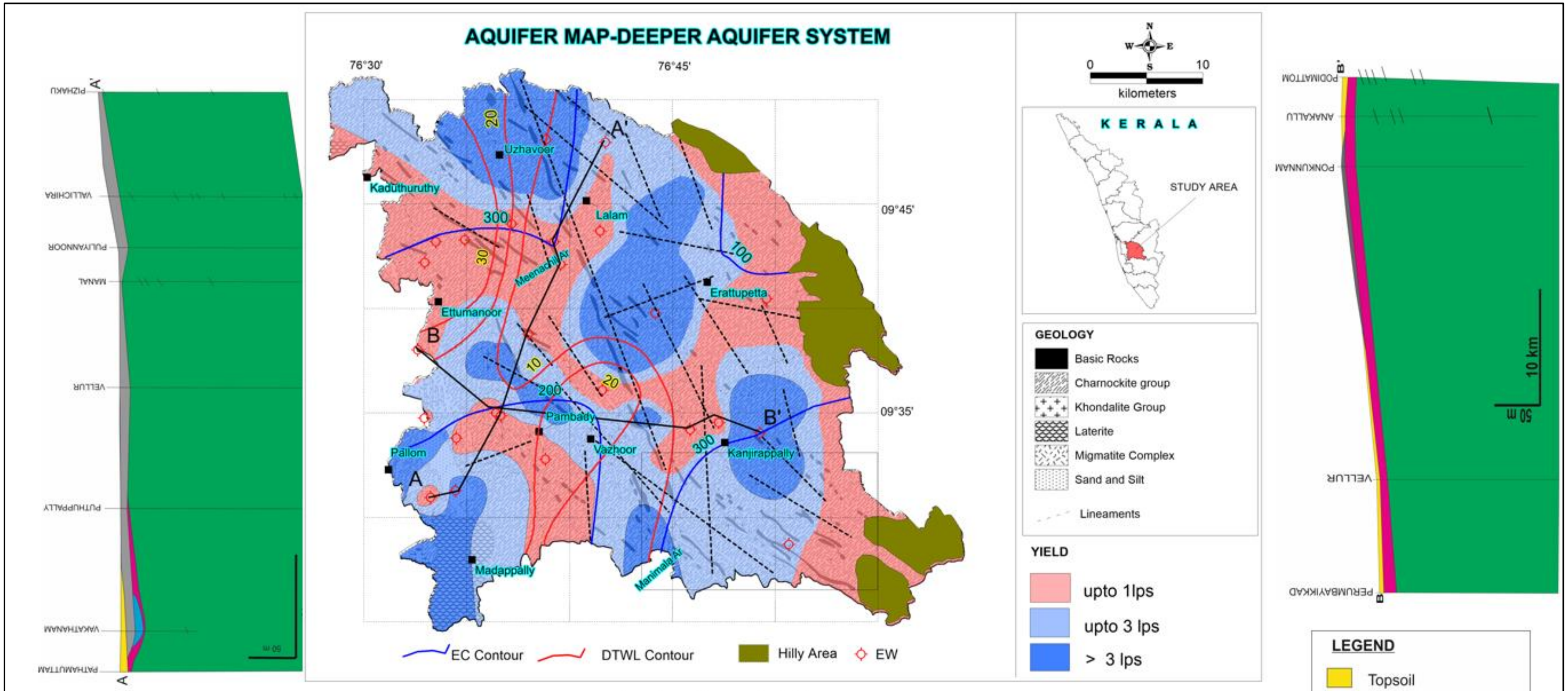


Fig:3.18: Aquifer Map-Phreatic aquifer system



Aquifer Characteristics

Transmissivity : 0.48 to 121.5 m^2/day

Storativity : 6.4×10^{-4} to 2.9×10^{-3}

Yield : 0.10- 20 lps

Potential fractures : down to 110 m depth

Fig:3.19: Aquifer Map-Deeper aquifer system

4.MANAGEMENT STRATEGIES & AQUIFER MANAGEMENT PLAN

The groundwater management strategies are inevitable for the sustainable development of the resources. Hence, it is the necessary to formulate a rational and scientific management plan suiting the area. In the present study sustainable management plan for groundwater resources is being proposed after a detailed understanding of the aquifer disposition down to the depth of 200 m bgl and estimation of available resources.

Even though the study area receives good annual rainfall of above 3000 mm, it has been experiencing increasing incidents of water scarcity during summer for meeting the irrigation as well as domestic requirements. Even in the years of normal rainfall, summer water scarcity problems are observed in the midland and highland regions of the study area. This ironic situation arose mainly due to natural reasons such as high gradient of the terrain (high rates of base flow) and limited aquifer thickness in hilly areas. Also, while formulating various groundwater development and management plans, geology and geomorphology of the area should be given prior importance. Development of water resources in the area needs a scientific management system co-ordinating the efforts of all concerned agencies for a speedy development of the agricultural sector in the area.

4.1 Sustainable Plan

An effective groundwater management practice must be preceded by an accurate account of the total available resources. From the current estimation, all the 10 blocks in the study area falls under safe category. So, there is further scope for groundwater extraction for irrigation, being stage of extraction low. One of the main problems in the development of resources in the area is the highly variable distribution of groundwaterresources in the blocks. A proper understanding of the sub-surface aquifer disposition and its properties are essential for optimal development of the resources.Thegroundwaterdevelopment should be coupled with management of water resources through rainwater harvesting and artificial recharge schemes. Farmers may be encouraged to adopt modern irrigation techniques like drip and micro irrigation to have optimal use of the available resources and community schemes must be encouraged in the eastern parts of the study area.

4.2 Augmentation Plan

Augmentation of groundwater can be achieved through periodic de-siltation as well as cleaning of existing check dams, bunds and ponds. It will increase the storage capacity as well as infiltration rate of the structures. Topography of the area plays a significant role in the selection of suitable structures for artificial recharge such as check dams, contour bunding, trenching, pitting, terrace cultivation etc. Also, uncommitted runoff from the adjoining localities may be transported to the needy areas through diversion channels. In the study area, along 1st order streams we may go for gully plugs; in 2ndorder for nallah bunds/cross bars and in 3rd and higher order for check dams to augment the groundwater recharge and also to ensure summer flow in rivers by limiting run off. Slope and soil thickness must be taken into account while constructing recharge structures, otherwise it may cause landslides.

4.3 Aquifer Management Plan

4.3.1 Short-Term Local Solutions for Groundwater Management

To provide quality drinking water, there should be an integrated water resources management system in water supply. The distribution of water should be equitable across the users. Also, proper waste collection and disposal measures are also equally important to prevent the pollution of the existing water bodies/resources. The challenge is to find ways to manage the available water resources and use it in a systematic manner without degrading the environment to sustain it for the future generations.

The conservation and renovation of existing artificial recharge structures and effective implementation of roof top rainwater harvesting is essential for resource sustainability. The role of local bodies in this regard is very important and there is a need for the convergence of State line departments and local bodies to work towards water conservation. All the existing recharge/conservation structures must be cleaned on annual basis before monsoon. Identification of high yielding, government bore wells drilled by various agencies with potable water quality helps to meet the drinking water needs of the populace especially during summer, but this is can only be considered as a short-term measure.

4.3.2 Long-Term Local Solutions for Groundwater Management

As per the Groundwater resource estimation, Net groundwater availability for future use is 135.19 MCM and stage of extraction is 37.5 %. Groundwater extraction for irrigation is low (38.61 % of the total groundwater extraction) and extraction for domestic and industrial use is the major component (61.38 %). Hence, it is proposed to construct more groundwater abstraction structures (of about 1300numbers of bore wells/ Dug wells) forcreating additionalirrigated agriculture in the cultivable/cultivable waste land of about 3200 ha available in the study area. The tentative details are given in table 4.1. Horticulture and vegetable cultivation are ideal for the area. Pollution free Industries may be proposed in identified panchayats falling along the banks of major rivers without affecting the local groundwater regime and the proposed tentative list of panchayaths are given in table 4.2.

To supplement the domestic demand in water scarce panchayaths falling along hilly areas spring development is suggested. The tentative list of perennial springs (Source: Springs of Kerala-An inventory, Centre for Water Resources Development and Management (CWRDM) ;1988) and their details are given in table 4.3.

Table 4.1: Block wise details of abstraction structures proposed for the study area

#	Block	Village	Cultivable waste land (Ha)	No. of abstraction structures (DW/BW) proposed
1	Erattupetta	Thalappalam	760	304
		Poonajar Thekkekkara	250	100
2	Kaduthuruthy	Mulakkulam	10	4
3	Kanjirappally	Erumely North	80.5	32
		Erumely South	19.4	8
4	Lalam	Vellilappally	189	76
		Kadanad	8.8	4
		Vallichira	155	62
5	Madappally	Vakathanam	567	227
		Vazhappally Padinjaru (Part)	28.5	11
6	Pallom	Ayarkunnam	20	8
7	Pampady	Chengalam East	26	10
		Anikkad	12	5
		Kooroppada	8.1	3

		Pampady	54	22
8	Uzhavoor	Veliyannoor	44.8	18
		Uzhavoor	81.7	33
9	Vazhoor	Nedumkunnam	300	120
		Vazhoor	266	106
		Vellavoor	347	139
Total			**3227.8**	**1292**

Table 4.2 List of panchayaths/municipalities where industries can be promoted

#	Block	Panchayaths	Municipality
1	Ettumanoor	--	Ettumanoor
2	Pallom	Ayarkunnam	--
		Manarcaud	--
		Vijayapuram	--
		Puthuppally	--
		Panchikkad	--
3	Uzhavoor	Kidangoor	--
4	Kaduthuruthy	Mulakkulam	--

Table 4.3:Tentative list of springs that can be developed in the study area

#	Name of Place	River Basin	Nearest Town	RL	Land use	Summer discharge
1	Mavady	Meenchil	Teekoy	330m	Rubber	3 lpm
2	Mavady	Meenchil	Teekoy	300m	Rubber	9 lpm
3	Vellathusserry	Meenchil	Vadakkekara	300m	Rubber	4 lpm
4	Vellathusserry	Meenchil	Vadakkekara	300m	Rubber	27 lpm
5	Vellathusserry	Meenchil	Vadakkekara	280m	Rubber	15 lpm
6	Vellathusserry	Meenchil	Vadakkekara	300m	Rubber	12 lpm
7	Vellathusserry	Meenchil	Vadakkekara	300m	Rubber	5l pm
8	Vellathusserry	Meenchil	Vadakkekara	280m	Rubber	5l pm
9	Kallamundimala	Meenchil	Teekoy	200m	Rubber	22 lpm
10	Vellikulam	Meenchil	Teekoy	620m	Shrubs	100 lpm
11	Kallam	Meenchil	Teekoy	140m	Tapioca	1 lpm
12	Vellikulam	Meenchil	Teekoy	620m	Shrubs	100 lpm
13	Kallam	Meenchil	Teekoy	140m	Tapioca	1 lpm
14	Vellikulam	Meenchil	Teekoy	580m	Shrubs	6 lpm
15	Thonikallu	Meenchil	Melukavu	300m	Rubber	5 lpm
16	Kallillakavala	Meenchil	Teekoy	940m	Tapioca	22 lpm
17	Vadakkum Bhagom	Meenchil	Melukavu	300m	Coconut	1 lpm
18	Kalluvettom	Meenchil	Melukavu	350m	Rubber	30 lpm
19	Poomchira	Meenchil	Melukavu	600m	Shrubs	500 lpm
20	Karakkal	Meenchil	Melukavu	380m	Rubber	10 lpm
21	Vithirikunnu	Manimala	Madappally	400m	Rubber	1 lpm

22	Thavarkavu	Manimala	Madappally	400m	Rubber	4 lpm

Several abandoned quarries are present in the study area; the water storage in the quarries can be used during lean periods to meet domestic/irrigational requirements after proper treatments if required. Based on available data on abandoned quarries (49.83 ha) collected from Kerala Land use Board and by taking an approximate of 2m water column storage in them, the quantum of water stored is estimated, and calculated to be 0.99 MCM and is given in table 4.4. The existing water stored in the quarries should be pumped out and cleaned after which a retaining wall should be constructed around them to prevent the inflow of polluted water from adjoining areas. If inflow of water from surrounding areas is facilitated, then the water should be purified before usage.

Table 4.4: Block wise area of abandoned quarries and tentative water storage (mcm)

#	Block	Area (Ha)	Water storage during Summer (MCM)
1	Kanjirappally	6.49	0.1298
2	Madappally	3.77	0.0754
3	Erattupetta	1.12	0.0224
4	Kaduthuruthy	6.21	0.1242
5	Lalam	5.49	0.1098
6	Pallom	11.55	0.231
7	Pampady	1.81	0.0362
8	Uzhavoor	8.24	0.1648
9	Vazhoor	3.86	0.0772
10	Ettumanoor	1.29	0.0258
Total		49.83	0.99

Large scale implementation of roof-top rainwater harvesting in storage tanks and recharge through existing dug wells in highland areas, needs to be encouraged. Recharge of rainfall (especially during summer) through such wells is expected to extend groundwater availability during summer months. Also, from the current study it has been observed that, even after receiving quite higher amounts of rainfall, major part of the study exhibits rise in water levels in the range of 0-2 m. Hence, recharge sites/structures should be selected site specifically considering this fact in background. The water scarcity in hilly areas (particularly in Erattupetta block) where the scope for artificial recharge is limited may be addressed by collecting and storing rain water in tanks.

Construction of a series of 68 nos. check dams,98 nos. nallah bunds (NB)/vented cross bars (VCB)and 46 percolation ponds are proposed along the river courses in the second, third and fourth order streams at suitable locations, after having detailed feasibility study. Gulley plugs and contour bunds can also be attempted across the first order streams and adjoining areas considering the slope of the terrain and thickness of weathered formation. Also, regulators may be constructed along higher order river courses, to store non-monsoon base flow without problems of land submergence. Again, five sub-surface dykes are proposed in the study area and the actual field feasibility may be re-affirmed after detailed hydrogeological investigations. Details of tentative block-wise feasiblegroundwater recharge/conservation structures proposed are given in Table 4.6 and is shown in Figure 4.1.CGWB has implemented the following artificial recharge structures in the district (Table 4.5.).

Table 4.5: Artificial recharge structures in Kottayam district constructed by CGWB

#	Location	Type of structure	Year of completion
1	Njeezhur	Sub surface Dyke	2000
2	Parinthanam	Roof Top Rain Water Harvesting	2001
3	Chirakulam	Percolation tank	2001

The quality of groundwater in the study area is good for domestic as well as irrigation purpose. However, problems of iron contamination (above the permissible limit as per BIS) are reported and it can be overcome by oxidation followed by filtration. The oxidant chemically oxidises the iron (forming particle) and kills coliform bacteria as well as other disease-causing bacteria that may be present. National Environmental Engineering Research Institute (NEERI) has developed a house hold iron removing unit. This unit works on the principle of oxidation of iron by $KMNO_4$ and removal of precipitated iron by sand and filtration. Required quantity of $KMNO_4$ is added in the iron contaminated water and mixed with a stick. The chemical oxidises the iron and yellowish-brown precipitate is formed. After 5 to 10 minutes of mixing water is allowed to flow by gravity into the sand filter at the rate of 300 to 400 ml/minute. Filtered water with iron concentration less than 0.3 mg/litre is collected in plastic container and may be used for domestic purpose. The dose of $KMNO_4$ required is about 50% of the iron concentration in water. Also, to prevent bacteriological contamination from septic tanks double or triple chambered septic tanks may be used in the study area.

Since groundwater is an invisible common pool resource, it brings with it a set of complexities about who uses and who provides. When a potential user overuses groundwater, it leads to a situation where it affects the availability of water for a community. Similarly, dilemmas arise about who develops and manages the water and who uses it, because being a common pool resource, it becomes difficult to exclude users.

Also, participation of the various stake holders in water management brings a discipline into the process and there by the users may arrive at mutually agreed decisions on usage and recharge. Also, it builds in an ethos of self-regulation and sustainable use of groundwater for all to follow.

Some of the educatedlocal people may be identified and imparted basic training on groundwater, relevance of aquifer mapping, participatory management, etc. With this objective, Central Ground Water Board organized one water management training programme during the year 2014 at Mahatma Gandhi University Campus, Athirampuzha, Kottayam and 30 participants attended the training. The main aim of the programme was to provide training to different stakeholders on various aspects of ground water management techniques. They can also be entrusted with activities like water budgeting, assessment of crop water requirements etc.

Participatory Groundwater Management (PGWM) should be an aquifer-based and community-centric approach, that has emerged as an alternative for managing groundwater. To ensure community participation in water level monitoring, Central Ground Water Board has entrusted 2-point observers in Kottayam district at Pallom (Nattakom) and at Kumarakom for measuring and recording weekly water levels from the dug well tapping phreatic aquifer at these places.

Table 4.6: Tentative details of groundwater recharge/conservationstructures feasible in the area

#	Block	Total Area (Sq.Km.)	Type	No: of Structures Feasible
1	Kanjirappally	222	Check Dam	13
			VCB/NB	20
			Percolation ponds	10
			Sub-surface Dyke	--
2	Madappally	44.38	Check Dam	2
			VCB/NB	5
			Sub-surface Dyke	1
			Percolation ponds	4
3	Erattupetta	152.51	Check Dam	6
			VCB/NB	12
			Percolation ponds	3
			Sub-surface Dyke	--
4	Kaduthuruthy	65.53	Check Dam	3
			VCB/NB	5
			Percolation ponds	3
			Sub-surface Dyke	--
5	Lalam	189.39	Check Dam	8
			VCB/NB	12
			Percolation ponds	6
			Sub-surface Dyke	--
6	Pallom	94.56	Check Dam	8
			VCB/NB	6
			Percolation ponds	6
			Sub-surface Dyke	--
7	Pampady	166.3	Check Dam	8
			VCB/NB	14
			Percolation ponds	3
			Sub-surface Dyke	1
8	Uzhavoor	223.3	Check Dam	8
			VCB/NB	12
			Percolation ponds	4
			Sub-surface Dyke	2
9	Vazhoor	142.24	Check Dam	12
			VCB/NB	10
			Percolation ponds	6
			Sub-surface Dyke	1
10	Ettumanoor	27.69	Check Dam	--
			VCB/NB	2
			Percolation ponds	1
			Sub-surface Dyke	--

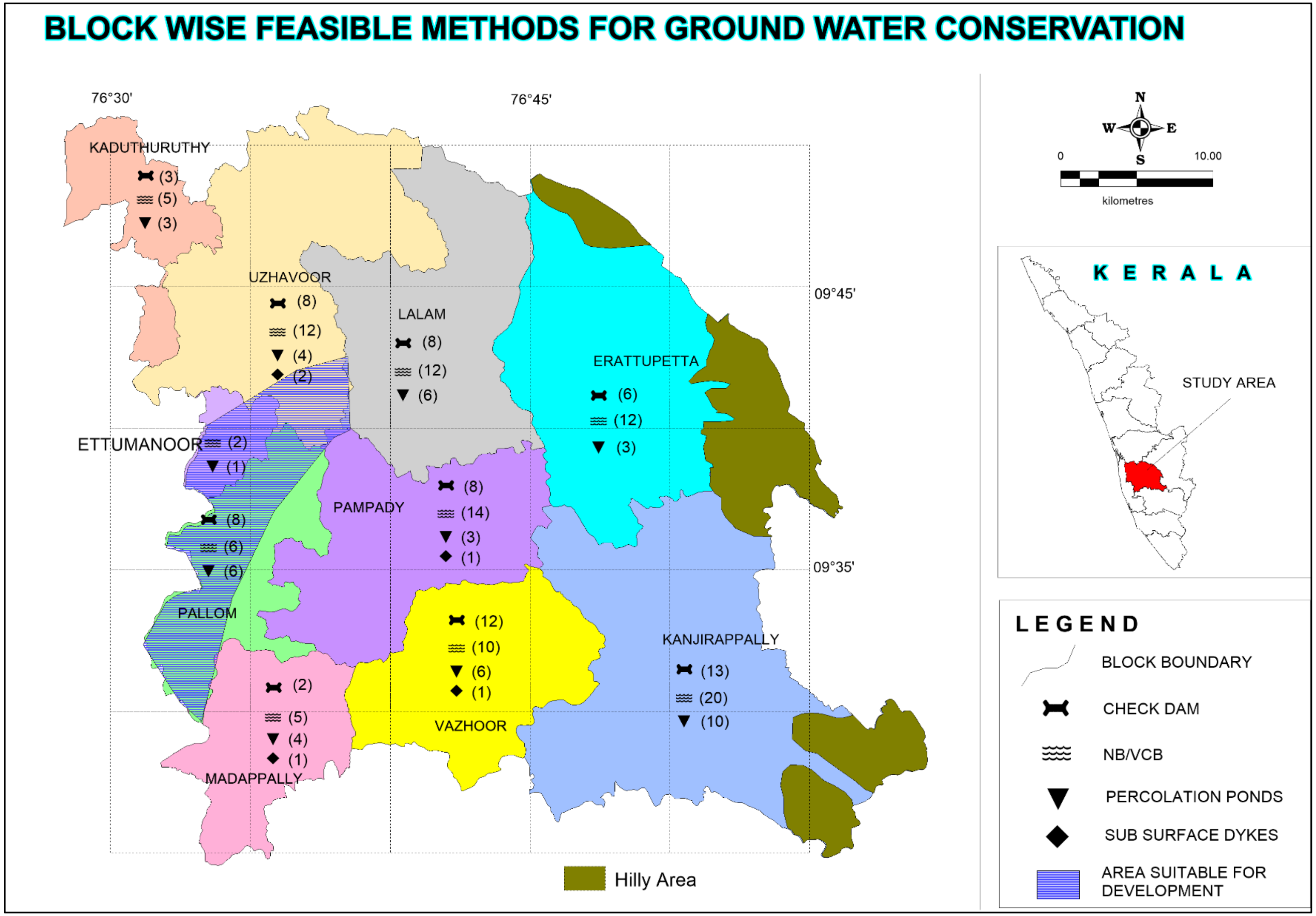


Fig.4.1: Feasible water conservation structures in the study area

Annexure I :Details of GWMWs in the Study area

#	Location	Latitude	Longitude	Type of Well	Altitude (amsl)	MP (magl)	Diameter (m)	Depth (mbgl)	Dtwl - Apr 2018 (mbgl)	Dtwl - Nov 2018 (mbgl)	Aquifer	Geology
1	Arunuttimangalam	9.8008	76.4979	Dug Well	30.4	0.63	2.34	8.5	--	5.92	Unconfined	Charnockite
2	Ayarkunnam	9.6333	76.6053	Dug Well	19	0.85	2.1	8.73	4.83	4.93	Unconfined	Charnockite
3	Chamampathal	9.538	76.7212	Dug Well	43.7	0.6	2.9	6.6	3.3	3.2	Unconfined	Charnockite
4	Cheruthikara	9.6088	76.6093	Dug Well	21.3	0.7	1.8	8.8	5	4.48	Unconfined	Charnockite
5	Cheruvalli	9.5184	76.7661	Dug Well	108.7	0.7	2.8	8.4	5.9	1.9	Unconfined	Charnockite
6	Chotti	9.566	76.8471	Dug Well	93.2	0.75	2.2	6.8	4.25	4.45	Unconfined	Charnockite
7	Edakadathy	9.4253	76.9124	Dug Well	112.9	0.5	2	12	DRY	9.15	Unconfined	Charnockite
8	Edamaruku	9.7402	76.7637	Dug Well	71.9	0.8	2.5	5.9	3.5	3.4	Unconfined	Charnockite
9	Elamkulam	9.5996	76.7319	Dug Well	146.7	0.78	2.8	7.5	4.48	3.42	Unconfined	Charnockite
10	Erumeli	9.4801	76.8435	Dug Well	53.9	1.1	2.1	7.97	5.17		Unconfined	Charnockite
11	Ettumannur	9.6688	76.5565	Bore well	24.3	0.6	0.17		0.97	1.21	Unconfined	Charnockite
12	Ettumannur East (R1)	9.6702	76.5722	Dug Well	21.9	0.75	2.5	7	7.79	4.7	Unconfined	Charnockite
13	Kadaplamattom	9.7147	76.6093	Dug Well	57.6	0.75	3	8.37	5.17	5.25	Unconfined	Charnockite
14	Kalakatty	9.617	76.7773	Dug Well	76	0.76	2.6	7.87	5.44	4.34	Unconfined	Charnockite
15	Kalathipady	9.59	76.5543	Dug Well	23	1.4	2.1	12.3	9.21	7	Unconfined	Charnockite
16	Kalathur	9.7203	76.5441	Dug Well	66.4	0.75	2.6	8.22	6.25	6.56	Unconfined	Charnockite

#	Location	Latitude	Longitude	Type of Well	Altitude (amsl)	MP (magl)	Diameter (m)	Depth (mbgl)	Dtwl - Apr 2018 (mbgl)	Dtwl - Nov 2018 (mbgl)	Aquifer	Geology
17	Kangazha	9.53	76.6732	Dug Well	89.3	1	3	9.35	5.34	6.05	Unconfined	Charnockite
18	Kanjirapally	9.5561	76.7811	Dug Well	120	0.8	2.7	11.38	7.2	9.9	Unconfined	Charnockite
19	Kidangoor	9.6657	76.6091	Bore well	23.7	0.7	0.17		7.3	6.3	Unconfined	Charnockite
20	Kidangur-R1	9.6656	76.6091	Dug Well	24	0.8	3.25	8.22	4.31	5.1	Unconfined	Charnockite
21	Kollappally	9.7646	76.6997	Dug Well	34.7	0.75	2.5	5.5	3.25	3.07	Unconfined	Charnockite
22	Kooroppada	9.5998	76.6477	Dug Well	65.3	0.8	2.75	5.84	4.2	2.28	Unconfined	Charnockite
23	Koothrappally	9.4944	76.6293	Dug Well	44.8	0.6	2.4	10	4.61	4.65	Unconfined	Charnockite
24	Kozha	9.7711	76.5697	Dug Well	34.4	0.9	2.5	5.35	1.8	1.95	Unconfined	Charnockite
25	Kozhuvanal	9.6548	76.6644	Dug Well	91.4	0.72	3	6.1	5	4.58	Unconfined	Charnockite
26	Kummannur	9.6883	76.6217	Dug Well	35.8	0.7	2.75	9.74	8.6	5.25	Unconfined	Charnockite
27	Kuravilangad	9.7573	76.5533	Bore well	38.7	0.77	0.17		5.85	3.58	Unconfined	Charnockite
28	Kuravilangad1	9.7573	76.5532	Dug Well	39.3	0.6	2.1	8.4	6	3.9	Unconfined	Charnockite
29	Kuttikal-R1	9.581	76.8826	Dug Well	93.9	0.8	1.75	5.53	--	3.4	Unconfined	Charnockite
30	Kuvapalli	9.5262	76.8269	Dug Well	107.5	0.85	2.5	9.1	7.15	--	Unconfined	Charnockite
31	Manimala	9.4918	76.7513	Dug Well	24.6	0.7	2	10.5	4.72	4.85	Unconfined	Laterite
32	Marangattupalli	9.7413	76.6139	Dug Well	31.6	0.98	3	7.72	5.02	2.92	Unconfined	Charnockite
33	Melukavumattom	9.7854	76.7616	Dug Well	88.6	0.6	2.75	9.36	3.4	5	Unconfined	Charnockite

#	Location	Latitude	Longitude	Type of Well	Altitude (amsl)	MP (magl)	Diameter (m)	Depth (mbgl)	Dtwl - Apr 2018 (mbgl)	Dtwl - Nov 2018 (mbgl)	Aquifer	Geology
34	Monipalli	9.8101	76.5757	Dug Well	64	0.68	2.9	3.98	1.6	2.85	Unconfined	Charnockite
35	Mukkada	9.4633	76.8071	Dug Well	99.5	0.7	2.4	9.86	DRY	5.75	Unconfined	Charnockite
36	Mukkoottuthara	9.4468	76.8766	Dug Well	115.3	0.7	1.7	6.5	4.44	2.58	Unconfined	Charnockite
37	Mundakayam	9.5414	76.886	Dug Well	111.4	0.7	3	10.16	DRY	4.5	Unconfined	Charnockite
38	Mundukuzhi	9.4633	76.6092	Dug Well	45.5	0.8	1.9	12.42	10.65	7.02	Unconfined	Charnockite
39	Mutholi	9.6929	76.6567	Dug Well	19.5	0.7	2.7	8	6.26	6.25	Unconfined	Gneiss/Amphibolite/Granulite
40	Narianganam	9.727	76.7391	Dug Well	92.4	0.75	2.2	8	4.45	4.13	Unconfined	Charnockite
41	Nedumkunnam	9.5076	76.6618	Dug Well	70	0.5	2.1	10.3	5.05	6.6	Unconfined	Gneiss/Amphibolite/Granulite
42	Paippad	9.4232	76.5829	Dug Well	26	0.8	1.6	11.1	9.2	7.44	Unconfined	Charnockite
43	Palai	9.4232	76.5829	Dug Well	26	0.83	3.25	9.67	5.57	4.72	Unconfined	Charnockite
44	Pallikkathodu (R1)	9.6	76.6847	Dug Well	95.2	0.85	1.7	10.5	6.15	5.73	Unconfined	Gneiss/Amphibolite/Granulite
45	Pambadi	9.5634	76.6455	Dug Well	41.6	2.8	2.13	9.95	5.9	5.4	Unconfined	Charnockite
46	Panackapalam Jn	9.6999	76.7582	Dug Well	28.4	0.8	2.2	8.2	4.9	4.75	Unconfined	Charnockite
47	Paruthumpara	9.5289	76.5407	Dug Well	32.2	1.05	3.2	12.4	7.13	6.9	Unconfined	Charnockite
48	Plakkalpadi	9.5124	76.7008	Dug Well	90	0.8	2.7	12	6.2	5.25	Unconfined	Charnockite
49	Ponad	9.7372	76.67	Dug Well	69.1	0.8	2.75	11.5	9.2	6.05	Unconfined	Charnockite
50	Ponthanpuzha	9.4642	76.7812	Dug	46.6	0.8	2.2	11	--	--	Unconfined	Laterite

#	Location	Latitude	Longitude	Type of Well	Altitude (amsl)	MP (magl)	Diameter (m)	Depth (mbgl)	Dtwl - Apr 2018 (mbgl)	Dtwl - Nov 2018 (mbgl)	Aquifer	Geology
				Well								
51	Poonjar	9.6734	76.7958	Bore well	57.8	0.77	0.17	--	5.79	5.38	Unconfined	Charnockite
52	Poovathilappu	9.6263	76.6743	Dug Well	125.9	0.9	2.75	5.95	4.4	3.65	Unconfined	Charnockite
53	Pravithanam	9.7461	76.7014	Dug Well	62	0.8	3	9.5	4.5	4.9	Unconfined	Charnockite
54	Pulikkal Kavala	9.5579	76.6811	Dug Well	64.4	0.7	1.85	5.44	4.44	3.6	Unconfined	Charnockite
55	Punjar	9.6747	76.8078	Dug Well	36	1	3.4	3.59	0.57	1.2	Unconfined	Charnockite
56	Punnaveli	9.475	76.6786	Dug Well	69.4	0.4	1.9	6.7	5.91	4.35	Unconfined	Charnockite
57	Puthupally	9.5558	76.5735	Dug Well	20.1	0.85	2.6	10.5	7.15	6.55	Unconfined	Charnockite
58	Ramapuram (R1)	9.7952	76.6636	Dug Well	42.4	0.6	1.7	10	5.58	4.05	Unconfined	Gneiss/Amphibolite/Granulite
59	Teekoy	9.6997	76.809	Dug Well	45.3	0.75	2.2	8	4.25	4.1	Unconfined	Charnockite
60	Thekethukavala	9.5364	76.7564	Dug Well	98.6	0.8	2.85	8.74	4.89	5.55	Unconfined	Charnockite
61	Thidanad	9.6576	76.7766	Dug Well	32.3	0.62	2.35	8	4.28	--	Unconfined	Gneiss/Amphibolite/Granulite
62	Thiruvanchoor	9.6228	76.5766	Dug Well	28.9	0.8	2.75	6.62	3.9	--	Unconfined	Charnockite
63	Thottakkad	9.5301	76.6055	Dug Well	25.1	1.1	3.55	8.6	5.46	5.65	Unconfined	Charnockite
64	Trikodithanam	9.4331	76.5663	Dug Well	20.8	0.75	2.85	15.4	DRY	11.3	Unconfined	Charnockite
65	Trikodithanam	9.4427	76.581	Bore well	33.4	0.75	0.17	--	16.25	11.76	Semi-Confined	Charnockite
66	Urulikunnam	9.6435	76.7095	Dug Well	57.2	0.72	2.74	6.75	4.8	3.88	Unconfined	Charnockite

#	Location	Latitude	Longitude	Type of Well	Altitude (amsl)	MP (magl)	Diameter (m)	Depth (mbgl)	Dtwl - Apr 2018 (mbgl)	Dtwl - Nov 2018 (mbgl)	Aquifer	Geology
67	Uzhavoor (R1)	9.7921	76.6111	Dug Well	78.1	0.8	2.1	4.55	3.2	2.65	Unconfined	Charnockite
68	Vakathanam	9.5227	76.5727	Dug Well	23	0.9	2.5	9.8	5.4	5.1	Unconfined	Charnockite
69	Vazhur	9.5696	76.7231	Dug Well	69.8	0.7	1.85	6.9	4.8	4.85	Unconfined	Charnockite
70	Vempalle	9.7191	76.5599	Dug Well	19.6	0.8	2.42	4.8	2.37	1.91	Unconfined	Charnockite
71	Veyilkanampara (Kondur)	9.671	76.781	Dug Well	79.7	0.85	3.1	9	5.35	5.1	Unconfined	Charnockite

Annexure II:Details of KOWs in the Study area

#	Location	Latitude	Longitude	Type of Well	Altitude (amsl)	MP (magl)	Diameter (m)	Depth (mbgl)	Dtwl - Apr 2018 (mbgl)	Dtwl - Nov 2018 (mbgl)	Aquifer	Geology
1	Arumanoor	9.6444	76.5875	Dug Well	15.3	0.62	1.6	5.66	3.74	3.16	Unconfined	Laterite After Charnockite
2	Manal-Mattakkara	9.6406	76.6366	Dug Well	19.6	0.3	3.73	4.7	0.35	1.8	Unconfined	Laterite
3	Manarcaud	9.5952	76.5851	Dug Well	26.2	0.55	2	7.45	4.55		Unconfined	Laterite
4	Pulimood Jn.-Kollad	9.5532	76.538	Dug Well	24.2	0.85	1.9	9.35	8.15	7.25	Unconfined	Laterite
5	Ithithanam	9.485	76.5357	Dug Well	27	0.75	2.5	10.55	8.05	8.55	Unconfined	Laterite
6	Vallikkad	9.5037	76.5723	Dug Well	21.9	0.75	2.2	12.15	11.15	12.05	Unconfined	Laterite
7	Velloor	9.5777	76.6158	Dug Well	31.6	1.2	4.2	6.65	5.2	5.3	Unconfined	Laterite
8	Mundathanam	9.4946	76.7081	Dug Well	108.9	0.8	2.2	7.6	6.3	6.7	Unconfined	Fractured Weathered Charnockite
9	Kulathoor Moozhi	9.4608	76.7107	Dug Well	26.3	1	2.6	6.5	3.5	3.28	Unconfined	Laterite
10	Karikkattoor-Centre	9.4831	76.784	Dug Well	107.2	1.1	2.8	5.9	2.18	4.33	Unconfined	Fractured Weathered Charnockite
11	Chenappady	9.5084	76.7951	Dug Well	43.8	0.9	2.65	4.9	1.8	3	Unconfined	Laterite
12	Anakallu	9.578	76.7863	Dug Well	47.1	1	1.5	6.15	3.9	3.6	Unconfined	Laterite
13	Ponkunnam-20th Mile	9.565	76.746	Dug Well	119.6	0.9	2.8	7.82	6.35	5.68	Unconfined	Fractured Weathered Charnockite
14	Poovarani	9.6687	76.7064	Dug Well	31.6	1.05	2.4	6.5	2.55	2.9	Unconfined	Fractured Weathered Charnockite
15	Mallikasserry	9.6486	76.7493	Dug Well	34.9	0.7	2.3	6.9	2	2.2	Unconfined	Laterite
16	Kannimala	9.4942	76.8705	Dug Well	90	0.85	2.45	7.05	1.35	1.45	Unconfined	Fractured Weathered Charnockite

#	Location	Latitude	Longitude	Type of Well	Altitude (amsl)	MP (magl)	Diameter (m)	Depth (mbgl)	Dtwl - Apr 2018 (mbgl)	Dtwl - Nov 2018 (mbgl)	Aquifer	Geology
17	Kulamamkuzhy	9.4473	76.847	Dug Well	97.9	0.68	1.85	7.3	2.55	3.42	Unconfined	Fractured Weathered Charnockite
18	Panackachira	9.5014	76.9274	Dug Well	173.7	0.8	2.3	6.2	3.5	4.4	Unconfined	Fwk
19	Koruthode	9.4766	76.9566	Dug Well	126.7	1.4	2.7	8.7	3.7	4	Unconfined	Fractured Weathered Charnockite
20	Pariyaramangalam	9.7023	76.609	Dug Well	22.6	0.7	3.2	5.4	2.95	2.95	Unconfined	Fractured Weathered Charnockite
21	Kadappoor	9.6992	76.5854	Dug Well	15.1	0.8	2.5	6.4	4.9	5.15	Unconfined	Laterite
22	Bharananganam	9.7027	76.7233	Dug Well	31.6	1	2.3	4.5	0.4	2.68	Unconfined	Fractured Weathered Charnockite
23	Pathambuzha	9.6223	76.8407	Dug Well	127.1	0.6	2.5	9.4	5.3	5.5	Unconfined	Fractured Weathered Charnockite
24	Njarkadu	9.6385	76.8808	Dug Well	304.6	0.7	2.8	8.9	7.5	7.1	Unconfined	Fractured Weathered Charnockite
25	Velathusserry	9.6905	76.8458	Dug Well	209.9	0.9	2.6	7.2	4.5	5.42	Unconfined	Fractured Weathered Charnockite
26	Mangalagiri	9.6997	76.8324	Dug Well	90.2	1.1	2.5	5	0.5	3	Unconfined	Fractured Weathered Charnockite
27	Elappunkal	9.7008	76.785	Dug Well	31.3	0.75	2.7	11.55	6.25	8.45	Unconfined	Fractured Weathered Charnockite
28	Kurumannu	9.7783	76.7296	Dug Well	116.5	0.8	2.8	5.2	1.7	3.48	Unconfined	Fractured Weathered Charnockite
29	Manathur	9.8069	76.6897	Dug Well	48.7	0.9	3.4	7.6	4.3	4.6	Unconfined	Fractured Weathered Charnockite
30	Idiyanal	9.8193	76.6676	Dug Well	80.9	0.85	1.6	8.65	4.15	5.85	Unconfined	Fractured Weathered Charnockite
31	Amanakara	9.8157	76.6387	Dug Well	61.3	0.8	2.4	6.9	4.2	5.4	Unconfined	Laterite
32	Thamarakadu	9.8302	76.621	Dug Well	68.3	0.6	2.8	8.2	5.3	5.2	Unconfined	Laterite

#	Location	Latitude	Longitude	Type of Well	Altitude (amsl)	MP (magl)	Diameter (m)	Depth (mbgl)	Dtwl - Apr 2018 (mbgl)	Dtwl - Nov 2018 (mbgl)	Aquifer	Geology
33	Veliyannoor	9.8219	76.6087	Dug Well	52.1	0.3	1.5	7.7	3.6	4.3	Unconfined	Laterite
34	Chethimattam	9.7784	76.6129	Dug Well	70.2	0.8	2.5	9.3	3.5	--	Unconfined	Fractured Weathered Charnockite
35	Vallichira	9.7236	76.646	Dug Well	27.2	0.8	2.4	7.2	3.3	3.85	Unconfined	Fractured Weathered Charnockite

Annexure -III Consolidated lithologs of EWs drilled by CGWB in the study area

<u>1). Site: Pathamuttam</u>
Latitude :9.5152
Longitude:76.5541

Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	7.24	7.24	Top Soil
7.24	8.24	1	Highly Weathered Charnockite
8.24	61.37	53.13	Weathered and Moderately Fractured Charnockite
61.37	114.71	53.34	Fresh and Slightly Fracturedcharnockite
114.71	164.43	49.72	Fresh and Massive with Occasional Fractures
164.43	200.53	36.1	Hard and Massive Charnockite
Casing	8.4 mbgl		
Discharge	Dry		
Static Water Level	NA		
Fractures	61 to 68 mbgl		
Transmissivity	NA		
Storativity	NA		

<u>2). Site: Vellur</u>
Latitude: 9.5806
Longitude: 76.6111

Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	6.8	6.8	Laterite
6.8	50.47	43.67	Moderately Fractured Charnockite
50.47	95.85	45.38	Slightly Fractured Charnockite
95.85	200.53	104.68	Hard Massive Charnockite
Casing	6.8 mbgl		
Discharge	0.5 lps		
Static Water Level	12.64 mbgl		
Fractures	38.84 mbgl		
Transmissivity	NA		
Storativity	NA		

<u>3). Site: Manal</u>
Latitude: 9.6458
Longitude: 76.6333

Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	9.43	9.43	Laterite
9.43	54.09	44.66	Charnockite Hard and Massive
54.09	152.81	98.72	Moderately Fractured Charnockite
152.81	200.53	47.72	Moderately Fractured Charnockite
Casing	9.5 Mbgl		
Discharge and Drawdown	3 lps and 20.07 m		
Static Water Level	2.13 mbgl		
Fractures	42.85, 73		
Transmissivity	0.5 m^2/day		

3). Site: Manal **Latitude: 9.6458** **Longitude: 76.6333**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
Storativity	NA		

4). Site: Vilakkumadam **Latitude: 9.6625** **Longitude: 76.7361**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	4.9	4.9	Laterite
4.9	90	85.1	Charnockite Highly Fractured, Melanocratic
90	130	40	Charnockite Highly Fractured, Leucocratic
130	183.3	53.3	Charnockite Highly Fractured, Coarse Grained
Casing	5 mbgl		
Discharge and Drawdown	20lps, 19.7 m		
Static Water Level	2.24mbgl		
Fractures	7, 54 ,73 ,130 mbgl		
Transmissivity	121.5m^2.day		
Storativity	NA		

5). Site: Vallichira **Latitude: 9.719271** **Longitude: 76.654018**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	8.25	8.25	Laterite
8.25	35.23	26.98	Charnockite Highly Fractured, Melanocratic
35.23	122.23	87	Charnockite Highly Fractured, Leucocratic
122.23	200.53	78.3	Charnockite Highly Fractured, Coarse Grained
Casing	8.3 mbgl		
Discharge and drawdown	1.2 lps and 16.91		
Static Water Level	1.54 mbgl		
Fractures	38.85 to 61.4 mbgl		
T	0.48m^2/d		
S	NA		

6). Site: Kalathoor **Latitude: 9.7194** **Longitude: 76.5583**			
Depth from (Mbgl)	**Depth to (Mbgl)**	**Thickness (M)**	**Lithology**
0	12.35	12.35	Laterite

12.35	15.35	3	Hard and Massive Charnockite
15.35	122.33	106.98	Slightly Fractured Charnockite
122.33	200.53	78.2	Hard and Massive Charnockite
Casing	12.4 mbgl		
Discharge	Dry		
Static Water Level	NA		
Transmissivity	NA		
Storativity	NA		

7). Site: Pizhaku **Latitude: 9. 7986** **Longitude: 76.6958**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	4.2	4.2	Laterite
4.2	54.09	49.89	Fractured Charnockite
54.09	99.47	45.38	Highly Fractured Charnockite
99.47	168.05	68.58	Moderately Fractured Charnockite
168.05	200.53	32.48	Charnockite Highly Fractured
Casing	4.2 mbgl		
Discharge	3 lps and 4.9 m		
Fractures	8.37, 35.23 and 58 mbgl		
Static Water Level	3.97 mbgl		
Transmissivity	20.85m^2/day		
Storativity	NA		

8). Site: Podimattom **Latitude: 9.5666** **Longitude: 76.8208**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	5.02	5.02	Laterite
5.02	15.5	10.48	Highly Weathered Charnockite
15.5	41	25.5	Slightly Fractured; More Fractures At 10-20 And 24-28 M Bgl
41	52	11	Moderately Fractured Charnockite With Highly Fractured Zone At 47-49.5
52	87	35	Highly Weathered Charnockite
87	91	4	Charnockite Hard Massive
91	117	26	Slightly Fractured
117	128	11	Massive Charnockite
128	139.07	11.07	Moderate to Highly Fractured
Casing	5.8 mbgl		
Discharge and Drawdown	13.7 lps and 5.31 m		
Static Water Level	5.09 mbgl		
Fractures	Full		

8). Site: Podimattom **Latitude: 9.5666** **Longitude: 76.8208**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
Transmissivity	104.8 m^2/day		
Storativity	2.9 X 10-^{3}		

9). Site: Anakallu **Latitude: 9.5750** **Longitude: 76.7875**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	4	4	Laterite
4	15	11	Highly Weathered Charnockite
15	30	15	Slightly Fractured
30	36	6	Highly Fractured Charnockite
36	50	14	Moderately Fractured Charnockites
50	69	19	Highly Fractured with Less Fractured Zone at 55-58 mbgl
69	161.5	92.5	Hard Massive Charnockite
161.5	164.5	3	Slightly Fractured
164.5	215.77	51.27	Hard Massive Charnockite
Casing	5.26 mbgl		
Discharge	0.1 lps		
Static Water Level	1.89 mbgl		
Fractures	36-50 mbgl		
Transmissivity	NA		
Storativity	NA		

10). Site: Erumely **Latitude :9. 4777** **Longitude: 76.8444**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	3.65	3.65	Laterite
3.65	15	11.35	Highly Weathered and Fracturedcharnockite
15	19	4	Slightly Fractured
19	21	2	Fractured Charnockite
21	27.5	6.5	Massive Charnockite

10). Site: Erumely **Latitude :9. 4777** **Longitude: 76.8444**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
27.5	107.1	79.6	Moderately Fractured
107.1	122.33	15.23	Highly Fracturedcharnockite
122.33	149.19	26.86	Moderately Fractured
149.19	160.43	11.24	Massive Charnockite
160.43	175.67	15.24	Quartz Vein
175.67	181	5.33	Highly Fracturedcharnockite
181	198.53	17.53	Quartz Vein
Casing	4.1mbgl		
Discharge and drawdown	2.6 lps and 19.01 m		
Static Water Level	1.73 mbgl		
Fractures	76-84, 92-96, 115-119		
Transmissivity	8.7 m^2/day		
Storativity	NA		

11). Site: Kanakkary **Latitude: 9.7027** **Longitude: 76.5494**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	4	4	Top Soil
4	9	5	Weathered Charnockite
9	45	36	Massive Charnockite: Leucocratic to Mesocratic, Medium to Coarse Grained.
45	45.5	0.5	Fractured Charnockite.
45.5	48	2.5	Massive Charnockite: Leucocratic to Mesocratic, Medium to Coarse Grained.
48	48.25	0.25	Fractured Charnockite.
48.25	65	16.75	Massive Charnockite: Leucocratic to Mesocratic, Medium to Coarse Grained.
65	106	41	Massive Charnockite: Leucocratic. Medium to Coarse Grained.
106	150	44	Massive Charnockite: Leucocratic to Mesocratic, Medium to Coarse Grained.
150	172	22	Massive Charnockite: Leucocratic. Medium to Coarse Grained.
Casing	9mbgl		
Discharge	Dry		
Static Water Level	Dry		
Fractures	45 to 45.5 and 48 to 48.25		
Transmissivity	NA		
Storativity	NA		

12). Site: Kanjikuzhy **Latitude: 9.5833** **Longitude:76.5469**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	3	3	Lateritic soil
3	17.5	14.5	Weathered Charnockite: light grey to purple in colour, consist of highly weathered feldspargroup of minerals and quartz grains. accessory mineral biotite
17.5	60	42.5	Massive charnockite: leucocratic to melanocratic, medium to coarse grained. Consists of green Coloured Feldspar Group of Minerals, Pyroxene and Quartz Group of Minerals.
60	61	1	Fractured Charnockite.
61	110	49	Massive Charnockite: Leucocratic, Medium to Coarse Grained.
110	111	1	Fractured Charnockite.
110	154	44	Massive Charnockite: Light Grey to Dark Grey in Colour, Medium to Coarse Grained.
154	200	46	Massive Charnockite: Dark Grey in Colour, Medium to Coarse Grained.
Casing	17.4 mbgl		
Discharge	0.5 lps		
Static Water Level	NA		
Fractures	19 to 19.5, 60.70 to 61.00 and 110 to 111		
Transmissivity	NA		
Storativity	NA		

13). Site: Kondadu **Latitude: 9.8008** **Longitude: 76.6477**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	3	3	Lateritic soil
3	8.5	5.5	Weathered Charnockite
6	38	32	Massive charnockite: leucocratic to melanocratic, medium to coarse grained.
38	39	1	Fractured charnockite: leucocratic to melanocratic, coarse to very coarse grained.
39	90	51	Massive charnockite
90	91	1	Charnockite intruded by dolerite dyke.
91	138	47	Massive charnockite
138	139	1	Fractured Charnockite
139	150	11	Massive Charnockite
Casing	8.5 mbgl		

13). Site: Kondadu **Latitude: 9.8008** **Longitude: 76.6477**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
Discharge	8 lps		
Static Water Level	10 mbgl		
Fractures	39 to 39.5, 90 to 90.5, 138 to 139 mbgl		
Transmissivity	49.45 m^2/day		
Storativity	0.00064		

<u>14). Site: Pampady</u> **Latitude: 9.5458** **Longitude: 76.6472**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	4	4	Top soil
4	7.4	3.4	Weathered charnockite
7.4	64	56.6	Massive charnockite: light grey to dark grey in colour, medium to coarse grained.
64	89	25	Massive charnockite: dark grey in colour, medium to coarse grained.
89	125	36	Massive charnockite: light grey to moderate dark grey in colour, medium to coarse grained.
125	168	43	Massive charnockite: moderate to dark grey in colour, medium to coarse grained.
168	200	32	Massive charnockite: dark grey in colour, medium to coarse grained.
Casing	7.4 mbgl		
Discharge	0.5 lps		
Static Water Level	6.73 mbgl		
Fractures	61 to 63 mbgl		
Transmissivity	NA		
Storativity	NA		

<u>15). Site: Perumbaikkad</u> **Latitude: 9.6275** **Longitude: 76.5327**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	4	4	Top soil: lateritic
4	19	15	Weathered charnockite
19	67	48	Massive charnockite: leucocratic to mesocratic, medium to coarse grained.
67	107	40	Massive charnockite: leucocratic, medium to coarse grained.
107	145	38	Massive charnockite: leucocratic to mesocratic, medium to coarse grained.

14). Site: Pampady **Latitude: 9.5458** **Longitude: 76.6472**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
145	200	55	Massive charnockite: mesocratic to melanocratic, medium to coarse grained.
Casing	19 mbgl		
Discharge	Dry		
Static Water Level	10.15 mbgl		
Fractures	67 to 67.15 mbgl		
Transmissivity	NA		
Storativity	NA		

16). Site: Ponkunnam **Latitude: 9.5694** **Longitude: 76.7644**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	3	3	Lateritic soil
3	17.5	14.5	Weathered charnockite
17.5	60	42.5	Massive charnockite: leucocratic to melanocratic, medium to coarse grained.
60	110	50	Massive charnockite: leucocratic, medium to coarse grained.
110	111	1	Fractured charnockite.
111	154	43	Massive charnockite: light grey to dark grey in colour, medium to coarse grained.
154	200	46	Massive charnockite: dark grey in colour, medium to coarse grained.
Casing	6.5mbgl		
Discharge	Dry		
Static Water Level	NA		
Transmissivity	NA		
Storativity			

17). Site: Puthuppally **Latitude: 9.5625** **Longitude: 76.575**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	3	3	Lateritic soil
3	8.9	5.9	Weathered charnockite
8.9	60	51.1	Massive charnockite: leucocratic to melanocratic, medium to coarse grained.
60	98	38	Massive charnockite: melanocratic, medium to coarse grained.
98	134	36	Massive charnockite: mesocratic to leucocratic, medium to coarse grained.

134	154	20	Massive charnockite: light grey to dark grey in colour, medium to coarse grained.
154	200	46	Massive charnockite: dark grey in colour, medium to coarse grained.
Casing	8.9mbgl		
Discharge	Dry		
SWL	NA		
Transmissivity	NA		
Storativity	NA		

18). Site: Puliyannoor **Latitude: 9.7011** **Latitude: 76.6597**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	1	1	Lateritic soil
1	1.25	0.25	Weathered charnockite
1.25	22	20.75	Massive charnockite: leucocratic medium to coarse grained.
22	57	35	Massive charnockite: mesocratic to melanocratic, medium to coarse grained.
57	99	42	Massive charnockite: melanocratic medium to coarse grained.
99	134	35	Massive charnockite: leucocratic, medium to coarse grained.
134	167	33	Massive charnockite: mesocratic to melanocratic, medium to coarse grained.
167	200	33	Massive charnockite: leucocratic, medium to coarse grained.
Casing	1.25 mbgl		
Discharge	Dry		
SWL	NA		
Transmissivity	NA		
Storativity	NA		

19) Site: Vakathanam **Latitude: 9.5208** **Longitude: 76.5744**			
Depth from (mbgl)	**Depth to (mbgl)**	**Thickness (m)**	**Lithology**
0	6	6	Top Soil
6	16..00	10	Laterite: Brownish yellow in colour
16	25	9	Kaolinite Clay
25	51.9	26.9	Highly Weathered Charnockite
51.9	70	18.1	Charnockite gneiss
70	71	1	Fractured Charnockite Gneiss.

71	82.5	11.5	Charnockite Gneiss: Leucocratic, medium to coarse grained.
Casing	51.9 mbgl		
Discharge and Drawdown	3.5 lps and 24.1 m		
SWL	17.8 mbgl		
Fractures	70 to 71 m		
Transmissivity	2.76 m^2/day		
Storativity	NA		

20). Site: Vayala
Latitude: 9.7208
Longitude:76.5819

Depth from (mbgl)	Depth to (mbgl)	Thickness (m)	Lithology
0	4	4	Top Soil
4	6.5	2.5	Weathered Charnockite
6.5	45	38.5	Massive Charnockite: Leucocratic to Mesocratic, Medium to coarse grained.
45	45.5	0.5	Fractured Charnockite.
45.5	48	2.5	Massive Charnockite: Leucocratic to Mesocratic, Medium to coarse grained.
48	48.25	0.25	Fractured Charnockite.
48.25	65	16.75	Massive Charnockite: Leucocratic to Mesocratic, Medium to coarse grained.
65	106	41	Massive Charnockite: Leucocratic. Medium to coarse grained.
106	150	44	Massive Charnockite: Leucocratic to Mesocratic, Medium to coarse grained.
150	172	22	Massive Charnockite: Leucocratic. Medium to coarse grained.
Casing	6.5 mbgl		
Discharge	Dry		
Static Water level	5.67 mbgl		
Transmissivity	NA		
Storativity	NA		

21). Site: Velloor
Latitude: 9.5827
Longitude: 76.6069

Depth from (mbgl)	Depth to (mbgl)	Thickness (m)	Lithology
0	3	3	Top Soil
3	11.4	8.4	Weathered Charnockite
11.4	65	53.6	Massive Charnockite: Leucocratic to mesocratic, Medium to coarse grained.

65	132	67	Massive Charnockite: Mesocratic, Medium to coarse grained.
132	176	44	Massive Charnockite: Leucocratic to mesocratic, Medium to coarse grained.
176	200	24	Massive Charnockite: Mesocratic, Medium to coarse grained.
Casing	11.4 mbgl		
Discharge	0.2 lps		
Static Water Level	6.8 mbgl		
Fractures	19 to 19.5 mbgl		
Transmissivity	NA		
Storativity	NA		

22). Site: Andoor (Marangattupally)
Latitude: 9.7339
Longitude: 76.6198

Depth from (mbgl)	Depth to (mbgl)	Thickness (m)	Lithology
0	3	3	Top Soil: Laterite, Medium, Brownish Red:
3	6	3	Charnockite: Weathered, Fine, Mesocratic
6	12	6	Charnockite: Fractured, Coarse, Mesocratic
12	18	6	Charnockite: Massive, Fine, Meso to melanocratic
18	24	6	Charnockite: Fractured, Coarse, Mesocratic
24	96	72	Charnockite: Massive, Medium, Meso to melanocratic
96	108	12	Charnockite: Massive, Fine, Mesocratic
108	168	60	Charnockite: Massive, Medium, Melanocratic
168	174	6	Charnockite: Massive, Fine, Mesocratic
174	200	26	Charnockite: Fractured, Coarse, Melanocratic
Casing	5.8 mbgl		
Discharge	Dry		
Static Water Level	NA		
Fractures	6 -12 (Dry) and 174 -200 (Dry)		
Transmissivity	NA		
Storativity	NA		

23). Site: Pala
Latitude: 9.7286
Longitude: 76.6914

Depth from (mbgl)	Depth to (mbgl)	Thickness (m)	Lithology
0	3	3	Top Soil: Laterite, Medium, Pale Grey
3	24	21	Charnockite: Weathered, Fine, Leuco to Mesocratic
24	30	6	Charnockite: Fractured, Coarse, Leuco to Mesocratic
30	36	6	Charnockite: Massive, Fine, Leuco to Mesocratic
36	48	12	Charnockite: Massive, Medium, Leuco to Mesocratic
48	54	6	Charnockite: Massive, Fine, Leuco to Mesocratic

54	79	25	Charnockite: Massive, Medium, Leuco to Mesocratic
79	102	23	Charnockite: Massive, Coarse, Leuco to Mesocratic
102	108	6	Charnockite: Massive, Fine, Leuco to Mesocratic
108	114	6	Charnockite: Massive, Medium, Leuco to Mesocratic
114	126	12	Charnockite: Massive, Fine, Leuco to Mesocratic
126	156	30	Charnockite: Massive, Medium, Leuco to Mesocratic
156	200	44	Charnockite: Massive, Fine, Leuco to Mesocratic
Casing	6.5 mbgl		
Discharge	Dry		
Static Water Level	NA		
Fractures	NA		
Transmissivity	NA		
Storativity	NA		

24) Site: Pallikkathodu
Latitude: 9.5996
Longitude: 76.6950

Depth From (mbgl)	Depth To (mbgl)	Thickness (m)	Description
0	3	3	Top Soil: Weathered, Laterite mix, Medium to coarse, Brick red
3	12	9	Sticky clay: Weathered, fine, brick red
12	15	3	Charnockite: Massive, Fine, Melanocratic
15	27	12	Charnockite: Massive, Fine to medium, Meso to melanocratic, with quartz veins
27	30	3	Charnockite: Fractured, medium, Mesocratic
30	48	18	Charnockite: Fractured, Coarse, Meso to Melanocratic, with quartz veins
48	54	6	Charnockite: Massive, Medium, Meso to Melanocratic
54	78	24	Charnockite: Massive, fine, Melanocratic
78	93	15	Charnockite: Fractured, Medium to coarse, melanocratic
93	120	27	Charnockite: Massive, Fine to Medium, Meso to Melanocratic
120	126	6	Charnockite: Massive, Fine, Meso to Melanocratic
Casing	30 mbgl		
Discharge	0.46 lps		
Static Water Level	25.90 mbgl		
Fractures	30 to48 mbgl		
Transmissivity	2.82 m^2/day		
Storativity	NA		

25). Site: Poonjar
Latitude: 9.6738
Longitude: 76.8255

Depth From (mbgl)	Depth To (mbgl)	Thickness (m)	Lithology

25). Site: Poonjar Latitude: 9.6738 Longitude: 76.8255			
Depth From (mbgl)	**Depth To (mbgl)**	**Thickness (m)**	**Lithology**
0	2	2	Top Soil: Weathered, Brownish colour
2	4.5	2.5	Charnockite: Weathered, Medium Grained, Leuco to Mesocratic
4.5	133	128.5	Charnockite: Massive, Fine to Medium Grained, Leuco to Mesocratic
133	164	31	Charnockite: Massive, Fine to Medium Grained, Meso to Melanocratic
164	165	1	Charnockite: Fractured, Fine to Medium Grained, Meso to Melanocratic
165	200	35	Charnockite: Massive, Fine to Medium Grained, Meso to Melanocratic
Casing	5.5 mbgl		
Discharge	0.5 lps		
Static Water Level	NA		
Fractures	164 to 165 mbgl		
Transmissivity	NA		
Storativity	NA		

AnnexureIV: Details of VES conducted in the study area

#	Location	Latitude	Longitude	VES No	r_1	r_2	r_3	r_4	r_5	r_6	h_1	h_2	h_3	h_4	h_5	h6	Total Depth (m)
1a	Anakallu	9.5750	76.7875	1	360	90	231	570	-	-	3.6	18	75.4	-	-	-	97
1b	Anakallu	9.5750	76.7875	CI	231	59	263	503	-	-	4.4	8.6	85	-	-	-	98
2	Endayar	9.6167	76.8833	2	510	1020	255	-	-	-	1.6	68.8	-	-	-	-	70.4
3	Kuttikkal	9.5861	76.8833	3	560	302	990	-	-	-	8	70	-	-	-	-	78
4	Mundakkayam	9.5389	76.9000	4	1680	1120	380	-	-	-	4.5	15.8	-	-	-	-	20.3
5	Mukkali	9.5667	76.8250	5	700	377	1260	440	1307	-	8.5	34.9	39.1	48	-	-	130.5
5a	Mukkali	9.5667	76.8250	6	2700	142	330	1280	-	-	3.4	5.5	70.7	-	-	-	79.6
6a	Podimattom	9.5667	76.8208	7	1100	122	232	1155	-	-	4	48	67.5	-	-	-	119.5
6b	Podimattom	9.5667	76.8208	8	1200	133	279	720	-	-	6.6	33	28	-	-	-	68
6c	Podimattom	9.5667	76.8208	CI	2585	151	143	1843	-	-	4.3	61.7	44	-	-	-	110
7a	Erumeli	9.4778	76.8444	9	120	147	560	41	120	390	1.2	9	2.5	6.2	60	-	79
7b	Erumeli	9.4778	76.8444	CI	93	203	673	29	112	654	1.3	5.8	2.9	8.1	33	-	51.1
7c	Erumeli	9.4778	76.8444	10	250	135	980	-	-	-	7	56	-	-	-	-	63
8	Vallichira	9.7181	76.6569	1	1630	146	292	VH	-	-	1.5	18.7	41.1	-	-	-	61.3
9	Pizakhu	9.7986	76.6958	2	1330	89	258	VH	-	-	2.9	17.2	148.1	-	-	-	168.2
10	Edamattom	9.6819	76.7292	3	1260	225	111	410	-	-	2	1.2	60.7	-	-	-	63.7
11	Manalu	9.6458	76.6333	4	605	286	345	VH	-	-	3.1	11.3	10	-	-	-	24.4
12	Vayala	9.7194	76.5714	5	440	169	225	-	-	-	2.3	49.2	54.3			-	105.8
13	Kalathur	9.7194	76.5583	6	1544	668	290	-	-	-	2.6	9.4	68	-	-	-	80
14	Vellur	9.5806	76.6111	7	442	122	89	-	-	-	2.9	62.1	35.3	-	-	-	100.3
15	Ettumanur	9.6639	76.5708	8	713	393	208	-	-	-	1.2	3.1	113	-	-	-	117.3
16	Vemballi	9.7147	76.5597	9	2013	1040	190	VH	-	-	2.1	3.8	63.8	-	-	-	69
17	Adichira	9.6250	76.5569	10	597	193	VH	-	-	-	3	76.9	-	-	-	-	79.9
18	Amayannur	9.6194	76.6042	11	2025	201	125	VH	-	-	4.9	67.3	17.3	-	-	-	89.5
19	Tottakkad	9.5278	76.6028	12	620	180	133	VH	-	-	5.2	39.3	55.8	-	-	-	100.3
20	Tottakkad	9.5278	76.6028	13	420	190	216	VH	-	-	3.9	48.2	47	-	-	-	99.1

#	Location	Latitude	Longitude	VES No	r_1	r_2	r_3	r_4	r_5	r_6	h_1	h_2	h_3	h_4	h_5	h6	Total Depth (m)
21	Panichakad	9.5347	76.5500	14	1031	671	213	VH	-	-	5.1	9.8	76	-	-	-	90.9
22	Pathamattom	9.5161	76.5875	15	1647	770	252	VH	-	-	3.1	13.6	113	-	-	-	129.7
23	Kanakkarry	9.7028	76.5494	NA	2700	500	200	-	-	-	3	5	ext.	-	-	-	
24	Kondadu	9.8008	76.6478	NA	940	460	-	-	-	-	2	ext.	-	-	-	-	
25	Ponkunnam	9.5694	76.7644	NA	700	2000	185				1.5	4	ext.				
26	Vayala	9.7208	76.5819	NA	900	170	800	150			1.5	5	18.5	ext.			
27a	Nattakom	76.5107	9.5574	1	376	608	160	891	25	3679	0.8	4.8	4.3	6.5	14		30.4
27b	Nattakom	76.5103	9.5571	2	633	292	1682	34	510	-	3.1	2.4	5.3	15.7	Ext.		26.5
28a	Ettumanoor	76.5591	9.6711	1	202	451	69	277	78	-	0.7	1.9	4.1	14.8	Ext.		21.5
28b	Ettumanoor	76.5593	9.6713	2	448	961	69	690	179	-	1.8	1.9	3.7	15.5	Ext.		22.9
29a	Pala	76.6649	9.7009	1	211	446	233	635	368	-	0.6	2.4	9.7	14.4	Ext.		27.1
29b	Pala	76.6642	9.7013	2	269	1153	238	337	626	200	0.5	2.4	6.1	14.8	22.1		23.8
30a	Mattakkara	76.6437	9.6445	1	418	939	170	2675	24	-	1.6	1.8	3.6	10.8	Ext.		17.8
30b	Mattakkara	76.6436	9.6447	2	213	1421	270	2986	102	-	1.1	2.9	5.6	11.3	Ext.		20.9
31a	Vayala	76.5792	9.7217	1	912	193	822	81	-	-	0.9	7.1	14.2	Ext.	-		22.2
31b	Vayala	76.5794	9.7220	2	766	335	1568	410	6058	-	2.3	2.4	5.5	20.9	Ext.		31.1
32a	Marangattupally	76.5969	9.7441	1	3603	1644	510	123	790	87	0.9	4.8	9.8	13	23.2		51.7
32b	Marangattupally	76.5970	9.7435	2	856	1411	190	676	238	-	0.9	6.3	12.4	25.5	Ext.		45.1
33a	Kuruvilangad (School)	76.5613	9.7564	1	158	787	15	81	-	-	1.1	2.3	6.6	Ext.			10
33b	Kuruvilangad (School)	76.5613	9.7560	2	141	1516	122	27	468	-	0.7	1.3	4.6	17.7	Ext.		24.3
33c	Kuruvilangad (College)	76.5641	9.7553	3	182	1096	212	1150	70	-	0.9	2	4.6	10.9	Ext.		18.4
33d	Kuruvilangad (College)	76.5644	9.7551	4	821	4367	214	560	VH	-	1.3	1.2	3.8	13.8	Ext.		20.1
34	Kurian ad	76.5769	9.7808	1	508	114	448	88	843	-	3.2	2.6	4.9	8.1	Ext.		18.8
35a	Thottuva (High School)	76.5474	9.7439	1	61	1442	52	VH	-	-	0.4	1.9	4.4	Ext.	-		6.7
35b	Thottuva (High School)	76.5473	9.7436	2	95	2832	43	219	36	253	0.4	1	3.8	7.1	13.9		26.2

#	Location	Latitude	Longitude	VES No	r_1	r_2	r_3	r_4	r_5	r_6	h_1	h_2	h_3	h_4	h_5	h6	Total Depth (m)
35c	Thottuva (High School)	76.5483	9.7432	3	896	166	940	69	-	-	3	10.7	10.5	Ext.	-		24.2
35d	Thottuva (High School)	76.5479	9.7434	4	341	708	202	722	241	3121	0.7	1.9	3.7	4.8	12.7		23.8
36a	Poonjar	76.8257	9.6740	1	561	3784	507	VH		-	0.09	7.32	28.3	Ext.			35.71
36b	Poonjar	76.8263	9.6742	2	2843	8688	2252	976.1	-	-	1.75	1.51	19.93	Ext.	-		23.19
36c	Poonjar	76.8253	9.6743	3	2055	13611	1677	9445	-	-	1.08	1.97	62	Ext.	-		65.05
37a	Vazhoor	76.6988	9.5627	1	49.4	18.9	1.71	1255	-	-	2.12	5.55	4.99	Ext.	-		12.66
37b	Vazhoor	76.6989	9.5622	2	271	2642	211	139	-	-	0.621	0.907	33.9	Ext.	-		35.428
37c	Vazhoor	76.7073	9.5655	3	179	97.7	987	163	-	-	1.38	3.81	4.11	Ext.	-		9.3
37d	Vazhoor	76.7076	9.5653	4	229	643	161	87.8	-	-	1.48	2.97	68.4	Ext.	-		72.85
38a	Andoor	76.6197	9.7331	1	VH	1595	310	3798	5.49	-	0.314	3.29	2.02	5.74	Ext.		11.364
38b	Andoor	76.6202	9.7347	2	1714	232	111	-	-	-	3.23	11.4	Ext.	-	-		14.63
39a	Pallikkathodu	76.6955	9.5994	1	720.7	196.7	121.3	111.2	VH	-	4.76	2.3	6.22	15.31	Ext.		28.59
39b	Pallikkathodu	76.6929	9.6006	2	1004	296	150	-	-	-	3.56	12.2	Ext.	-	-		15.76
40a	Uzhavoor	76.6138	9.8020	1	252.8	1718	382.4	79.52	9257	-	1.012	0.76	11.48	12.63	Ext.		25.882
40c	Uzhavoor	76.6137	9.8021	2	238	637	135	VH	-	-	1.05	1.63	42.5	Ext.	-		45.18
41a	Pala	76.6924	9.7284	1	264.7	131.6	23.73	5349	-	-	1.103	5.25	6.94	Ext.	-		13.293
42a	Erattupetta	76.7788	9.6826	1	228	934	77.5	VH	-	-	2.09	4.27	6.15	Ext.	-		12.51
42b	Erattupetta	76.7791	9.6829	2	413	205	VH	-	-	-	7.93	3.63	Ext.	-	-		11.56
43	Thadani	76.7775	9.6576	1	234.3	1386	310	-	-	-	0.97	0.804	Ext.	-	-		1.774

AnnexureV: Water quality data of samples analysed from the study area

#	Location	Latitude	Longitude	Date of collection	Source/ Type	pH	EC in µS/cm at 25°C	TH as $CaCO_3$	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	F	NO_3
								←---mg/l---→										
1	Arumannoor	9.6444	76.5875	15.5.18	DW/KOW	6.07	122	38	15	0	2	5.5	0	41	4.1	8.5	0	9.4
2	Mattakkara	9.6406	76.6366	15.5.18	DW/KOW	5.35	80	12	3.2	1	7.6	2.6	0	15	1.4	13	0.06	8.5
3	Manarcaud	9.5952	76.5851	15.5.18	DW/KOW	5.04	89	14	4	1	7.8	2	0	7.3	2.6	16	0	12
4	Pulimoodu Jn	9.5532	76.5380	15.5.18	DW/KOW	4	102	6	2.4	0	11	3.2	0	0	0.98	20	0.08	15
5	Ithithanam	9.4850	76.5357	15.5.18	DW/KOW	4.71	84	14	4	1	8	1	0	2.4	7.5	17	0.06	4.8
6	Vallikkad	9.5037	76.5723	15.5.18	DW/KOW	5.88	126	20	8	0	12	4	0	20	2.6	21	0	14
7	Velloor	9.5777	76.6158	15.5.18	DW/KOW	5.78	65	20	7.2	0.49	1.8	4.4	0	27	2.2	5.7	0.08	3.9
8	Mundathanam	9.4946	76.7081	15.5.18	DW/KOW	5.65	194	38	12	1.9	13	9.6	0	15	8.4	27	0	34
9	Kulathur Moozhi	9.4608	76.7107	15.5.18	DW/KOW	5.57	56	12	3.2	1	4.1	2.2	0	9.8	2.6	8.5	0.1	7.9
10	Karikkaatoor Centre	9.4831	76.7840	15.5.18	DW/KOW	4.99	59	12	2.4	1.5	5.8	1.3	0	4.9	2.3	8.5	0	9.9
11	Chenappady	9.5084	76.7951	15.5.18	DW/KOW	5.73	38	6	1.6	0.49	2.2	1	0	4.9	1.5	2.8	0.02	6.3
12	Anakallu	9.5780	76.7863	15.5.18	DW/KOW	5.83	175	42	13	2.4	10	3.1	0	22	8	16	0.04	31
13	Ponkunnam 20th Mile	9.5650	76.7460	15.5.18	DW/KOW	5.82	129	22	7.2	1	10	3.8	0	9.8	7.5	20	0	14
14	Poovarani	9.6687	76.7064	16.5.18	DW/KOW	5.45	70	16	4.8	1	3.5	1.7	0	20	1.7	5.7	0.04	6.3
15	Mallikassery	9.6486	76.7493	16.5.18	DW/KOW	5.08	62	12	3.2	1	4.8	0.62	0	7.3	2.4	9.9	0	7.5
16	Kannimala	9.4942	76.8705	16.5.18	DW/KOW	5.22	71	16	4	1.5	3	1.7	0	7.3	2.1	4.3	0.02	20
17	Kulamamkuzhy	9.4473	76.8470	16.5.18	DW/KOW	5.44	78	14	4	1	7.1	1.7	0	12	3.3	16	0.13	3.5
18	Panackachira	9.5014	76.9274	16.5.18	DW/KOW	4.32	153	20	5.6	1.5	12	4.7	0	0	4.3	18	0	42
19	Koruthode	9.4766	76.9566	16.5.18	DW/KOW	5.51	85	30	6.4	3.4	5.3	2.6	0	20	4.8	7.1	0.07	14
20	Pariyaramangalam	9.7023	76.6090	16.5.18	DW/KOW	5.4	84	16	4.8	1	6.1	2	0	15	5	9.9	0.05	5.6
21	Kalapoor	9.6992	76.5854	16.5.18	DW/KOW	4.78	310	34	8	3.4	24	21	0	0.01	17	36	0.03	57
22	Bharananganam	9.7027	76.7233	17.5.18	DW/KOW	5.33	57	14	4	1	4	0.91	0	15	0	7.1	0.14	3.9
23	Pathambuzha	9.6223	76.8407	17.5.18	DW/KOW	5.89	54	18	6.4	0.49	1.8	0.77	0	17	2.8	5.7	0	2
24	Njarkadu	9.6385	76.8808	17.5.18	DW/KOW	5.7	29	6	1.6	0.49	2.5	0.64	0	12	0	2.8	0.16	1.3

#	Location	Latitude	Longitude	Date of collection	Source/ Type	pH	EC in µS/cm at 25°C	TH as $CaCO_3$	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	F	NO_3
								←mg/l→										
25	Velathussery	9.6905	76.8458	17.5.18	DW/KOW	5.38	66	12	3.2	1	4.5	2.7	0	7.3	0	5.7	0.06	15
26	Mangalagiri	9.6997	76.8324	17.5.18	DW/KOW	5.18	58	16	4.8	1	1.5	1.5	0	12	0	2.8	0.12	14
27	Elappunkal	9.7008	76.7850	17.5.18	DW/KOW	5.12	33	8	1.6	1	2.3	0.94	0	7.3	0	2.8	0.1	4.9
28	Kurumannu	9.7783	76.7296	17.5.18	DW/KOW	5.68	102	18	5.6	1	6.4	7.9	0	22	9.4	8.5	0	9.1
29	Manathur	9.8069	76.6897	17.5.18	DW/KOW	6.07	94	36	11	1.9	2.4	1.5	0	32	9.9	5.7	0.24	6.3
30	Idiyanal	9.8193	76.6676	17.5.18	DW/KOW	5.65	43	10	3.2	0.49	2.8	1	0	12	0	5.7	0.03	3
31	Amanakara	9.8157	76.6387	17.5.18	DW/KOW	4.89	44	8	2.4	0.49	2.5	1.1	0	2.4	0	4.3	0.2	11
32	Thamarakadu	9.8302	76.6210	17.5.18	DW/KOW	5.57	131	34	8.8	2.9	7.3	4.7	0	17	0	18	0.31	23
33	Veliyannoor	9.8219	76.6087	17.5.18	DW/KOW	6.01	92	32	11	1	2.8	2.3	0	34	3.1	2.8	0.11	8.1
34	Chetimattam	9.7784	76.6129	17.5.18	DW/KOW	6.7	71	26	7.2	1.9	2.4	1.7	0	29	0.89	2.8	0.34	5.8
35	Vallichira	9.7236	76.6460	17.5.18	DW/KOW	5.64	65	12	3.2	1	4.9	2.5	0	9.8	0	9.9	0.37	12
36	Cheruthikkara	9.6087	76.6092	7.4.17	DW/GWMW	5.58	95	18	4	1.9	6	1.7	0	17	2.2	11	0	9.6
37	Ettumannoor	9.6702	76.5721	5.4.17	DW/GWMW	5.98	90	14	4.8	0.49	8.1	2.8	0	17	0	16	0	8.3
38	Kozha	9.7710	76.5696	8.4.17	DW/GWMW	5.64	125	24	5.6	2.4	6.5	4.4	0	12	0	14	0	24
39	Kuttikkal	9.5810	76.8825	11.4.17	DW/GWMW	5.9	104	14	4	1	6.2	2.1	0	17	0	11	0	9.4
40	Naranganam	9.7269	76.7391	15.4.17	DW/GWMW	5.2	53	12	2.4	1.5	2.1	0.85	0	12	0.76	7.6	0	5.1
41	Paipad	9.4231	76.5828	4.4.17	DW/GWMW	4.94	270	44	14	2.4	19	10	0	7.3	8	37	0	50
42	Pala	9.7107	76.6792	5.4.17	DW/GWMW	6.75	110	28	8	1.9	5.7	1.9	0	41	2.4	9.9	0.01	4.3
43	Pallikathodu	9.5999	76.6846	7.4.17	DW/GWMW	6.02	121	28	5.6	3.4	5.3	1.6	0	41	0.43	8.5	0	6.2
44	Pambadi	9.5633	76.6455	10.4.17	DW/GWMW	5.92	71	20	4.8	1.9	3.5	1.6	0	24	0.65	8.5	0	3.4
45	Paruthumpara	9.5289	76.5406	4.4.17	DW/GWMW	6.02	143	20	4	2.4	14	3.3	0	22	0.33	24	0.02	13

#	Location	Latitude	Longitude	Date of collection	Source/ Type	pH	EC in µS/cm at 25°C	TH as $CaCO_3$	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	F	NO_3
								←------mg/l------→										
46	Plakkalpadi	9.5124	76.7007	9.4.17	DW/GWMWW	5.63	170	24	5.6	2.4	15	4.8	0	17	0.54	28	0	17
47	Tottakkad	9.5300	76.6055	4.4.17	DW/GWMW	6.37	97	20	4.8	1.9	5.3	1.2	0	29	0.1	8.5	0	6.9
48	Vazhur	9.5696	76.7231	9.4.17	DW/GWMW	7.42	122	22	4.8	2.4	3.2	1.4	0	34	0.32	5.7	0	3.5
49	Vakathanam	9.5208	76.5744	NA	BW/CGWB	7.41	130	30	7.2	2.9	9.7	5.4	0	71	6.5	4.3	0.24	5.6
50	Sangokushi	9.5833	76.5469	NA	BW/CGWB	7.35	220	60	12	7.3	18	2.9	0	122	12	9.9	0	1.2
51	Kondadu	9.8008	76.647	NA	BW/CGWB	7.52	310	130	38	8.5	7.5	1.8	0	214	3.5	7.1	0.1	0.23
52	Podimattom	9.5666	76.8208	NA	BW/CGWB	7.4	300	135	38	9.7	11	2	0	188	0	8.5		
53	Erumely	9.4777	76.8444	NA	BW/CGWB	7.99	400	42	11	3.5	77	1.6		232	0	7.1		
54	Manal	9.6458	76.6333	NA	BW/CGWB	8.34	260	115	28	11	17	1.4	12	152	0	9.9		
55	Vilakkumadam	9.6625	76.7361	NA	BW/CGWB	7.5	200	86	18	10	7.4	2		112	0	9.9		
56	Vallichira	9.7180	76.6569	NA	BW/CGWB	7.19	300	65	14	7.3	45	1.4	0	220	0	5.7		
57	Pizhaku	9.7986	76.6958	NA	BW/CGWB	6.57	270	120	28	12	14	2.9		183	0	7.1		

AnnexureVI: Details of aquifer parameters in the study area (Based on EWs drilled by CGWB

#	Location	Latitude	Longitude	Year of construction	Depth drilled (mbgl)	Major lithology encountered	Depth to bed rock (casing)	Fracture zones with yield (lpm)	SWL (mbgl)	Discharge (lps)	Draw down (m)	T (m2/day)	S	EC (µS/cm)	Cl (ppm)
1	Erumeli	9.4778	76.8444	1985-86	198.5	Charnockite	4	76 - 84, 92 - 96, 115 - 119/150.	1.73	2.64	19.01	8.7		390	8.5
2	Pattamuttam	9.5153	76.5542	1986-87	200.5	Charnockite	8.35	61-68	NA	dry	NA	NA		NA	NA
3	Podimattam	9.5667	76.8208	1985-86	139.1	Charnockite	5.77	full/1300	5.09	13.7	5.31	105	0.003	300	8.5
4	Vellur	9.5806	76.5778	1986-87	200.5	Charnockite	6.8	38.85/30	12.64	0.5	NA	NA		__	
5	Anakkallu	9.5750	76.7875	1986-87	215.8	Charnockite	5.26	36 - 50	1.89	0.1	NA	NA		NA	NA
6	Manalu	9.6458	76.6333	1986-87	200.5	Charnockite	9.48	42.85, 73/180	2.13	3	20.07	0.5		290	7.1
7	Vilakkumadam	9.6625	76.7361	1986-87	183.3	Charnockite	5	7/120, 54/360, 73/720, 130/1200	2.24	20	19.7	121		220	7.1
8	Vallichira	9.7181	76.6569	1986-87	200.5	Charnockite	8.25	38.85-61.4/72	1.54	1.2	16.91	0.5		320	5.7
9	Kalathur	9.7194	76.5583	1986-87	200.5	Charnockite	12.35	75.8	dry	Nil	NA	__		__	__
10	Pizhaku	9.7986	76.6958	1986-87	200.5	Charnockite	4.2	8.37, 35.23 &58/200	3.97	3.3	4.9	20		300	13
11	Pampadi	9.5458	76.6472	2011-12	200	Charnockite	7.4	61.00-62.00	6.73	0.5					
12	Ponkunnam	9.5694	76.7644	2011-12	200	Charnockite	6.5			Dry					
13	Vayala	9.7208	76.5819	2011-12	200	Charnockite	6.5		5.67						
14	Puliyanoor	9.7011	76.6597	2011-12	200	Charnockite	1.25			Dry					
15	Vakathanam	9.5208	76.5744	2011-12	80.5	Charnockite	51.9	70.00-71.00	17.8	3.5	24.1	2.76		130	4.3
16	Pudupalli	9.5625	76.5750	2011-12	200	Charnockite	8.9			Dry					

#	Location	Latitude	Longitude	Year of construction	Depth drilled (mbgl)	Major lithology encountered	Depth to bed rock (casing)	Fracture zones with yield (lpm)	SWL (mbgl)	Discharge (lps)	Draw down (m)	T (m2/day)	S	EC (µS/cm)	Cl (ppm)
17	Kanjikuzhi	9.5833	76.5469	2011-12	200	Charnockite	17.4	19.00-19.50, 60.70-61.00, 110.00-111.00		0.5				220	9.9
18	Perumbaikad	9.6275	76.5328	2011-12	200	Charnockite	19	67.00-67.15	10.15						
19	Velloor	9.5828	76.6069	2011-12	200	Charnockite	11.4	19.00-19.5	6.8	0.2					
20	Kondadu	9.8008	76.6478	2011-12	150	Charnockite	8.5	39.00-39.50, 90.00-90.50, 138.00-139.00	10	8	14.6	49.45	6E-04	310	7.1
21	Kanakkary	9.7028	76.5494	2011-12	172	Charnockite	9	45.00-45.50, 48.00-48.25		Dry					
22	Andoor	9.7339	76.6198	2018-19	200	Charnockite	5.8	164-165							
23	Pala	9.729	76.691	2018-19	200	Charnockite	6.5								
24	Pallikkathodu	9.5996	76.695	2018-19	129.30	Charnockite	30	30-48/28	25.90	0.5	2.83	2.82		46	5.7
25	Poonjar	9.6738	76.8255	2018-19	200	Charnockite	5.5	164-165/30		0.5				270	5.7

Annexure VII: Details of Large diameter pump test conducted in the study area

Location: Purappanthanam, Plassanal (P O), Panakkappalam (Erattupetta block) **Aquifer: Fractured weathered crystalline (Charnockite)** **Date of Test:19-3-2016**		
SWL	7.56 mbgl	
Discharge	0.5077 m^3/min	
Diameter	3 m	
Depth of well	9.70 mbgl	
Time Since pumping started (minutes)	**DTWL (mbgl)**	**Drawdown (m)**
1	7.65	0.09
2	7.68	0.12
3	7.72	0.16
4	7.76	0.2
5	7.78	0.22
6	7.81	0.25
7	7.84	0.28
8	7.87	0.31
9	7.9	0.34
10	7.92	0.36
12	7.97	0.41
14	8.02	0.46
16	8.07	0.51
18	8.11	0.55
20	8.16	0.6
25	9.06	1.5
30	9.15	1.59
35	9.24	1.68
40	9.33	1.77
45	9.41	1.85
50	9.49	1.93
55	9.57	2.01
60	9.65	2.09
70	9.67	2.11

Annexure VIII: Details of soil infiltration tests carried out in the study area

Site: Kozha (Kuravilangad panchayath, Uzhavoor Block), With in the premises of District Agricultural Farm
Date of Test: 28.2.2019
Soil Type: Gravelly Clay
Land use: Agriculturalland

Time (Minutes)	Time Difference (min)	Initial Head (cm)	Fall in Head (cm)	Cumulative fall in head (cm)	Infiltration rate (cm/min)	Infiltration rate (cm/hour)
0	0	18.5	0	0	0	0
1	1	16	2.5	2.5	2.5	150
2	1	14.2	1.8	4.3	1.8	108
3	1	12.8	1.4	5.7	1.4	84
4	1	11.3	1.5	7.2	1.5	90
5	1	10	1.3	8.5	1.3	78
6	1	8.6	1.4	9.9	1.4	84
7	1	7.6	1	10.9	1	60
8	1	6.5	1.1	12	1.1	66
9	1	5.5	1	13	1	60
10	1	5	0.5	13.5	0.5	30
12	2	16.6	1.9	15.4	0.95	57
14	2	14	2.6	18	1.3	78
16	2	11.5	2.5	20.5	1.25	75
18	2	9.5	2	22.5	1	60
20	2	7.7	1.8	24.3	0.9	54
25	5	12.8	5.7	30	1.14	68.4
30	5	8	4.8	34.8	0.96	57.6
35	5	4	4	38.8	0.8	48
40	5	13.2	5.3	44.1	1.06	63.6
45	5	9.2	4	48.1	0.8	48
50	5	6.2	3	51.1	0.6	36
60	10	10.8	7.4	58.5	0.74	44.4
70	10	6.2	4.6	63.1	0.46	27.6
80	10	12.9	5.6	68.7	0.56	33.6
90	10	8.5	4.4	73.1	0.44	26.4
100	10	14.2	4.3	77.4	0.43	25.8
110	10	10.9	3.3	80.7	0.33	19.8
120	10	5	5.9	86.6	0.59	35.4
140	20	11.6	6.9	93.5	0.345	20.7
160	20	7.1	4.5	98	0.225	13.5
170	10	15	3.5	101.5	0.35	21
180	10	13	2	103.5	0.2	12
190	10	10	3	106.5	0.3	18
200	10	8	2	108.5	0.2	12
210	10	6.5	1.5	110	0.15	9
220	10	4	2.5	112.5	0.25	15
230	10	1.49	2.51	115.01	0.251	15.06

Site: Chengalam (Akalakunnam panchayath, Pampady Block), With in the School Premises Date of Test: 27.2.2019 Soil Type: Gravelly Clay Land use: Agricultural plantation (Rubber)						
Time (Minutes)	**Time Difference (min)**	**Initial Head (cm)**	**Fall in Head (cm)**	**Cumulative fall in head (cm)**	**Infiltration rate (cm/min)**	**Infiltration rate (cm/hour)**
0	0	22	0	0	0	0
1	1	21	1	1	1	60
2	1	20.5	0.5	1.5	0.5	30
3	1	19.8	0.7	2.2	0.7	42
4	1	19.1	0.7	2.9	0.7	42
5	1	18.6	0.5	3.4	0.5	30
6	1	17.9	0.7	4.1	0.7	42
7	1	17.2	0.7	4.8	0.7	42
8	1	16.9	0.3	5.1	0.3	18
9	1	16.5	0.4	5.5	0.4	24
10	1	16	0.5	6	0.5	30
12	2	15	1	7	0.5	30
14	2	14	1	8	0.5	30
16	2	13.2	0.8	8.8	0.4	24
18	2	12.8	0.4	9.2	0.2	12
20	2	12	0.8	10	0.4	24
25	5	10.05	1.95	11.95	0.39	23.4
30	5	8.8	1.25	13.2	0.25	15
35	5	7.5	1.3	14.5	0.26	15.6
40	5	20.8	1.2	15.7	0.24	14.4
50	10	17.1	3.7	19.4	0.37	22.2
60	10	14	3.1	22.5	0.31	18.6
70	10	11.5	2.5	25	0.25	15
80	10	9.2	2.3	27.3	0.23	13.8
90	10	18.3	3.7	31	0.37	22.2
100	10	15.6	2.7	33.7	0.27	16.2
110	10	13.5	2.1	35.8	0.21	12.6
120	10	11.8	1.7	37.5	0.17	10.2
130	10	19.6	2.4	39.9	0.24	14.4
140	10	17.2	2.4	42.3	0.24	14.4
150	10	15	2.2	44.5	0.22	13.2
160	10	13.2	1.8	46.3	0.18	10.8
170	10	11	2.2	48.5	0.22	13.2
180	10	8.8	2.2	50.7	0.22	13.2

File No.GW1/181/2019-WRD

GOVERNMENT OF KERALA

Water Resources(Ground Water)Department

No.GW1/181/2019-WRD 02/08/2019,Thiruvananthapuram

From
Secretary to Government

To
The Regional Director,
Central Ground Water Board
Kerala Region,
Kedaram,Thiruvananthapuram-695004

Sir,

Sub: Water Resources(Ground Water) Department-Meeting of the State Level Coordination Committee for National Aquifer Mapping & Management -minutes forwarding Reg

Ref: -------

I am to forward herewith the approved minutes of the meeting of the State Level Coordination Committee for National Aquifer Mapping & Managementheld on 03.07.2019 in the chamber of secretay,Water Resources Department for necessary action.

Yours Faithfully,
DR.B.ASHOK IAS
SECRETARY
For Secretary to Government.

Approved for Issue,

Section Officer.

e – 3645103

MINUTES OF THE 7TH MEETING OF THE STATE LEVEL COORDINATION COMMITTEE(SLCC) FOR NATIONAL AQUIFER MAPPING & MANAGEMENT (NAQUIM), KERALA, HELD ON 03.07.2019

The 7th meeting of the State Level Coordination Committee of National Aquifer Mapping Programme of GGWB was held on 03.07.2019 at 16.00 hours in chamber of Shri. B. Ashok, IAS, Secretary, Water Resources, Power & Industries, Govt. of Kerala and Chairman, SLCC of NAQUIM chaired the meeting. The following Members attended the meeting.

1.	Shri. K. Biju, IAS, Director of Industries & Commerce, Government of Kerala	Member
2.	Shri. K. H. Shamsudeen, Chief Engineer (I&A)	Member
3.	Shri.V.Kunhambu, Regional Director, CGWB, Kerala Region, Thiruvananthapuram	Member Secretary
4.	Smt. Thresiamma Antony, Administrative Assistant, Panchayath Directorate	Member
5.	Shri. K. Rajan, Hydrogeologist, GWD	Member
6.	Dr. N. Vinayachandran, Scientist D	Invitee
7.	Smt. Rani V. R., Scientist – C	Invitee

At the outset, the Chairman welcomed the members and invited Regional Director, CGWB to appraise the members about the developments and progress of NAQUIM as per agenda set up for the meeting. Shri. V. Kunhambu, Regional Director, CGWB, Kerala Region informed that Report on Aquifer Mapping & Management plan of the entire sedimentary area of Kerala along with hard rock areas of Thiruvananthapuram, Kollam, Pathanamthitta & Palakkad districts have already been issued. Followed by this item, a power point presentation on Aquifer Mapping and Management plan of Kottayam and Ernakulam district (2966 sq.km) were presented by Dr. N. Vinayachandran, Sc- D and Nodal Officer (NAQUIM), CGWB. During the course of presentation, provision was given for clarifications and interaction. After listening to the presentation, Chairman expressed satisfaction on the contents of the report and commented that artificial recharge should not be promoted everywhere since the thickness of unsaturated aquifer is minimum in both districts. Dr. N. Vinayachandran informed the possibility and stressed that instead of constructing widespread recharge structures it should be site specific, considering the thickness of the phreatic aquifer. After interactions, Secretary(WR) approved the aquifer management plan presented and advised CGWB to circulate an executive summary of the report to all the departments which RD, CGWB readily agreed. Chairman also pointed out that the details of mapped aquifer could become a powerful management tool especially for the ensuing Jal Sakthi Abhiyan activities. He also suggested the full-hearted involvement of all line departments in this mission and advised RD, CGWB to extend all support to the team.

The meeting ended with thanks to the Chair.

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