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Ground Water Quality of Kerala for Irrigation Purpose

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All India Coordinated Research Project

on

Management of Salt Affected Soils & Use of Saline Water in Agriculture

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FOREWORD

Ground water is an important natural resource with high economic value and has great social significance. It is the major source of water for meeting drinking, agricultural and industrial needs in India. Kerala receives the annual rainfall of about 3000 mm and has abundant surface water resources. Still drinking and domestic water requirements are mainly met from ground water resources, especially in rural habitations. The increasing demand for fresh water resources from several sectors may lead to increased stress on ground water resource of the state. The situation may aggravate further due to sea level rise and climate change.

The state is underlain by diverse rock types of different geological ages from Pre- Cambrian to Recent. Nearly, 88% of the State is underlain by crystalline rocks of Archaean Age while about 12% of the State is underlain by semi-consolidated and unconsolidated sedimentary formations. Total annual groundwater recharge of the state has been estimated as 5.77 bcm and annual extractable groundwater resource is 5.21 bcm. The stage of groundwater extraction is 51%. Out of 152 blocks, 1 has been categorized as 'Overexploited', 2 as 'Critical', 30 as 'Semi-Critical' and 119 as 'Safe'. There is no saline block in the state. More than 80% of ground water is of good quality for irrigation purpose. The poor quality groundwater is found only in deltaic coastal areas as state has a long coastal line of 560 km and has 16 lagoons linked to the sea. Sea water intrusion up to a distance of 10 to 20 km upstream is noticed during high tide in these areas. In the coastal areas, good quality water is not available for irrigation and the agriculture is dependent on monsoon rains. But due to climate change in recent times, crop failure due to non availability of the good quality of water often occurs. In this context, appraisal of ground water quality for irrigation is the need of the hour.

This publication on ground water quality of Kerala for irrigation purpose depicts a comprehensive study on assessment of groundwater quality for 14 districts of the state. The efforts made by the AICRP (SAS&USW) Vyttila under Kerala Agricultural University (KAU) in bringing out this publication are well appreciated. This bulletin will useful to scientists, planners, policy makers and other stakeholders involved in sustainable management of groundwater resources of Kerala.

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FOREWORD

Groundwater is a dynamic and replenishable precious natural resource. It has been the mainstay for meeting the domestic needs of more than 80% of rural and 50% of the urban population as well as the irrigation needs of around 50% of irrigated agriculture. It is essential to be aware of this regime's changes and to monitor it on a regular basis. Kerala, a tiny swath of land cushioned between the Western Ghats on the east and the sandy beaches of the Arabian Sea on the west, is regarded as a water surplus state because of its 44 rivers, back waters, and numerous lakes and ponds.

In Kerala, ground water contributes 60% of the total demand for drinking water. Based on the local climatic, geomorphological, and hydrogeological circumstances, there are significant regional variations in the availability and occurrence of ground water. About 88 percent of the total geographical area of the State is underlain by crystalline rocks devoid of any primary porosity, with limited ground water prospects. In the alluvial formations having multiple aquifer systems, quality is sometimes a constraint in the optimal development of available resources. Recent problems of decline in the water table, contamination of groundwater, seawater intrusion etc. are being reported at many places due to increasing population, rapid urbanization and industrialization over the last few decades in the State. Judicious and planned development of ground water and its scientific management have become necessary to ensure long-term sustainability of this precious natural resource. In view of this, a database on ground water quality for irrigation is very important.

The voluntary centre of AICRP on the management of salt-affected soils and use of saline water in agriculture, ICAR-CSSRI, Kamal started functioning at Rice Research Station, Vyttila of Kerala Agricultural University in 2014 with the mandate of conducting· research in the management of saline acidic soils and groundwater quality for irrigation. The centre has completed the assessment of ground water quality for irrigation in all districts of Kerala. This technical bulletin is the outcome of the study conducted on ground water quality for irrigation in different districts of Kerala. I congratulate the concerted efforts of AICRP (SAS&USW), Vyttila and Project Co-ordinating unit of AICRP (SAS & USW), lCAR-CSSRI, Kamal for bringing out this publication and hope that this bulletin will serve as a valuable reference document in the field of groundwater quality for irrigation in Kerala.

Date 6-10-2022

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Introduction

Location

Kerala State is a narrow stretch of land covering 38863 sq.km area bordering the Lakshadweep Sea on the western side and Tamil Nadu and the Karnataka States on the eastern side. The length of the State from north to south is 560 km and the average width is 70 km with a maximum of 125 km. It lies between North latitudes $08^0$18' and $12^0$48'and East longitudes $74^0$52' and $77^0$22. The occurrence and movement of ground water is mainly controlled by factors like physiography, geological setting, etc.

Physiography

Physiographically the State is divided into three major units viz. the coastal plains, the midlands and the hill ranges. The coastal plains have an elevation of less than 7.6 m whereas the elevation of the midland ranges from 7.6 to 76 m and that of the hill ranges is more than 76 m above mean sea level (AMSL).

Geology

Geologically 88% of the State is underlain by crystalline rocks of the Archaean age which is a part of the peninsular shield. The crystalline complex of Kerala is composed of charnockites, gneisses, schists, migmatites and rocks of the Wayanad supracrustals. Along the western portion of the state the crystalline rocks are overlain by the sedimentary formations of tertiary age and recent alluvial formations. The Tertiary sequence of formations have been divided into four beds viz. Alleppey, Vaikom, Quilon and Warkalli, the age of which ranges from Eocene to Lower Miocene. Laterites of Subrecentage derived from the crystallines as well as sedimentary formations are seen all along the midlands. Along the coastal plains, sedimentary and laterites are overlain by alluvium of Recent age.

Groundwater

Ground water occurs under phreatic, semi-confined and confined conditions in the above formations. The weathered crystallines, laterites and alluvial formations form the major phreatic aquifers, whereas the deep fractures in the crystallines and the granular zones in the Tertiary sedimentary formations form the semi-confined and confined aquifers. Thick zones of weathered crystallines are seen along midland region. The depth to water level in the weathered crystallines in the midland area ranges from 3 to 16 mbgl. The midland area sustains medium capacity dug wells for irrigation. Along the hill ranges, the crystalline rocks are covered by thin weathered zone. Mostly

dug wells that can cater to domestic needs are feasible along topographic lows. Bore wells tapping deeper fracture aquifers are feasible along potential fractures in the midland and hill ranges. Potential fractures are seen down to 240 mbgl and the most productive zone lies between 60 and175 mbgl and the discharge of bore wells range between 36,000 and 1,25,000 lph. Among the four Tertiary beds, the two beds viz. the Vaikom and Warkalli form potential aquifers. The oldest Alleppey beds contain brackish water as inferred from electrical logs, whereas the Quilon beds are poor aquifers. The Vaikom aquifer is seen all along the coast between Quilon and Ponnani and the piezometric surface ranges from 1 to 18 m above msl. The aquifer is extensively developed between Quilon and Kayamkulam. The aquifer contains fresh water south of Karuvatta in Alleppey district and also in isolated pockets in Ernakulam district. The annual flow in the aquifer is computed as 43 MCM, of which 10 MCM is brackish. The Warkalli aquifer is seen south of Cochin. The piezometric head in the aquifer varies from 2.6 m above msl to 10 m below msl. The aquifer is largely developed in and around Alleppey. The annual flow in the aquifers is computed as 63 MCM and the draft is around 22 MCM. Laterites are the most widely distributed lithological unit in the State and the thickness of the formation varies from a few meters to about 30 m. The depth to water level in the formation ranges from less than a meter to 25 mbgl. Laterite forms potential aquifers along valleys and can sustain medium duty irrigation wells with the yields in the range of 0.5 - 6 m^3 per day. The alluvium forms potential aquifer along the coastal plains and ground water occurs under phreatic and semi-confined conditions in this aquifer. The thickness of this formation varies from few meters to above 100 m and the depth to water level ranges from less than a meter to 6 mbgl. Filter point wells are feasible wherever the saturated thickness exceeds 5 m.

The ground water resources for the state have been assessed block-wise. Total annual groundwater recharge has been estimated as 5.77 bcm and annual extractable ground water resource is 5.21bcm. The annual ground water extraction is 2.67bcm and stage of ground water extraction is 51%. Out of 152 blocks, 1 has been categorized as ‘Overexploited’, 2 as ‘Critical’, 30 as ‘Semi-Critical’ and 119 as ‘Safe’. There is no saline block in the state. As compared to 2013 assessment, total annual groundwater recharge of the state has decreased from 6.27 to 5.77 bcm, annual extractable ground water resources from 5.66 to 5.21 bcm. The annual ground water extraction has increased from 2.63 to 2.67 bcm and the stage of ground water extraction from 47% to 51%. The change in precipitation, consequent water level fluctuation and deeper water levels are reasons for marginal reduction in the recharge figures. The district wise groundwater recharge, extraction for different uses and groundwater extraction rates are provided in Table 1. The number of semi critical blocks is increased from 18 to 30 and the increase is mainly due to the present computation method

because of which some of the blocks have exceeded the 'safe category' limit of stage of ground water extraction and became semi critical (Table 2)(CGWB, 2019).

Table 1. Dynamic groundwater resources of Kerala.

District	Total groundwater recharge	Annual extractable Ground water resources	Current annual groundwater extraction				Stage of GW Extraction (%)
			Irrigation	Domestic	Industry	Total	
Alappuzha	43920.45	40457.33	3982.61	258.29	9423.86	13664.76	33.78
Ernakulam	55502.81	49952.53	8862.61	184.65	12847.63	21894.88	43.83
Idukki	20681.82	18613.64	6295.75	12.68	4557.61	10866.04	58.38
Kannur	45838.56	41254.71	8888.11	20.34	9876.92	18785.37	45.54
Kasargod	31750.27	28575.25	16450.76	13.90	6292.92	22757.58	79.64
Kollam	36847.12	33293.56	5351.11	17.50	11097.67	16466.28	49.46
Kottayam	41615.49	37453.94	5243.10	0.00	8360.61	13603.71	36.32
Kozhikode	34012.94	30611.65	5078.46	1.03	12750.09	17761.63	58.02
Malappuram	52281.29	47053.16	10113.27	0.00	21514.11	31627.38	67.22
Palakkad	65715.33	59143.78	19420.79	572.10	13389.54	33238.72	56.20
Pathanamthitta	28308.61	25583.23	3927.38	0.00	5521.15	9448.53	36.93
Thiruvananthapuram	29485.17	26970.47	5429.26	2.30	11784.24	17215.80	63.83
Thrissur	65226.52	59048.35	21348.86	38.93	12668.30	34056.10	57.67
Wayanad	25736.83	23163.14	1665.46	316.80	3695.35	5677.61	24.51
Total (Ham)	576923.20	521174.74	122057.53	1438.52	143780.00	267064.38	51.24
Total (Bcm)	5.77	5.21	1.22	0.01	1.44	2.67	51.36

Table 2: Categorization of blocks based on Ground water extraction

Sl. No	District	Sl. No.	Semicritical	Sl. No.	Critical	Sl. No.	Over Exploited
1	Ernakulam	1	Parakkadavu				
2	Idukki	1	Elam Desom				
		2	Kattappana				
		3	Nedumkandam				
3	Kannur	1	Kannur				
		2	Panur				
		3	Thalassery				
4	Kasargod	1	Kanhangad	1	Kasargod		
		2	Karadka				
		3	Manjeswar				
5	Kollam	1	Mukhathala				
6	Kozhikode	1	Ballussery				
		2	Kunnamangalam				
7	Malappuram	1	Kondotty				
		2	Kuttippuram				
		3	Malappuram				
		4	Thanur				
		5	Thriurangadi				
		6	Tirur				
		7	Vengara				
8	Palakkad	1	Pattambi	1	Malampuzha	1	Chittur
		2	Thrithala				
9	Thiruvananthapuram	1	Athiyannur				
		2	Chirayinkil				
		3	Parassala				
		4	Pothencode				
		5	Nedumangad				
10	Thrissur	1	Chowannur				
		2	Mathilakom				
		3	Thalikkulam				
Total No. of Assessed Units			**Semicritical**	**Critical**		**Over Exploited**	
152			**30**	**2**		**1**	

Ground water quality assessment

Ground water is an important source of water for meeting the drinking, agricultural, and industrial needs in India. Over the last few decades use of ground water in the country has increased manifolds exerting pressure on the limited resources available and threatening their long term sustainability in many places. Kerala, though blessed with copious rainfall and an abundance of surface water resources, depends heavily on the limited ground water resources to meet its drinking and domestic water requirements, especially in rural habitations.

Kerala state has limited ground water development prospects owing to largely undulating topography and the predominance of crystalline rocks devoid of any primary porosity. The increase in demand for fresh water resources due to changes in lifestyles, agricultural practices and urbanization has resulted in an increase in stress of ground water regime in several areas of the state. Anticipated impact of climate change and sea level rise also has the potential to change ground water regime in the state.

Physicochemical quality of water is necessary to evaluate its suitability for different usages. Quality of ground water depends on natural processes i.e. dissolution and precipitation of minerals, as well as recharge of water and its interaction with other water types. The natural chemical quality of groundwater depends on the concentrations of a number of constituents which may cause problems for soil or plant on the long term. Hydro-geochemical processes of groundwater are influenced by various factors, such as rock-water interaction and human activities. Many factors decide the rate of suitability of water for irrigation, eg. water quality, soil type, salt tolerance characteristics of plants, climate and drainage. Sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) are the most important factors of quality criteria, which have high influence on water suitability for irrigation. The integration of the geographic information system (GIS) platform to the assessment procedure not only allows the decision maker to create parameter maps for easy visual interpretation but also makes the overall analysis more sound, objective and simple Water Quality Index (WQI) is a very useful and efficient method to evaluate the suitability of water quality and for communicating the information on overall quality of water. The determination of WQI helps in deciding the suitability of groundwater sources for its intended purpose. As for as ground water irrigation water quality is concerned, All India Coordinated Research Project (AICRP) on Management of Salt Affected Soils and Use of Saline Water in Agriculture, Central Soil Salinity Research Institute (CSSRI), Haryana Agricultural University (HAU) and Punjab Agricultural University (PAU) recommended realistic guidelines on utilizing poor quality waters applicable to Indian monsoon based agriculture. In addition to water quality parameters, importance of soil

texture, crop tolerance, rainfall and concentration of soil solution due to evapo-transpiration have also been recognized in developing these guidelines (Gupta *et al.*, 1994). These guidelines are well accepted and routinely used for classifying the quality of irrigation water (Table 3).

Table 3. Criteria for ground water quality classification (CSSRI)

Categories	EC (dS m^{-1})	SAR	RSC (me L^{-1})
Good	<2	<10	<2.5
Marginally saline	2-4	<10	<2.5
Saline	>4	<10	<2.5
High SAR saline	>4	>10	<2.5
Marginally alkaline	<4	<10	2.5 – 4.0
Alkaline	<4	<10	>4.0
Highly alkaline	Variable	>10	>4.0

Chapter II

Ground water quality of Thiruvananthapuram district

Thiruvananthapuram, the southern most district of Kerala State, is situated between North latitude of 8° 16’ 59” and 8° 49’ 59” East longitude of 76° 28’ 59” and 77° 16’59”, covers a geographical area of 2192 sq. km is the capital city of Kerala State . The district stretches 76 kms along the shores of Lakshadweep Sea on the west, bordered by Kollam district on the north and with Tirunelveli and Kanyakumari districts of Tamil Nadu on the east and south respectively. The groundwater extraction stage of the district is 63.83% and five blocks namely, Athiyannur, Chirayankil, Parassala, Pothencode, Nedumangad of the district are semi-critical with stage of groundwater development between 70 to 90% (CGWB, 2019).

A total of thirty eight ground water samples were collected from Thiruvananthapuram district (Fig. 1a), 89.47 % was good for irrigation purposes. The remaining 2.63 % was marginally saline and 7.89 % was under saline categories of irrigation water quality respectively. Spatial variability of EC, SAR, RSC and ground water quality of Thiruvananthapuram district were expressed in fig. 1b, 1c, 1d, 1e and 1f respectively.

Table 4: EC, SAR, RSC and ground water quality of Thiruvananthapuram district

Sl no.	Location	EC	SAR	RSC	Type of Groundwater
		dS/m	(mmol l^{-1})[1]	meq/l	(As per CSSRI Classification)
1	Azhoor		2.874	0	Good
2	Kadakkavur(R1)	0.23	2.388	0	Good
3	Perumathura	0.25	4.093	0	Good
4	Perumgulam	0.53	1.367	0	Good
5	Perumkuzhi	0.1	2.372	0	Good
6	Sasthavattom	0.36	1.354	0	Good
7	Vakkom	0.12	2.394	0	Good
8	Chirayinkeezhu	0.42	2.88	0	Good
9	Cherunniyoor	0.13	2.509	0	Good
10	Palayamkunnu	0.56	3.347	0	Good
11	Varkala	0.42	4.6	0	Good
12	Varkala beach	3.6	5.605	0	Marginally saline
13	Pappanasam	1.8	6.602	0	Good
14	Edavai	0.1	4.106	0	Good
15	Kappil	0.32	7.736	0	Good
16	Kappilkayal	4.2	4.631	0	Saline
17	Kulathur 1	0.11	3.299	0	Good
18	Kulathur 2	0.22	2.013	0.924	Good
19	Venpakal	0.42	1.588	0	Good
20	Kochuthura	0.42	2.36	0	Good
21	Kovalam Beach	4.5	2.483	0	Saline
22	KovalamLps	0.28	1.678	0	Good
23	Kazhakkuttom	0.93	2.107	0	Good
24	Thumba	0.43	2.563	0	Good
25	Veli	1.14	2.287	0	Good
26	Kochuveli	0.47	2.361	0	Good
27	Poonthura	0.45	1.779	0	Good
28	Vizhinjam	4.48	2.154	0	Saline
29	Vizhinjam house	1.26	2.224	0	Good
30	Shankumugam	0.24	2.314	0	Good
31	Chittagode	1.37	3.904	0	Good
32	Thiruvallam	0.51	3.363	0	Good
33	Poonkulam	0.31	1.656	0	Good
34	Vellayani	0.42	2.565	0	Good
35	Poovar	0.7	2.179	0	Good
36	Pozhiyoor	1.93	2.496	0	Good
37	Mavilakadavu	0.18	3.566	0	Good
38	Kalmora	0.35	2.302	0	Good

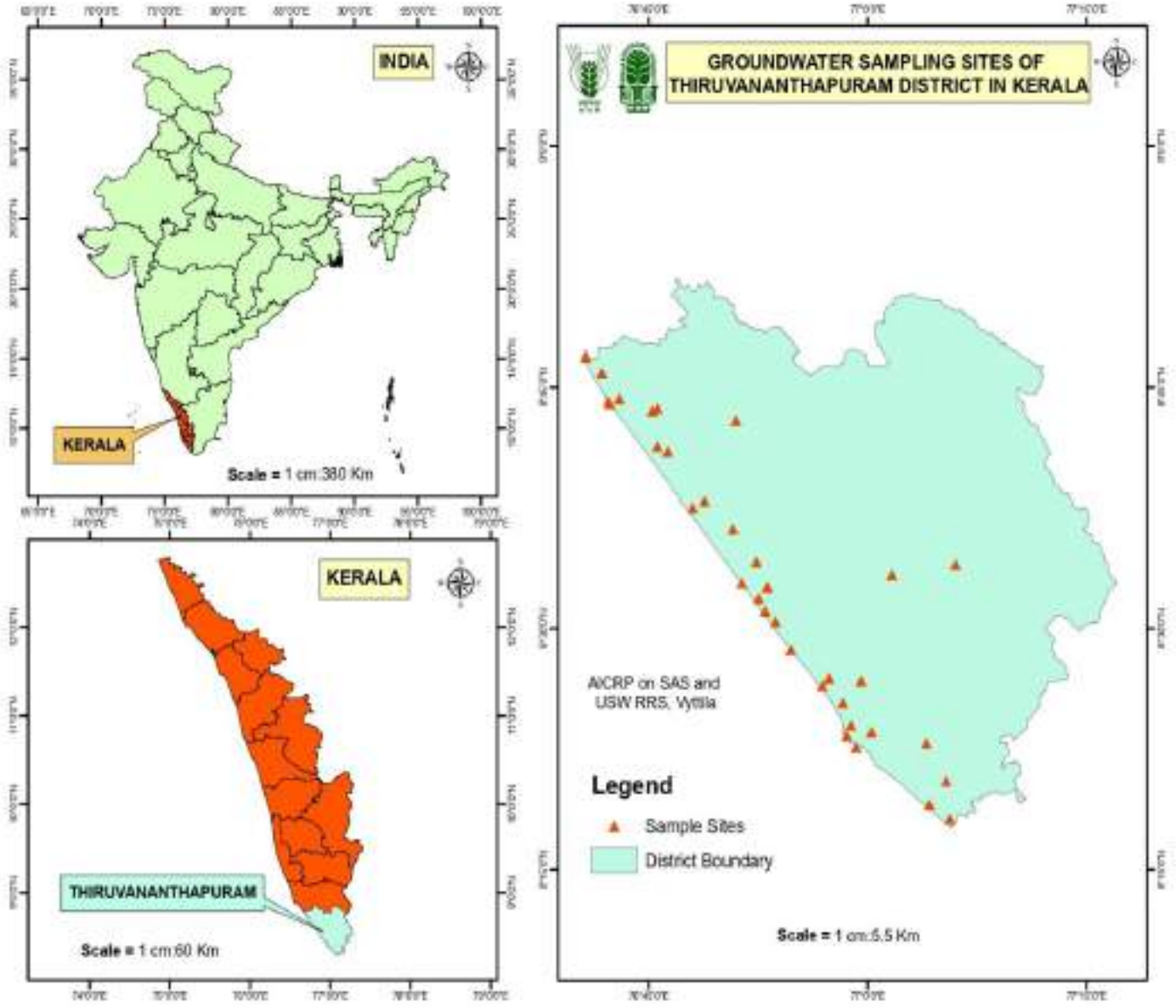

Fig 1a. Ground water sampling sites of Thiruvananthapuram district in Kerala

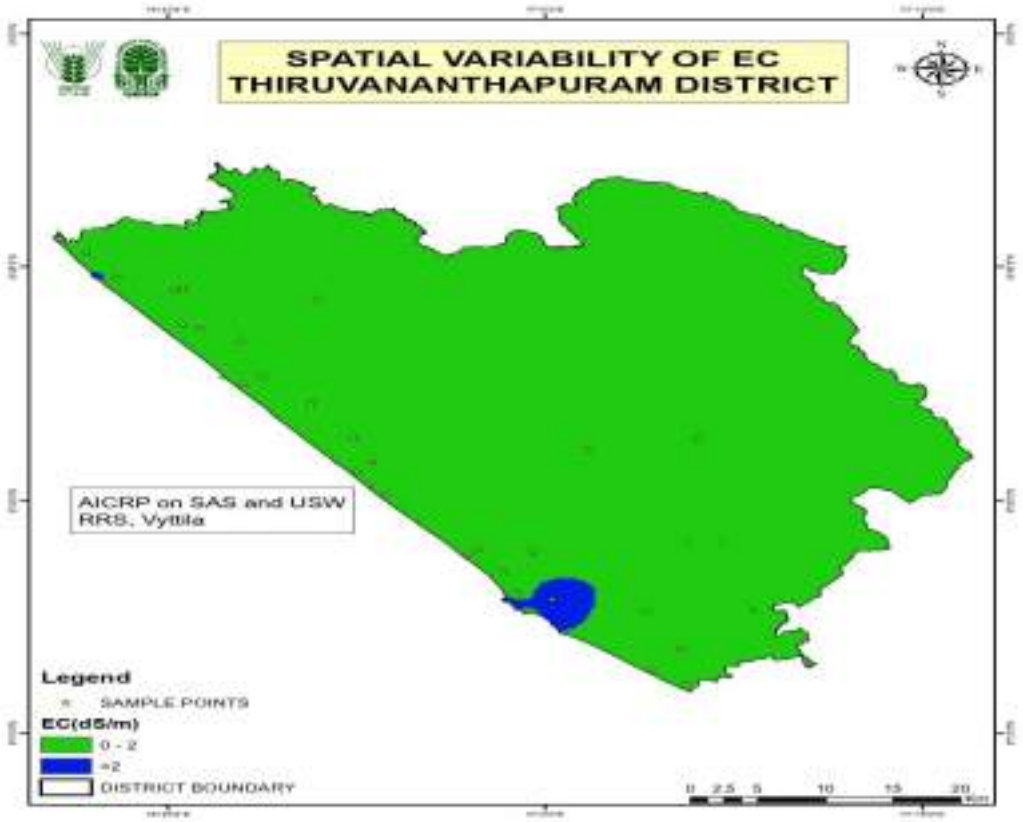

Fig 1b. Spatial variability of electrical conductivity of Thiruvananthapuram district

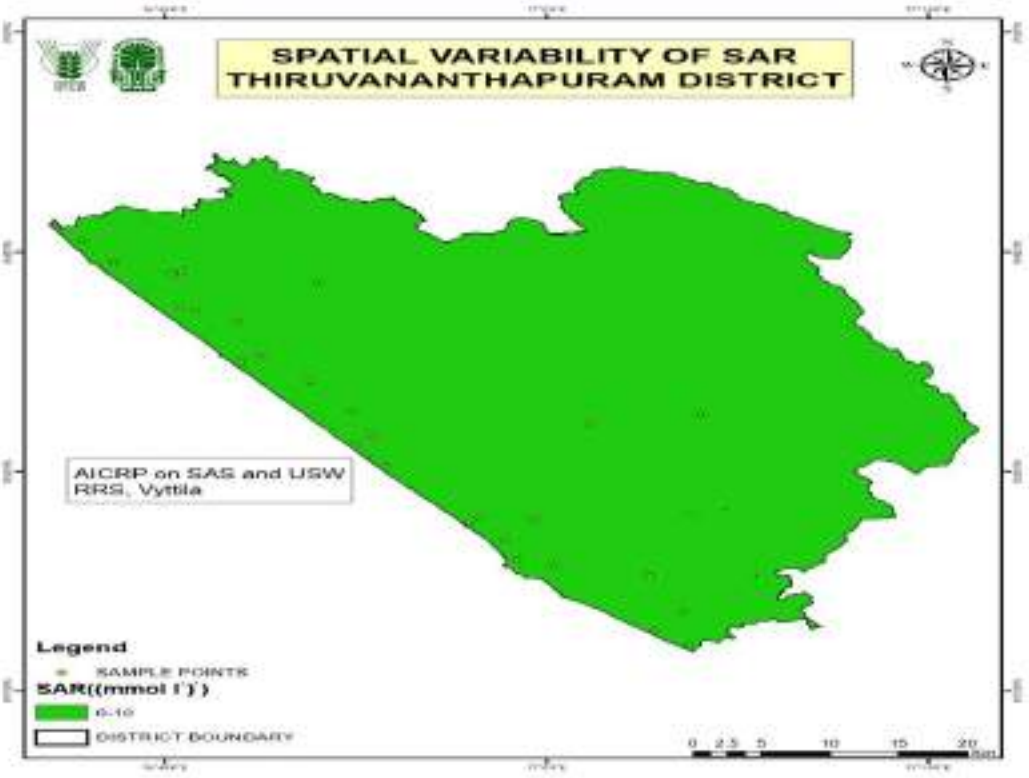

Fig 1c. Spatial variability of SAR of Thiruvananthapuram district

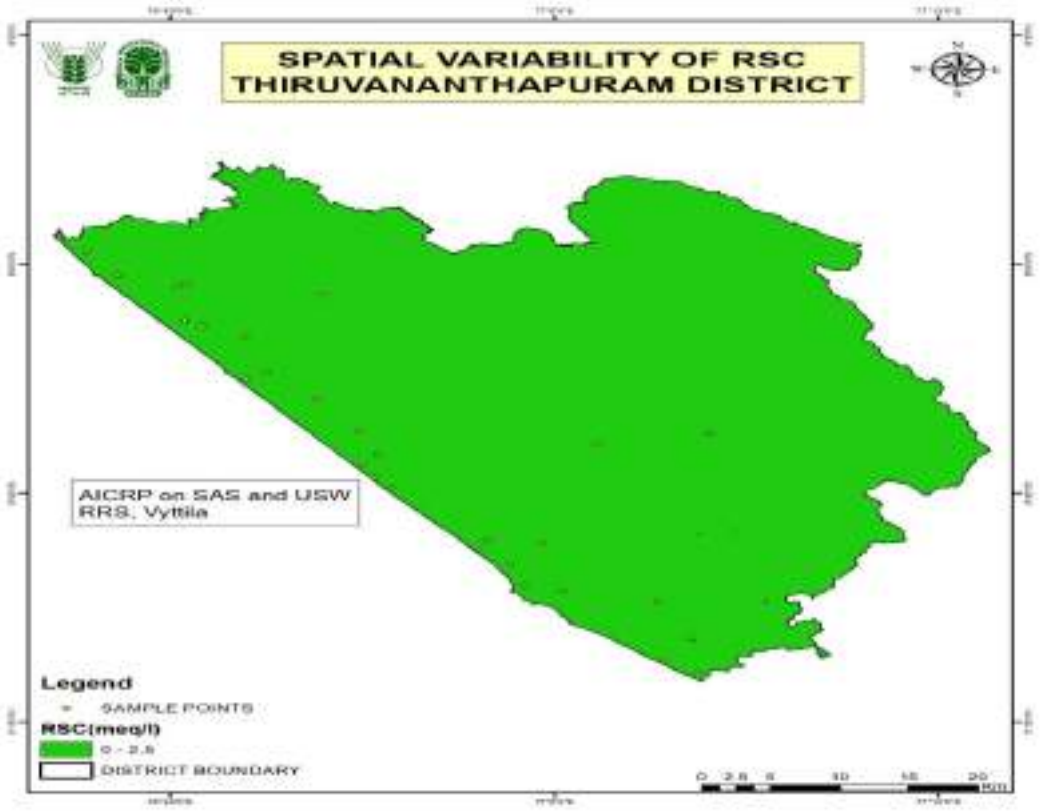

Fig 1d. Spatial variability of RSC of Thiruvananthapuram district

Fig 1e. Spatial distribution of ground water quality for irrigation purpose for Thiruvananthapuram district

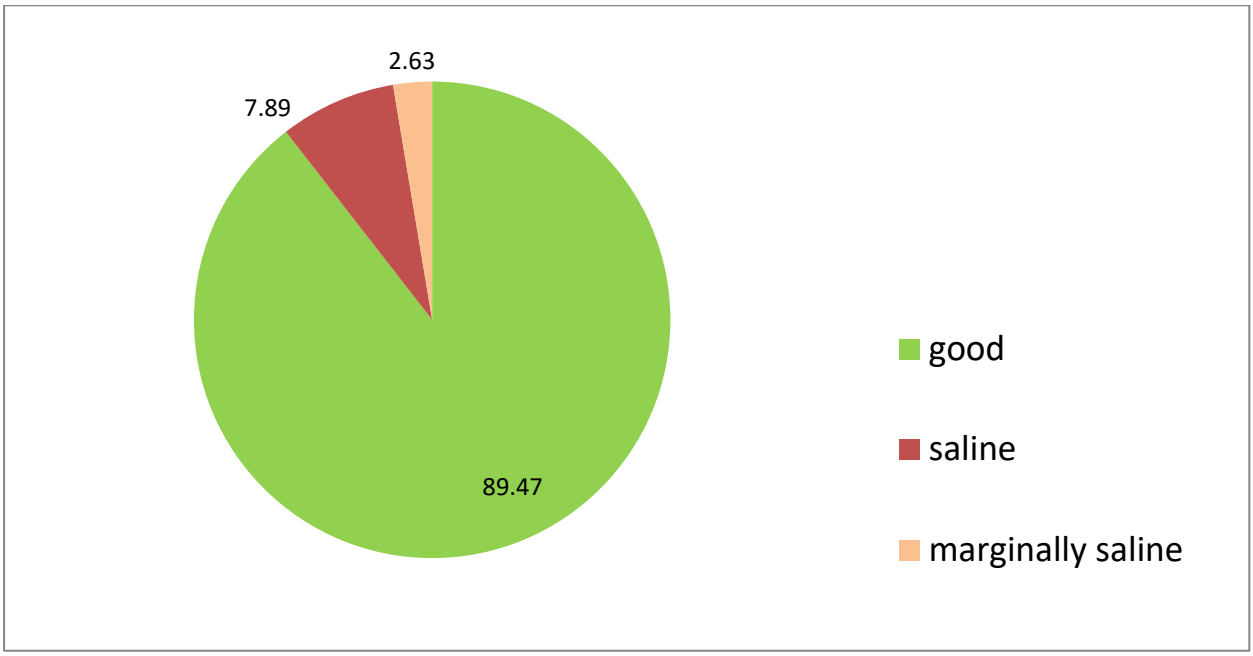

Fig 1f. Groundwater quality distribution for irrigation purpose in Thiruvananthapuram

Chapter III

Ground water quality of Kollam district

Kollam district is located on the southwest part of Kerala State and extends from Lakshadweep Sea to the Western Ghats and is bordered by Trivandrum district on the South and Alleppey and Pathanamthitta districts in the North and Tirunelveli district of Tamil Nadu State in the East and Lakshadweep Sea in the west. It lies between North latitudes 8 0 45' and 90 07' and East longitudes 760 29' and 770 17'. It has a geographical area of 2491 sq km. The groundwater extraction stage of the district is 49.46 % and Mukhathala blocks of the district is in semi-critical stage (CGWB, 2019).

A total of twenty one ground water samples were collected from Kollam district. Out of this, 95.23 % and 4.76 % fall under good and marginally saline categories of irrigation water quality respectively (Fig 2a, 2b, 2c, 2d, 2e and 2f) Saline water ingress is observed in the shallow alluvial aquifer in the western part of the district which is in hydraulic connection with the back water.

Table 5: EC, SAR, RSC and ground water quality of Kollam district

Sl No.	Location	EC	SAR	RSC	Type of Groundwater
		dS/m	$(mmol\ l^{-1})^1$	meq/l	(As per CSSRI Classification)
1	Azheekal	3.5	7.21	0	Marginally Saline
2	Alappad	1.51	7.43	0	Good
3	Parakkadavu	1.4	19.67	0	Good
4	Maruthukulangara	1.4	19.22	0	Good
5	Manapilly	0.9	79.79	0	Good
6	Sooranedu	1.2	15.96	0	Good
7	Sasthamkotta	1.1	24.46	0	Good
8	PonmanaManayil	1	20.92	0	Good
9	Vadakumthala	1.2	34.87	0	Good
10	Puthanthura	1.8	6.79	0	Good
11	Neendakara	1.9	3.98	0	Good
12	Kavanad	1.3	2.23	0	Good
13	Kangathumukku	1	7.9	0	Good
14	Taluk Office	1.8	9.89	0	Good
15	Iravipuram 1	1.5	11.34	0	Good
16	Iravipuram 2	1.5	10.35	0	Good
17	Poothakulam	0.8	8.56	0	Good
18	Pozhikkara	1.2	6.78	0	Good
19	Anchaloomude	1.1	39.18	0.3	Good
20	Ashtamudikayal	3.9	109.4	0	Good
21	Karunagapilly	0.5	33.95	0	Good

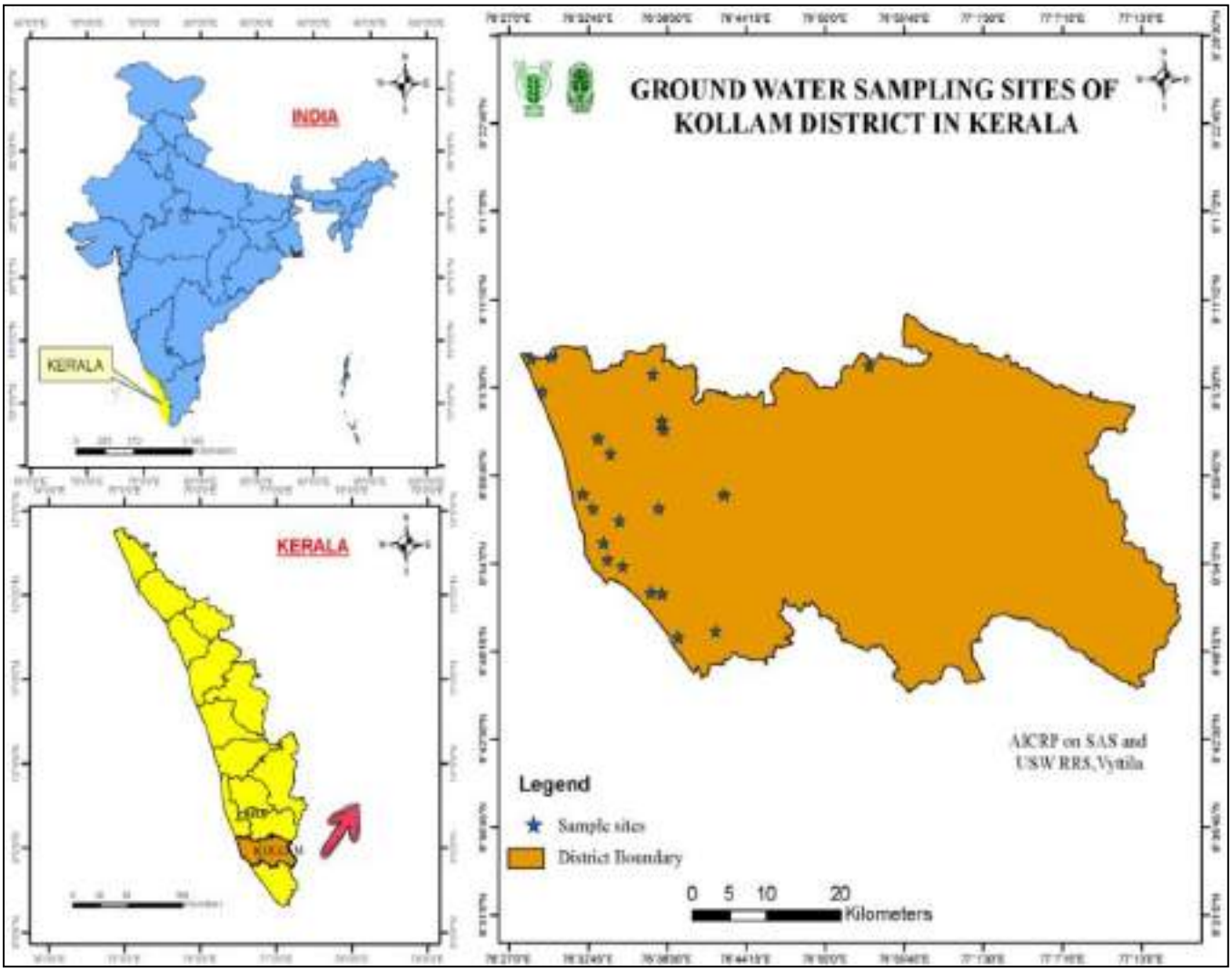

Fig 2a: Ground water sampling sites of Kollam district

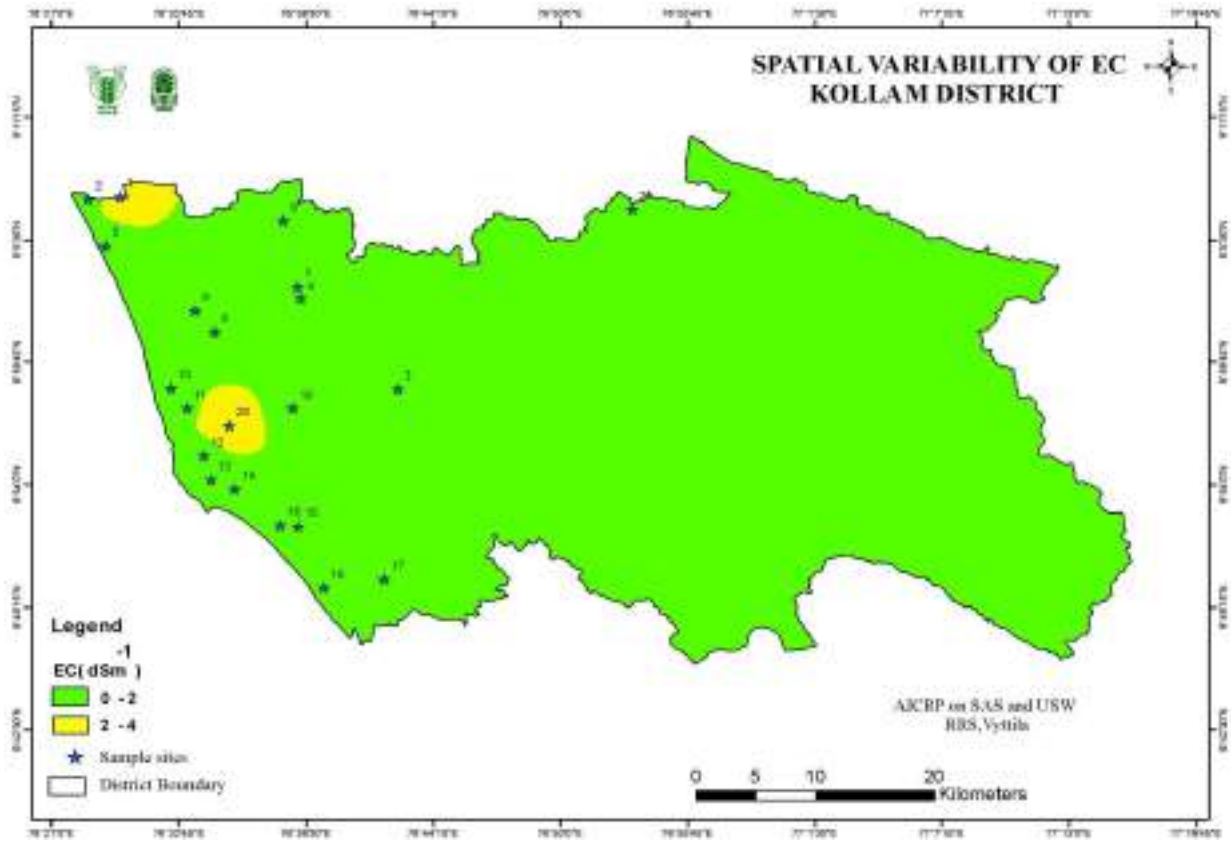

Fig 2b: Spatial variability of electrical conductivity of Kollam district

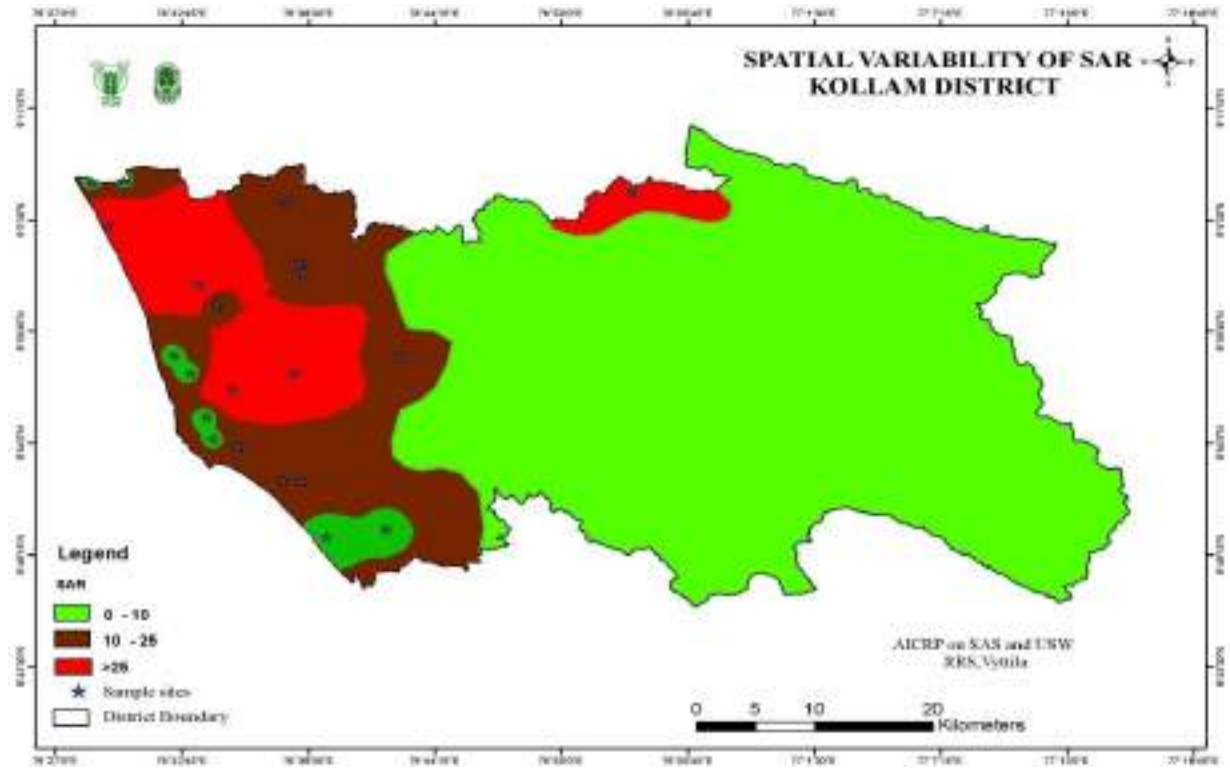

Fig 2c: Spatial variability of SAR of Kollam district

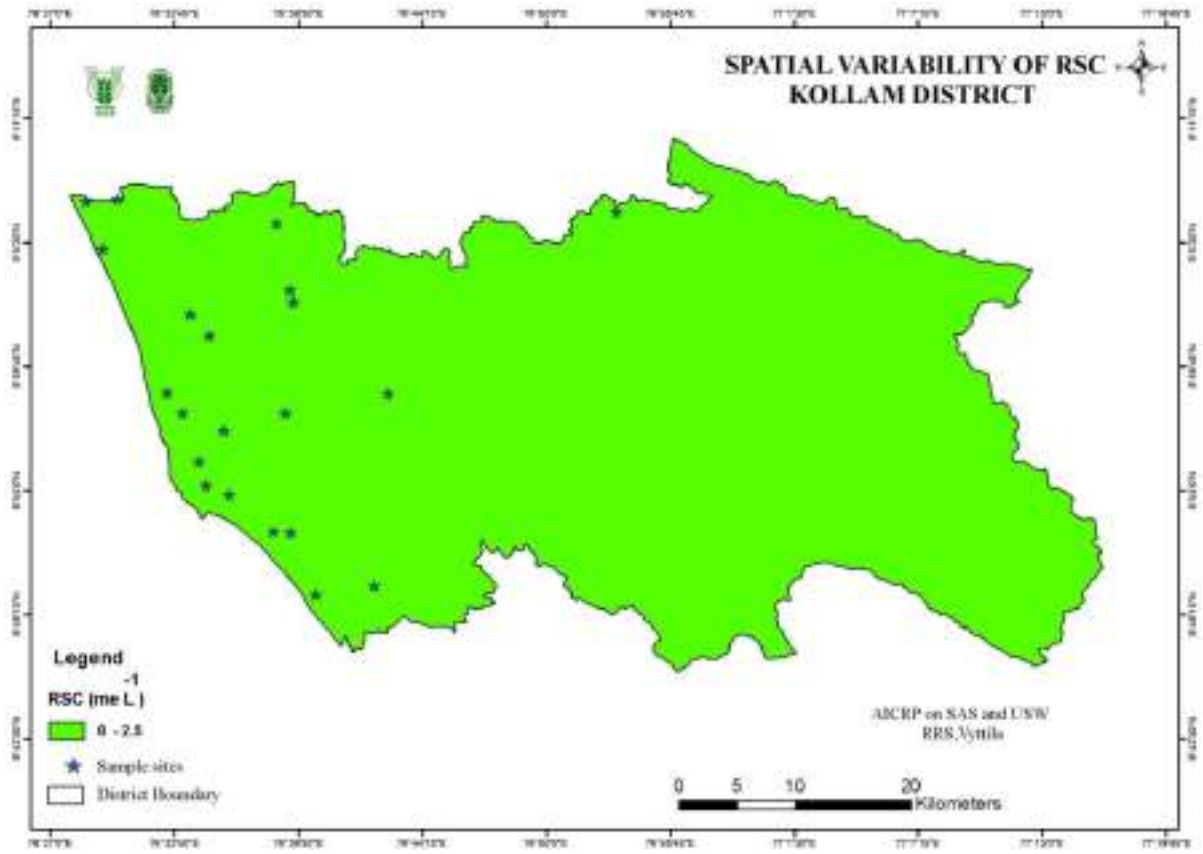

Fig 2d: Spatial variability of RSC of Kollam district

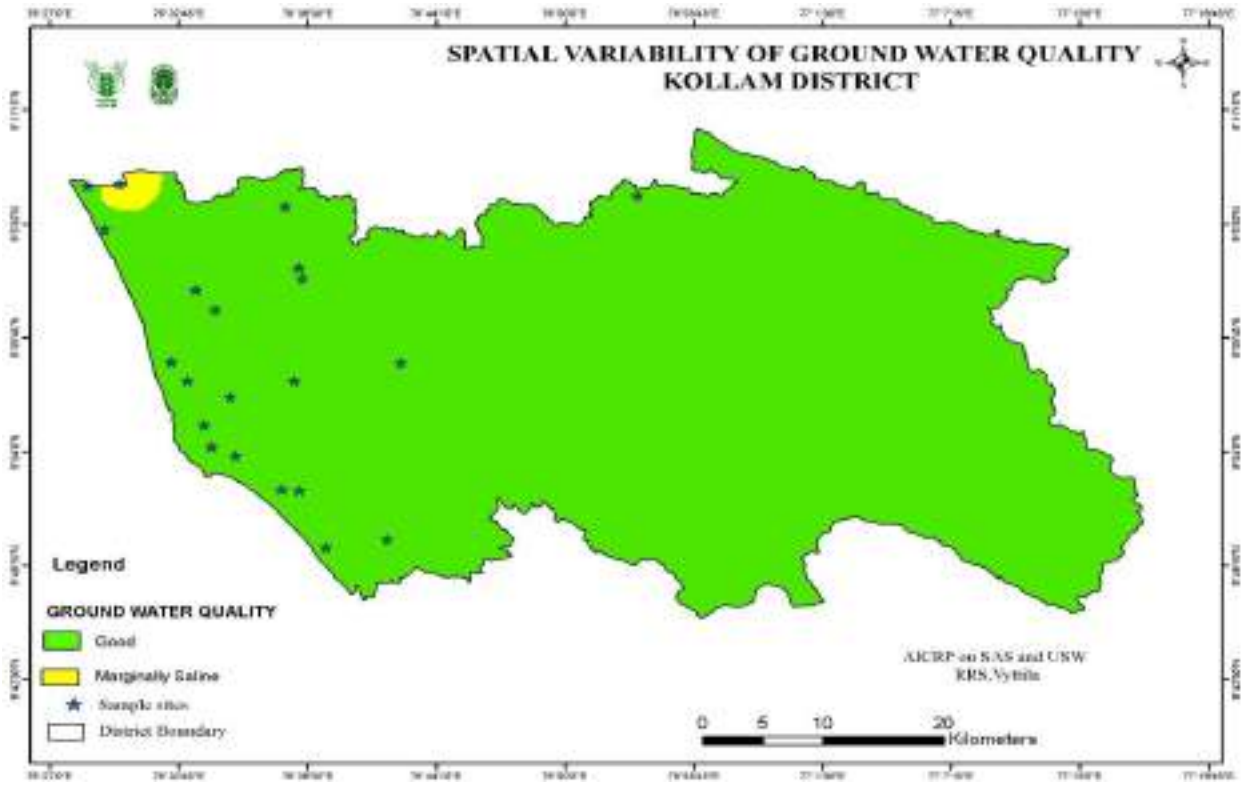

Fig 2e. Spatial distribution of ground water quality for irrigation purpose for Kollam district

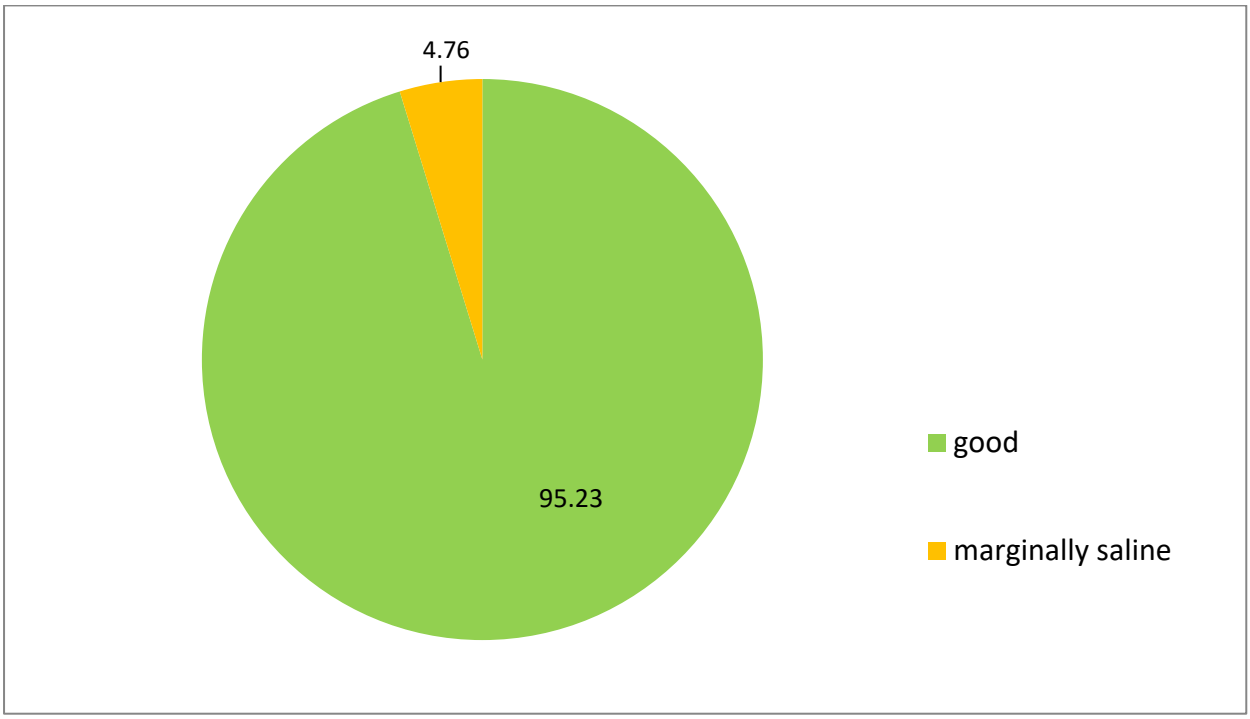

Fig 2f: Groundwater quality distribution for irrigation purpose in Kollam

Chapter IV
Ground water quality of Pathanamthitta district

Pathanamthitta is a landlocked district, located at 9°16′N 76°47′E, spanning over an area of 2,637 square kilometers. The district is bordered by the districts Kottayam and Idukki districts in the north, Alappuzha district in the west, Kollam district in the south. To the east it borders the Tenkasi district of the Tamil Nadu state. The highland, the midland, and the lowland are the three natural geographical divisions of the district. The Western Ghats, where the hills are lofty and densely forested, are where the highland extends. The Western Ghats maintain an elevation of about 800 metres on average. It then descends to the midland's smaller hills before reaching the lowlands. Along the eastern boundaries of Alappuzha district, the lowland with its profusion of coconut trees may be found. The groundwater extraction stage of the district is 36.93% (CGWB, 2019).

A total of five water samples were collected from Pathanamthitta district (fig.3a). All the samples fall under good category of irrigation water quality. Spatial variability of EC, SAR, RSC and ground water quality of Pathanamthitta district were expressed in fig. 3b, 3c, 3d, 3e and 3f respectively.

Table 6: EC, SAR, RSC and ground water quality of Pathanamthitta district

Sl No.	Location	EC	SAR	RSC	Type of Groundwater
		dS/m	$(mmol\ l^{-1})^1$	meq/l	(As per CSSRI Classification)
1	Muthoor	0.15	3.831	0	Good
2	Peringara	0.5	4.394	0	Good
3	Pulikeezhu	0.28	2.997	1.131	Good
4	Podiyadi	0.24	4	0	Good
5	Thiruvalla	0.2	2.53	0.947	Good

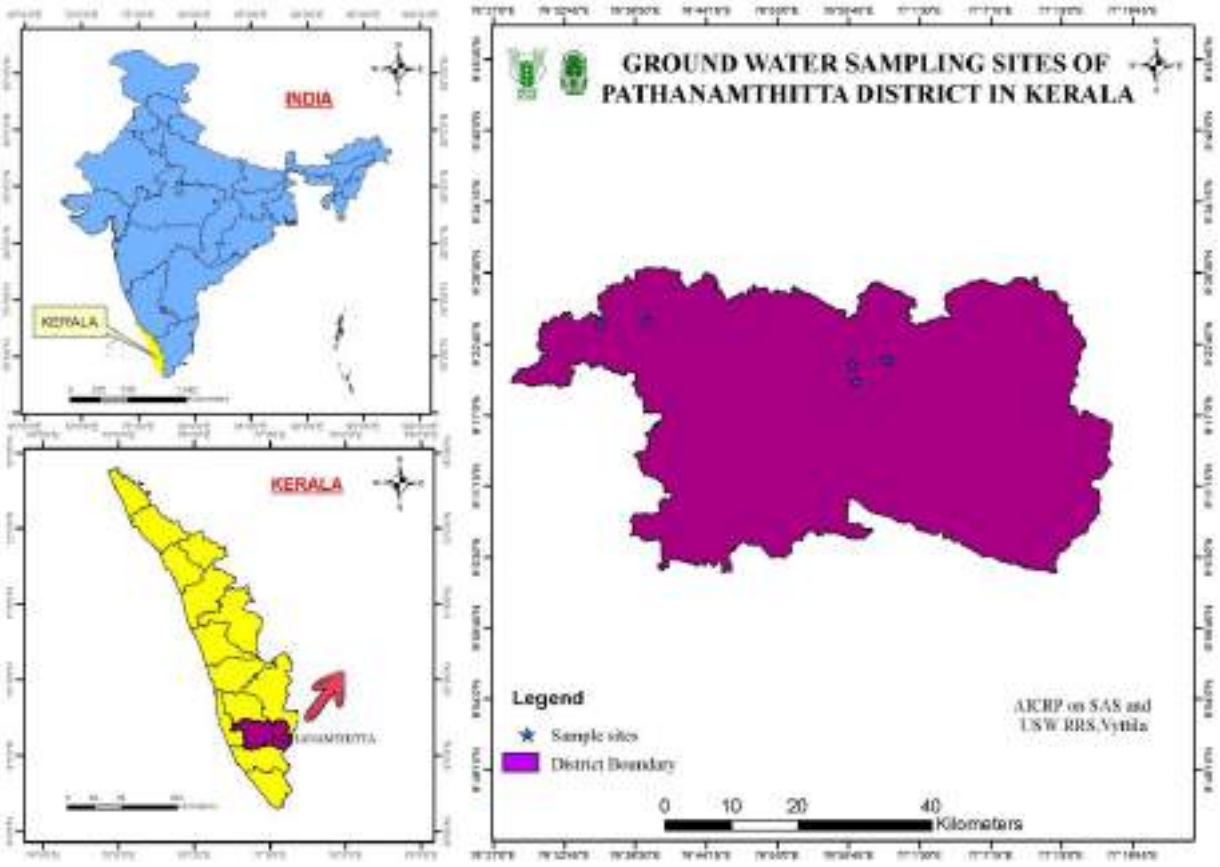

Fig 3a: Ground water sampling sites of Pathanamthitta district

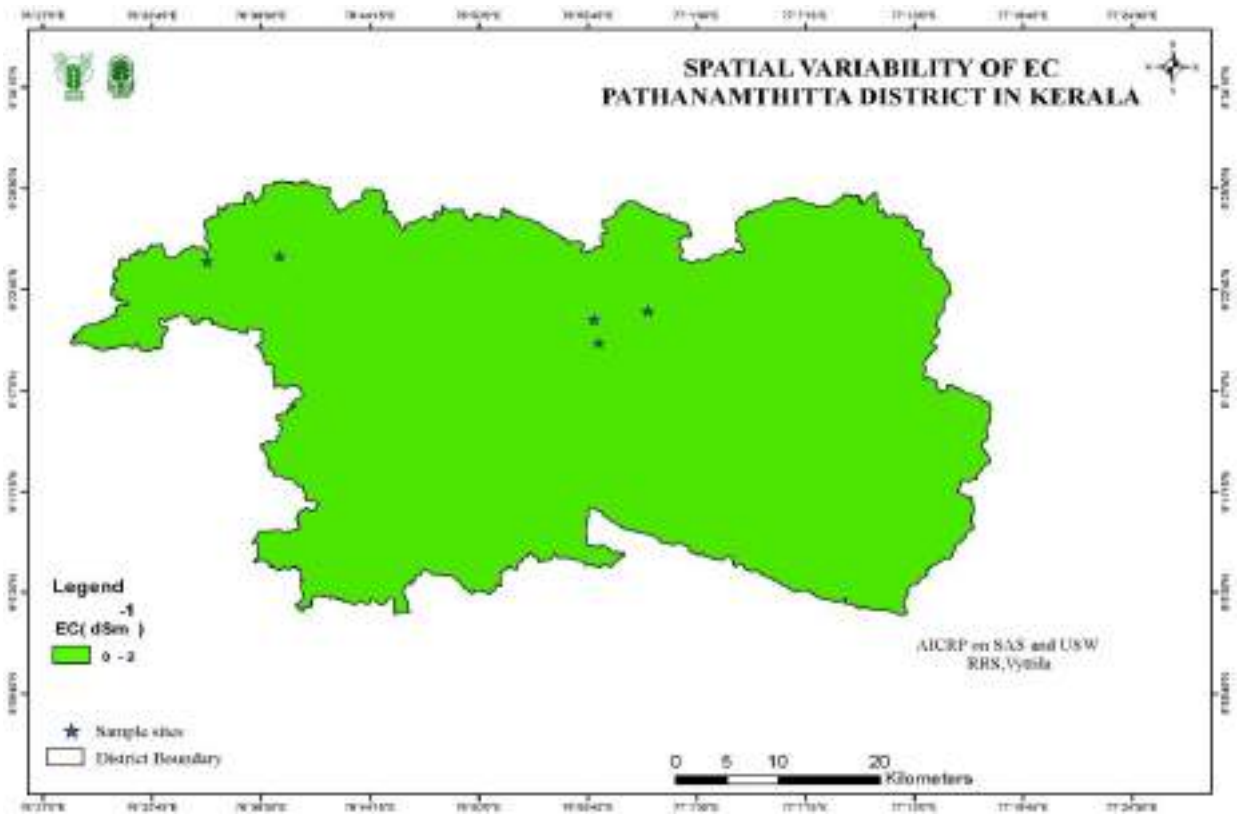

Fig 3b: Spatial variability of electrical conductivity of Pathanamthitta district

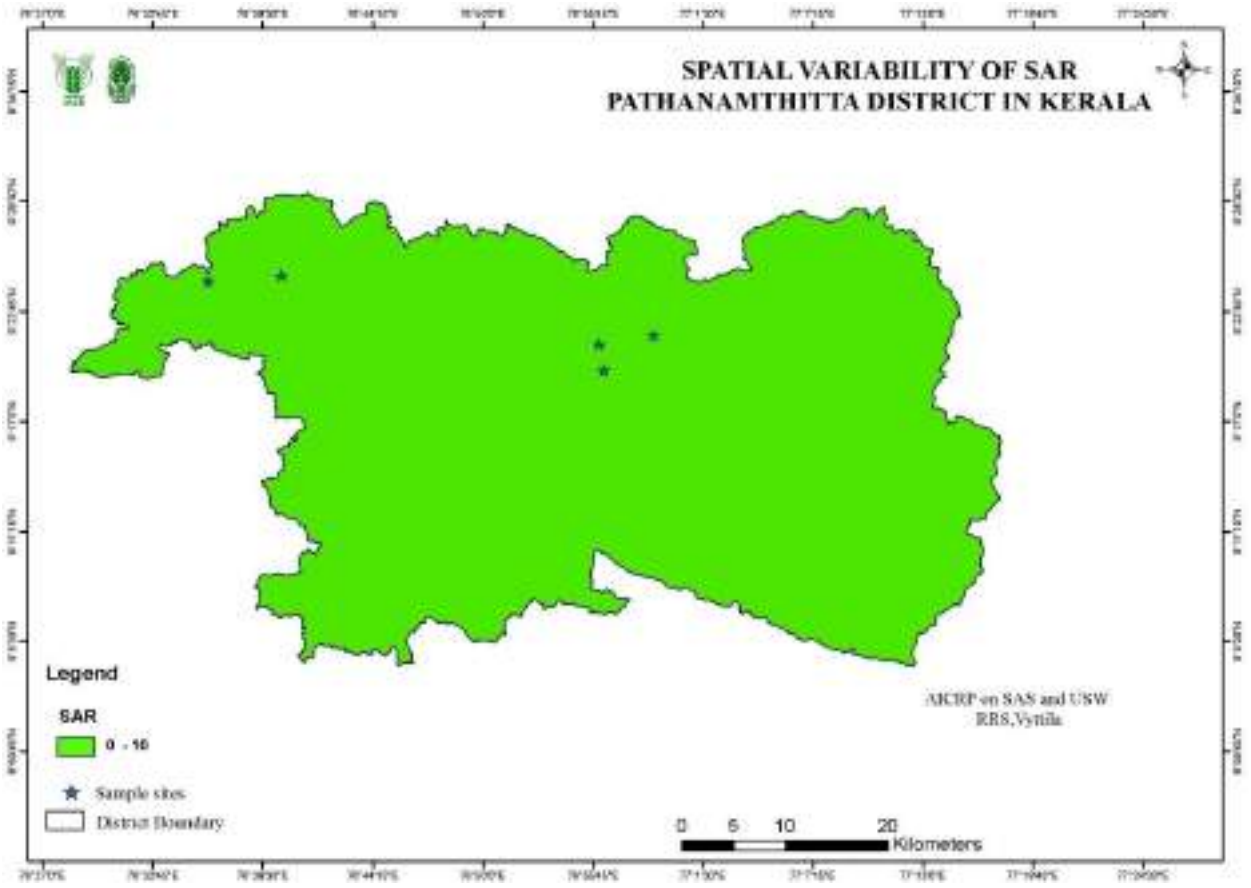

Fig 3c: Spatial variability of SAR of Pathanamthitta district

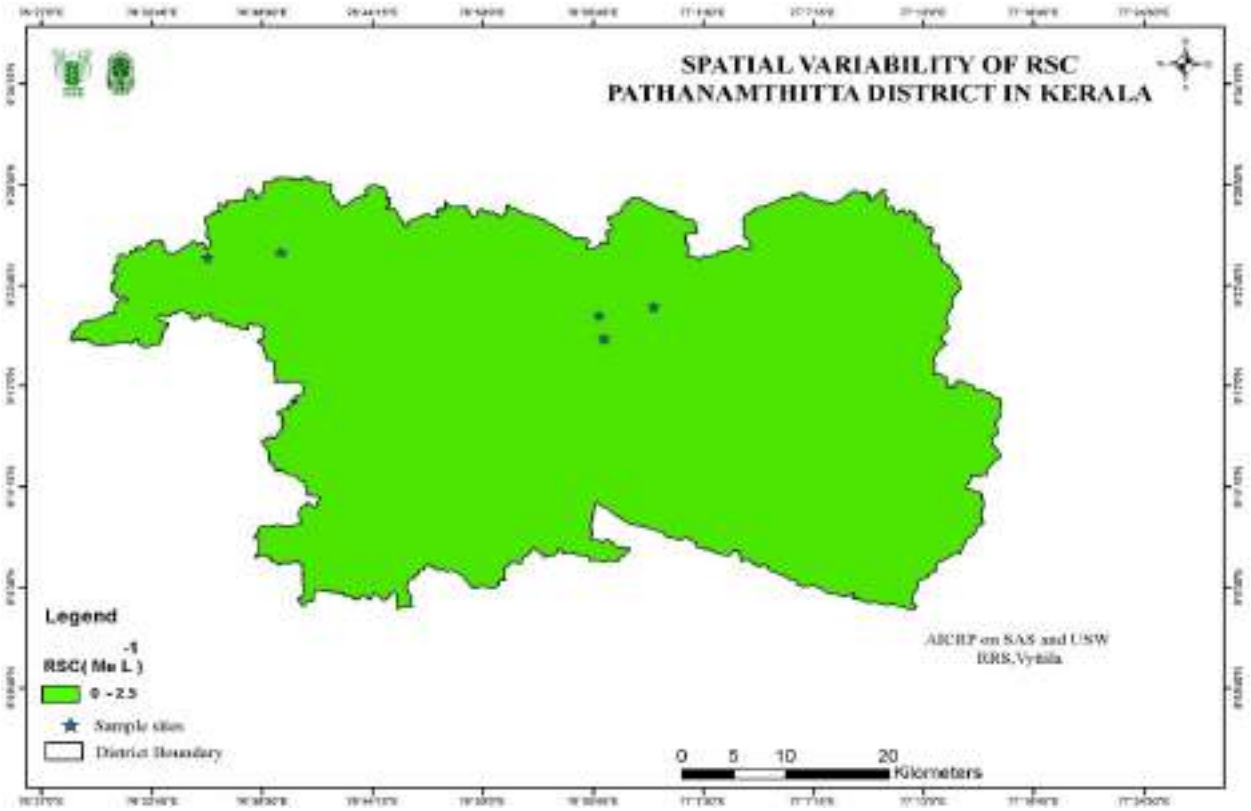

Fig 3d: Spatial variability of RSC of Pathanamthitta district

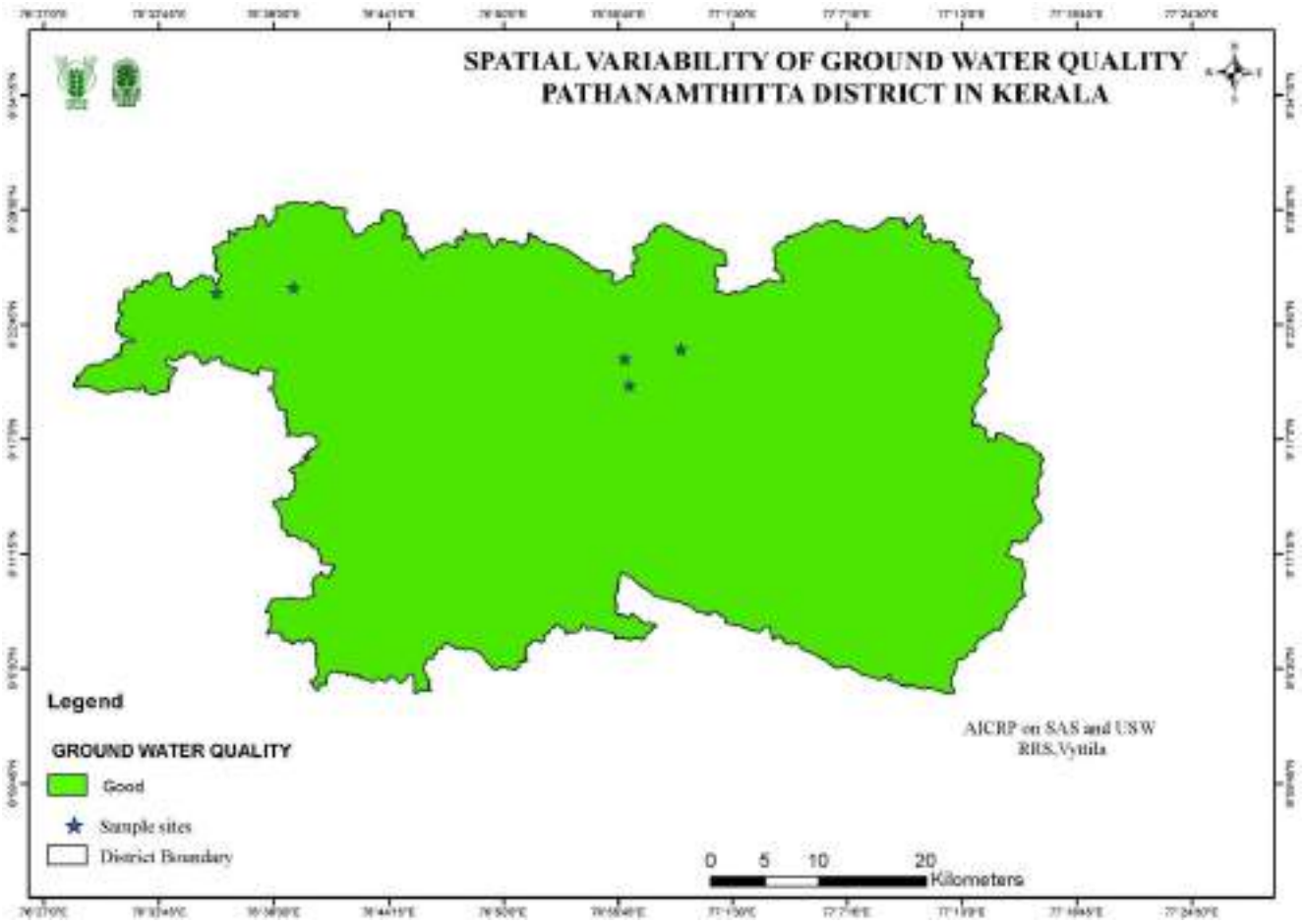

Fig 3e. Spatial distribution of ground water quality for irrigation purpose for Pathanamthitta district

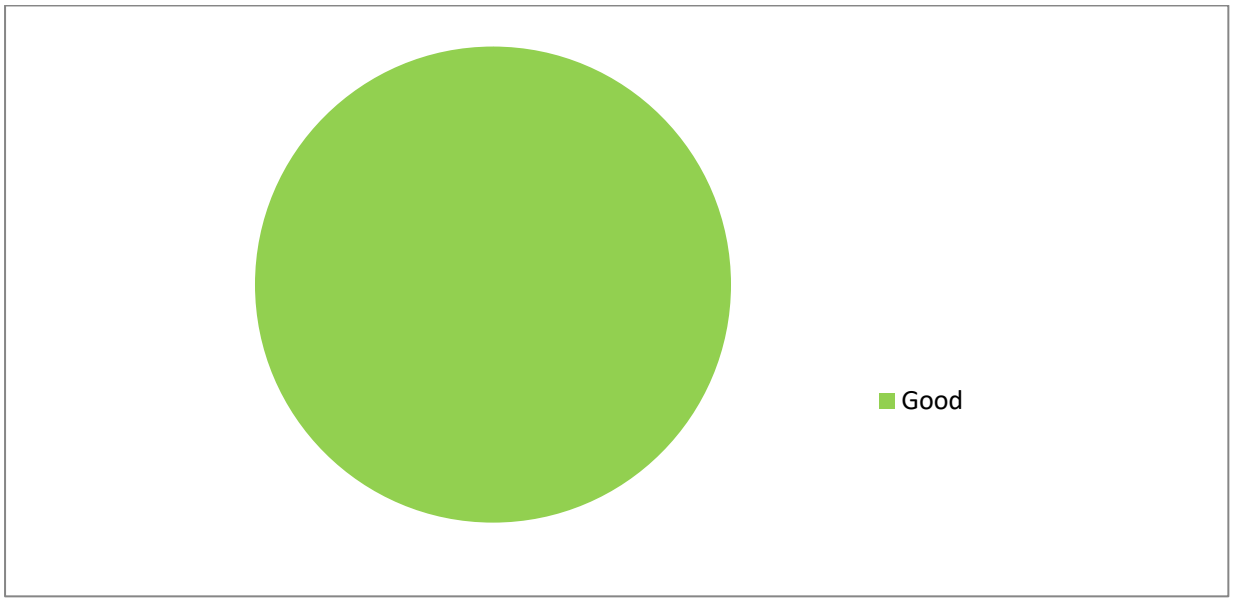

Fig 3f. Groundwater quality distribution for irrigation purpose for Pathanamthitta district

Chapter V

Ground water quality of Alappuzha district

Alappuzha is located on a peninsular landmass between the Arabian Sea and the Vembanad lake at 9.54°N 76.40°E, and it covers an area of 1,414 square kilometres. The district is a sandy strip of land with lagoons, rivers, and canals in between. Except for a few isolated hillocks between the Bharanikkavu and Chengannur blocks in the eastern part of the district, there are no mountains or hills in the district. This district doesn't have any forests. The groundwater extraction stage of the district is 33.78 % (CGWB, 2019).

A total of fifty six ground water samples were collected from Alappuzha district (fig.4a). Out of this, 87.50 % falls under good category of irrigation water. Remaining 7.14 % and 5.35 % falls under marginally alkaline and high alkaline categories of irrigation water quality respectively. Spatial variability of EC, SAR, RSC and ground water quality of Alappuzha district were expressed in fig. 4b, 4c, 4d, 4e and 4f respectively.

Table 7: EC, SAR, RSC and ground water quality of Alappuzha district

Sl no.	Location	EC	SAR	RSC	Type of Groundwater (As per CSSRI Classification)
		dS/m	(mmol l^{-1})^1	meq/l	
1	Mannamcherry	0.2	2.59	1.43	Good
2	Mannamcherry RF	0.29	3.84	0.57	Good
3	Kattoor	0.09	3.18	1.55	Good
4	Valavanad	0.18	2.46	2.68	Marginally alkaline
5	Kanichukulangara	0.15	2.32	1.9	Good
6	Vanaswargam	0.09	3.93	0.97	Good
7	Cheruvarnam	0.14	2.67	0.44	Good
8	Cherthala	0.38	1.43	4.54	Good
9	Kalavamkodam	0.14	2.77	4.33	Alkaline
10	Pattanakkad	0.42	1.21	4.3	Alkaline
11	Thuravur	0.35	1.4	3.64	Good
12	Eramallur	0.3	1.79	3.24	Good
13	Chandirur	0.12	1.81	0.45	Good
14	Aroor	0.19	3.23	3.23	Good
15	Panavally	0.21	1.72	2.07	Good
16	Ottappunna	0.14	1.75	1.09	Good
17	Harippad	0.26	0.27	0	Good
18	Naduvattom	0.22	0.89	0	Good
19	Mahadevikkad	0.36	0.56	0	Good
20	Karuvatta	0.51	0.53	0	Good
21	Thottappally	0.14	1.57	0.26	Good
22	Purakkadu	0.47	0.93	0	Good
23	Ambalappuzha	0.4	1.13	0	Good
24	Neerkkunnam	0.34	0.52	0	Good
25	Punnapra	0.21	0.75	0	Good
26	Kaidavanam	0.52	1.66	0	Good
27	Alappuzha	0.32	0.68	0	Good
28	Alappuzha light house	0.36	0.3	0	Good
29	Kalavoor	0.65	1.64	0	Good
30	Nedumudi	0.39	0.25	0	Good
31	Chambakkulam	0.19	0.33	0	Good
32	Chambakkulam RF	0.36	2.28	0	Good
33	Vandanam	0.2	0.44	0.92	Good
34	Moncombu 1	0.36	2.28	0	Good
35	Moncombu 2	0.59	1.38	0	Good
36	Ramankari	0.17	0.81	0.53	Good
37	Ramankari RF	0.43	0.58	0	Good

38	Kumaramkari	0.17	0.84	0.49	Good
39	Edathuva	0.43	0.58	0	Good
40	Edathuva RF	0.07	1.00	0.54	Good
41	Muttar	0.08	1.15	0.55	Good
42	Veeyapuram	0.14	1.05	0.29	Good
43	Veeyapuram RF	0.08	1.15	0.55	Good
44	Paccha	0.27	0.36	0	Good
45	Thakazhi	0.07	1	0.54	Good
46	Onattukara	0.27	1.48	0	Good
47	Kuttitherivu	0.03	1.25	0.46	Good
48	Kattanam	0.82	2.88	0	Good
49	Charumoodu	1.03	4.36	0	Good
50	Kuzhamathu	0.23	0.6	0	Good
51	Noornadu	0.11	0.64	0.18	Good
52	Athikattukulangara	0.07	1.04	0.2	Good
53	Thamarakkulam	0.07	0.58	0	Good
54	Vallikkunnam	0.09	1.46	0.17	Good
55	Ochira	0.02	2.33	0.56	Good
56	Kayamkulam	0.14	2.35	0.2	Good

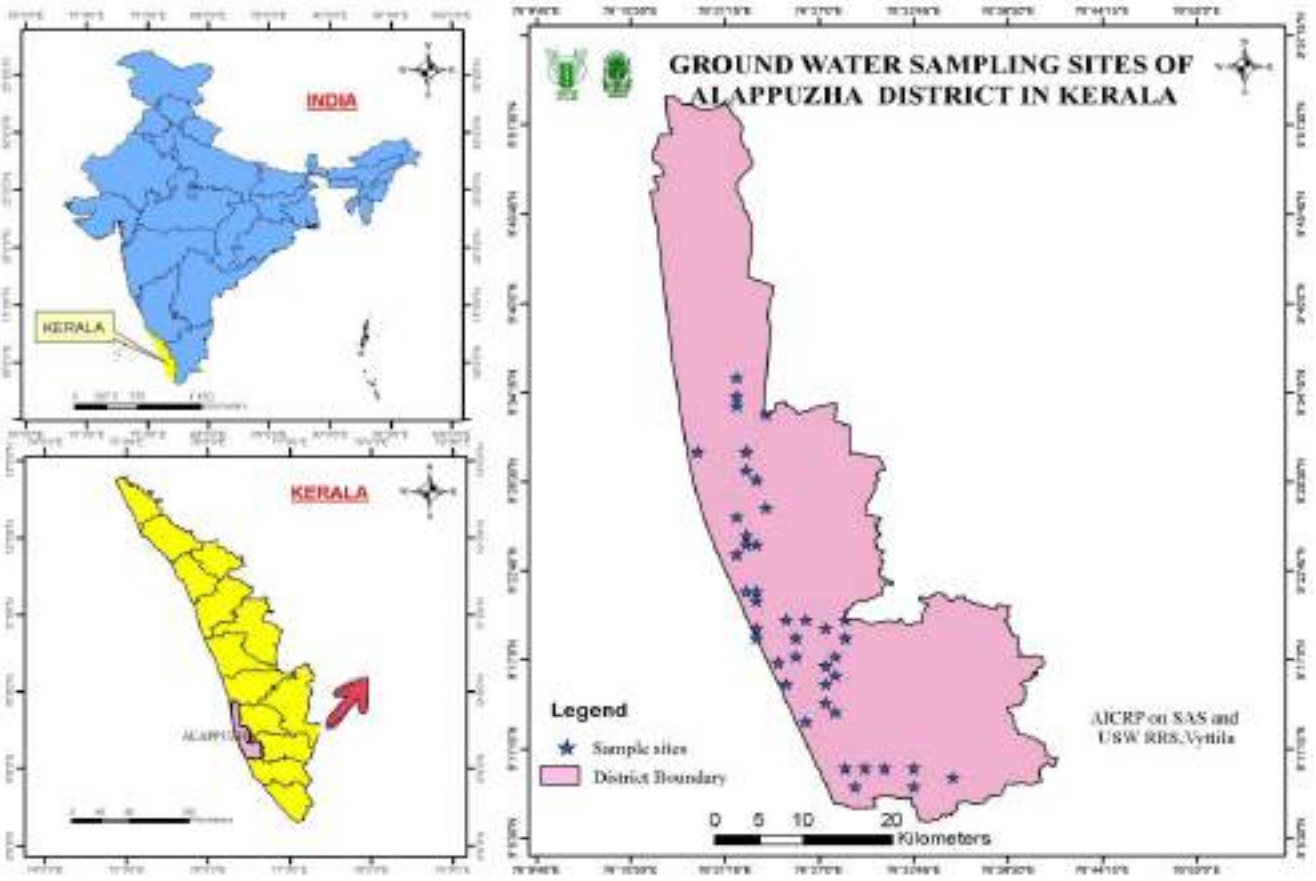

Fig 4a. Ground water sampling sites of Alappuzha district

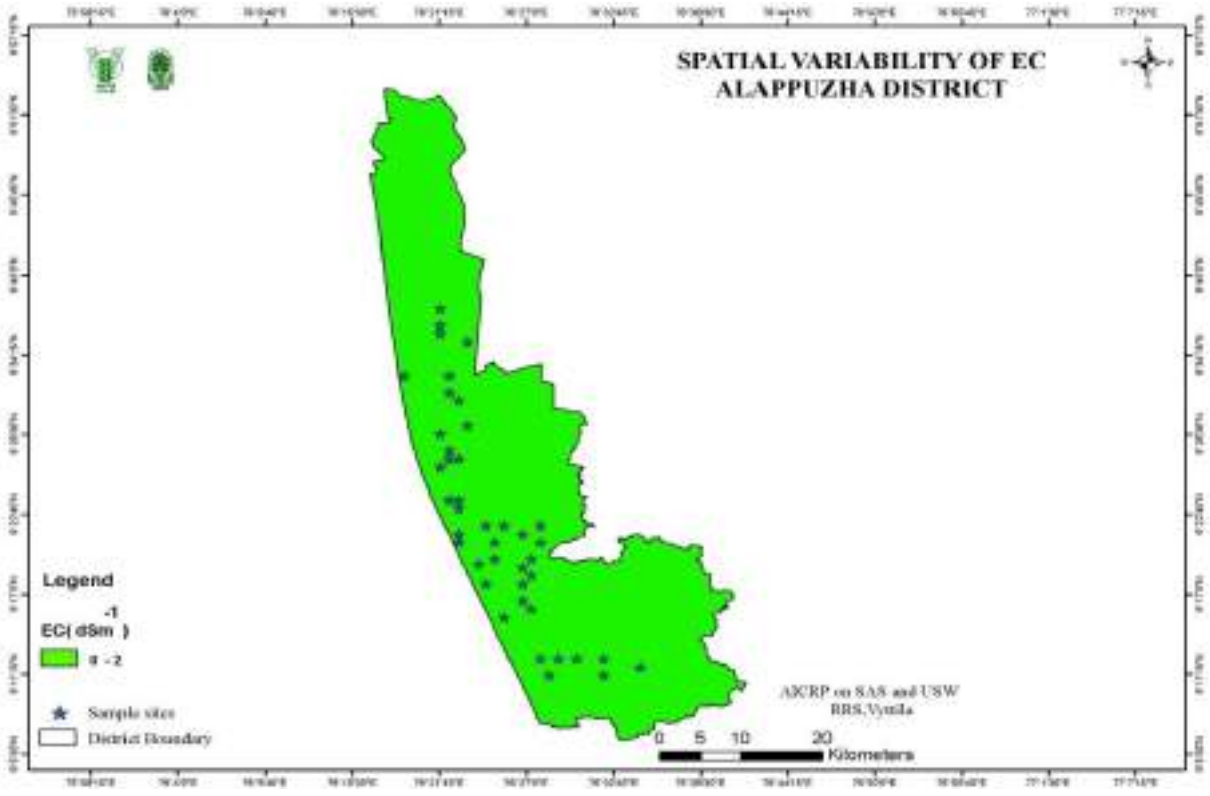

Fig 4b: Spatial variability of electrical conductivity of Alappuzha district

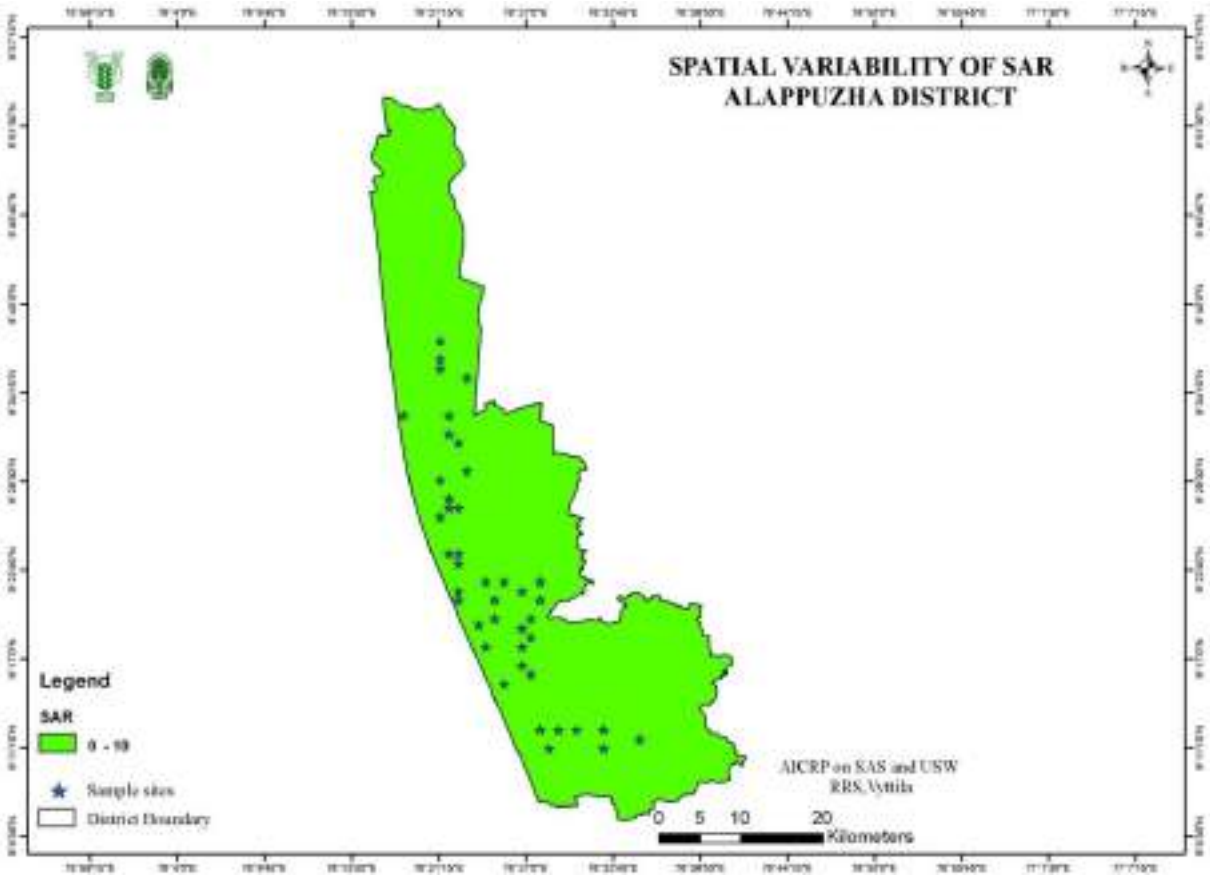

Fig 4c: Spatial variability of SAR of Alappuzha district

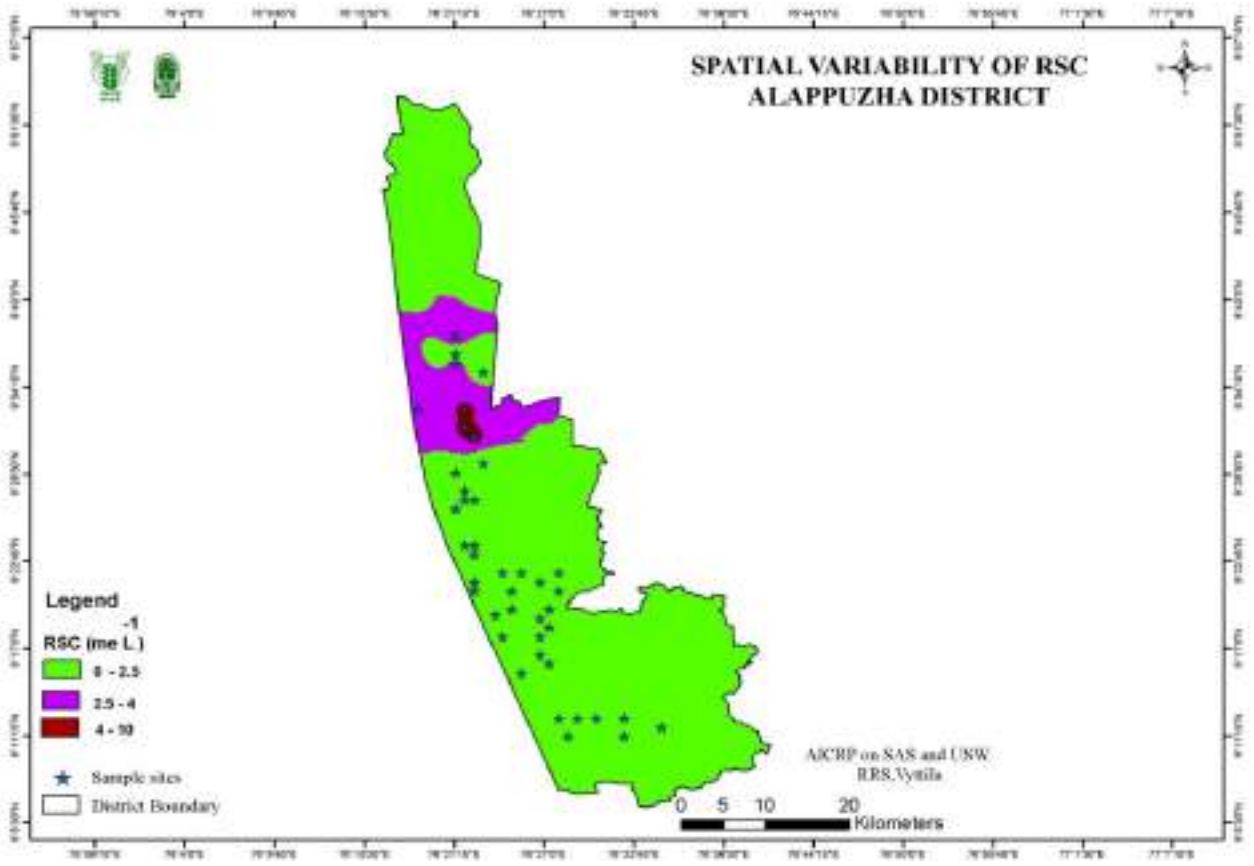

Fig 4d: Spatial variability of RSC of Alappuzha district

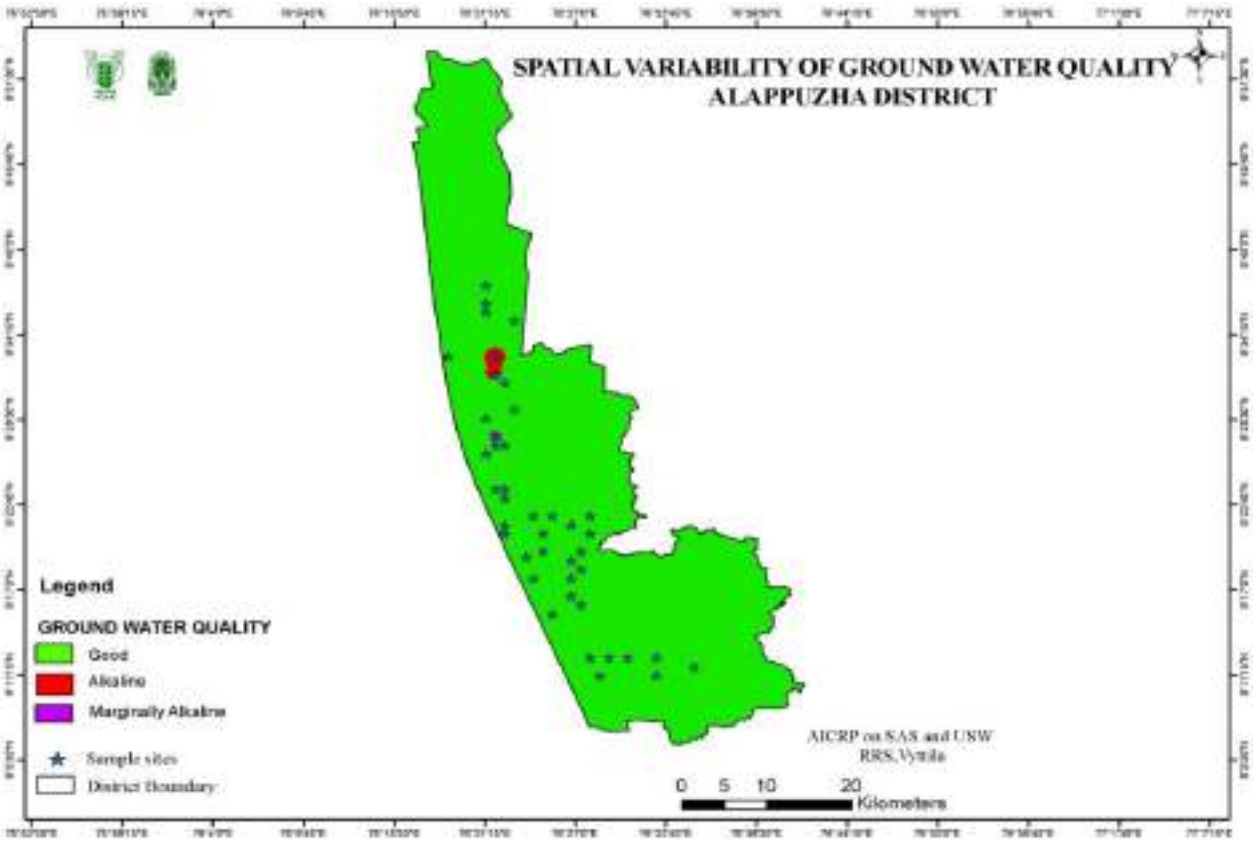

Fig 4e: Spatial distribution of ground water quality for irrigation purpose for Alappuzha

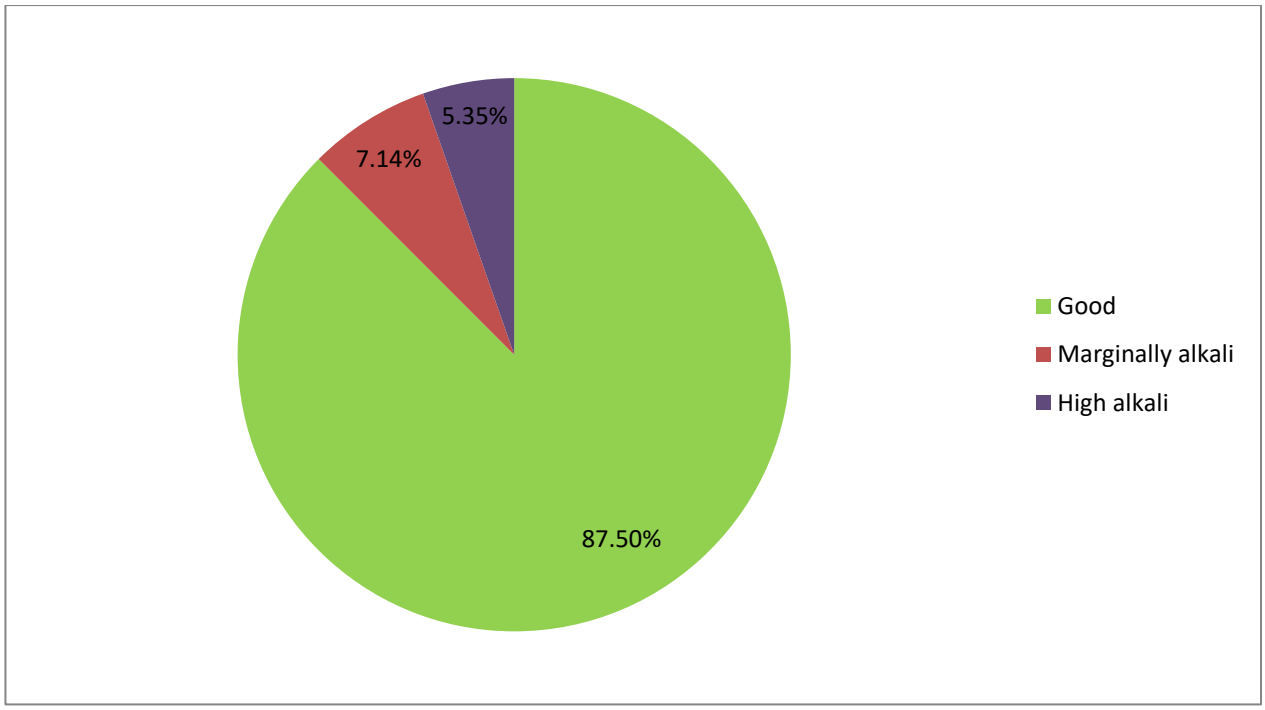

Fig 4f. Groundwater quality distribution for irrigation purpose in Alappuzha

Chapter VI

Ground water quality of Kottayam district

Kottayam is located at 9.5947087°N 76.4855729°E in the basins of the Meenachil River and the Vembanad backwaters, which were created from a number of streams in the Idukki district's Western Ghats. Kottayam is categorized as a midland region where alluvial soil is the predominant form of soil. Most of the vegetation is moist deciduous and tropical evergreen. The groundwater extraction stage of the district is 36.32% (CGWB, 2019).

A total of seventeen ground water samples were collected from Kottayam district (Fig 5a). Out of this, 82.35 %, 11.76 % and 5.88 % falls under good, marginally saline and saline categories of irrigation water quality respectively (Fig 5b, 5c, 5d,5e and 5f).

Table 8: EC, SAR, RSC and ground water quality of Kottayam district

Sl No.	**Location**	**EC**	**SAR**	**RSC**	**Type of Groundwater** (As per CSSRI Classification)
		dS/m	$(mmol\ l^{-1})^1$	meq/l	
1	Murinjupuzha	5.1	18.28	0	saline
2	Chempu	0.3	23.48	0	Good
3	Palamkadavu	2.1	30.36	0	Good
4	Udayanapuram	0.2	17.64	0	Good
5	Vaikom1	0.3	16.28	0	Good
6	Vaikom 2	0.42	15.77	0	Good
7	Vaikom Beach	1.76	11.43	0	Good
8	Thottakam	0.24	9.92	0	Good
9	Kudavechoor	0.41	17.88	0	Good
10	Vechur	0.64	22.22	0	Good
11	Kaipuzhamuttu	2.1	25.08	0	Marginally saline
12	Kumarakom	0.33	26.05	0	Good
13	Chengalam	0.89	17.88	0	Good
14	Pulikattussery	2	12.75	0	Marginally saline
15	Nattagam	0.14	20.32	0	Good
16	Changanassery 1	1.92	19.01	0	Good
17	Changanassery 2	0.23	22.36	0	Good

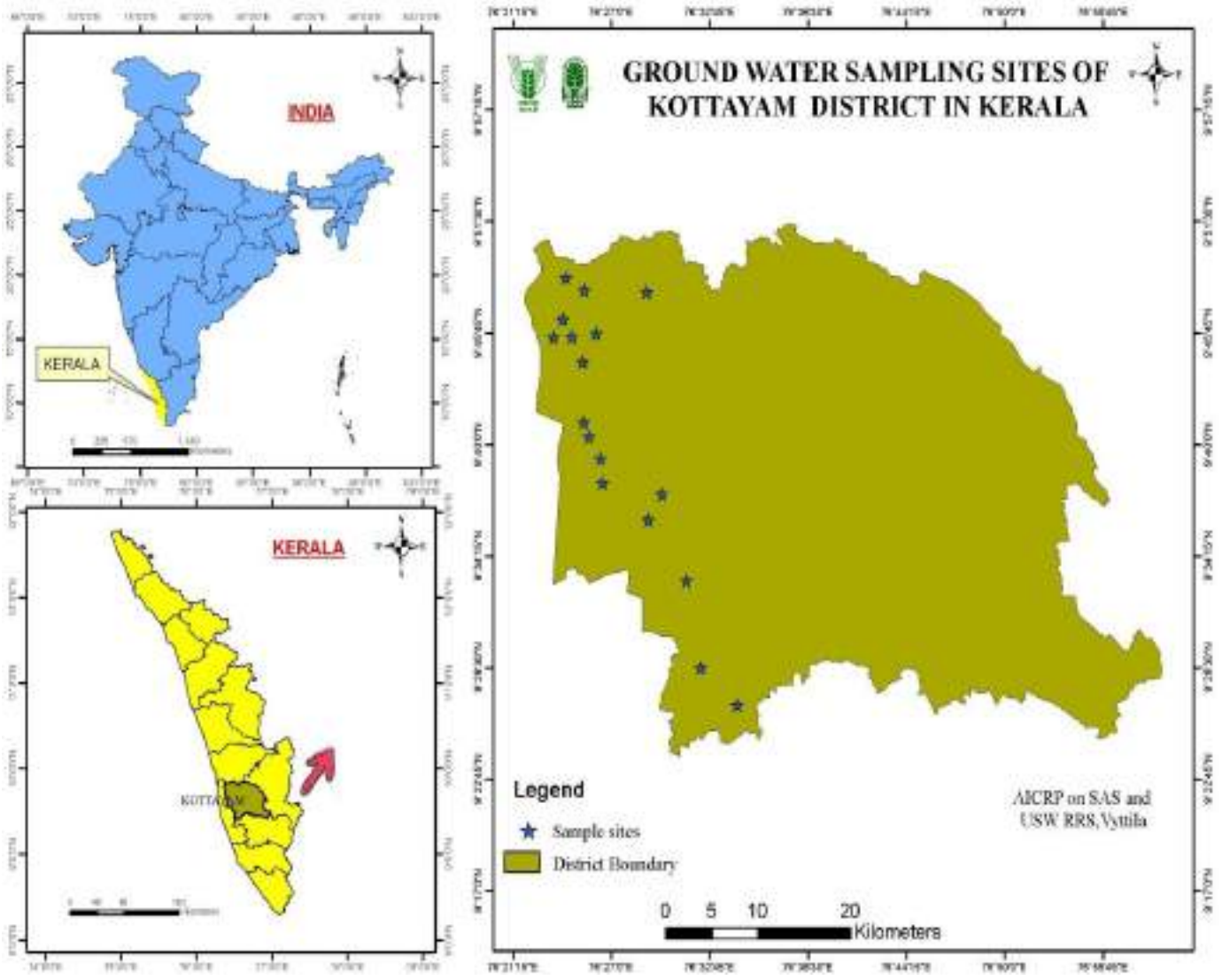

Fig 5a: Ground water sampling sites of Kottayam district

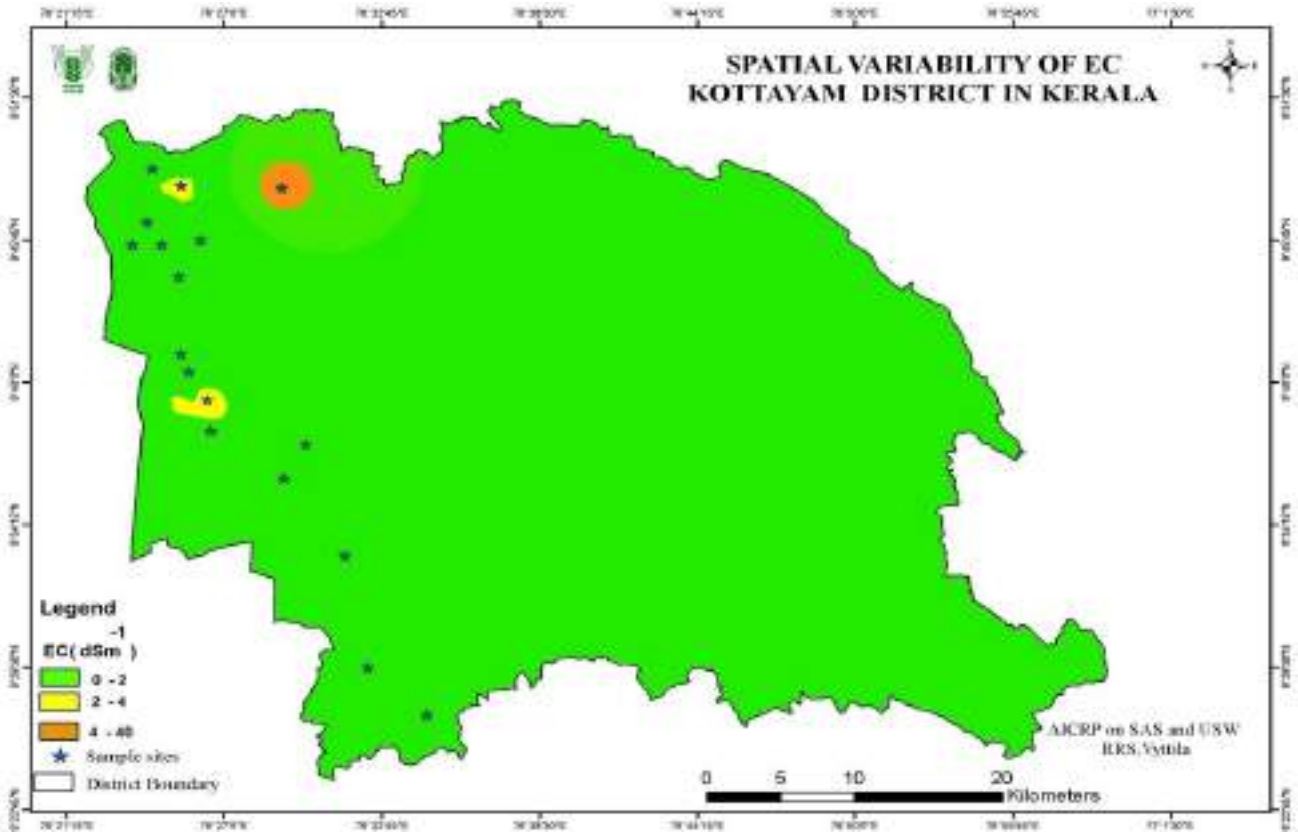

Fig 5b: Spatial variability of electrical conductivity of Kottayam district

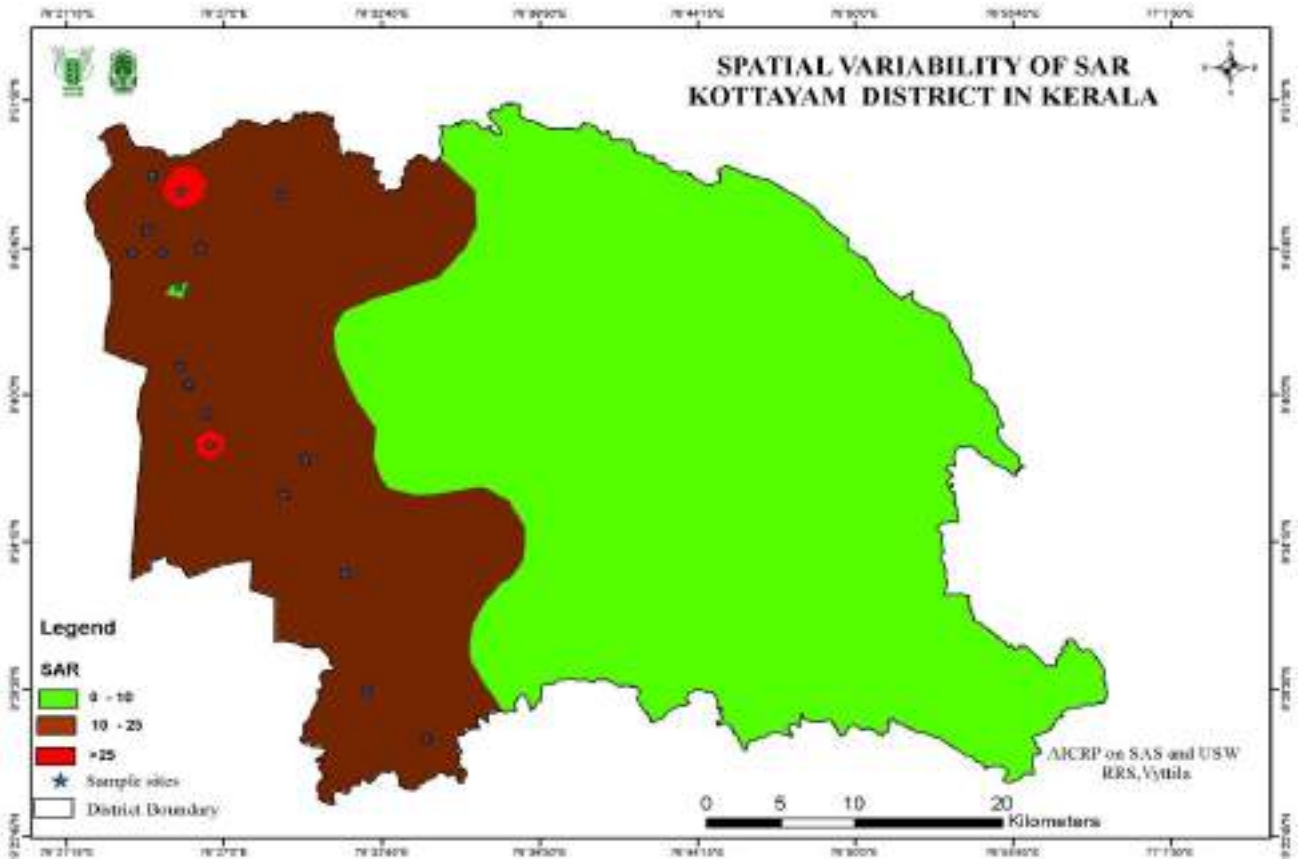

Fig 5c: Spatial variability of SAR of Kottayam district

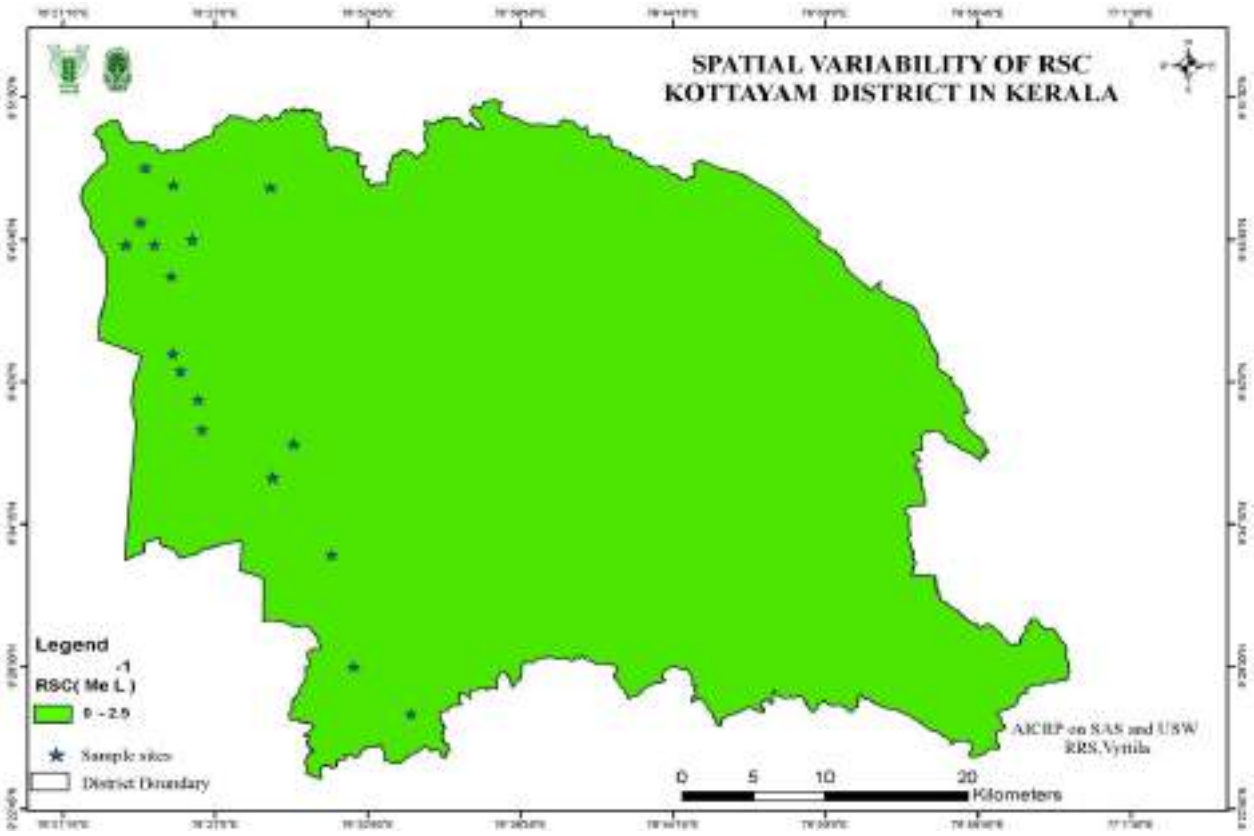

Fig 5d: Spatial variability of RSC of Kottayam district

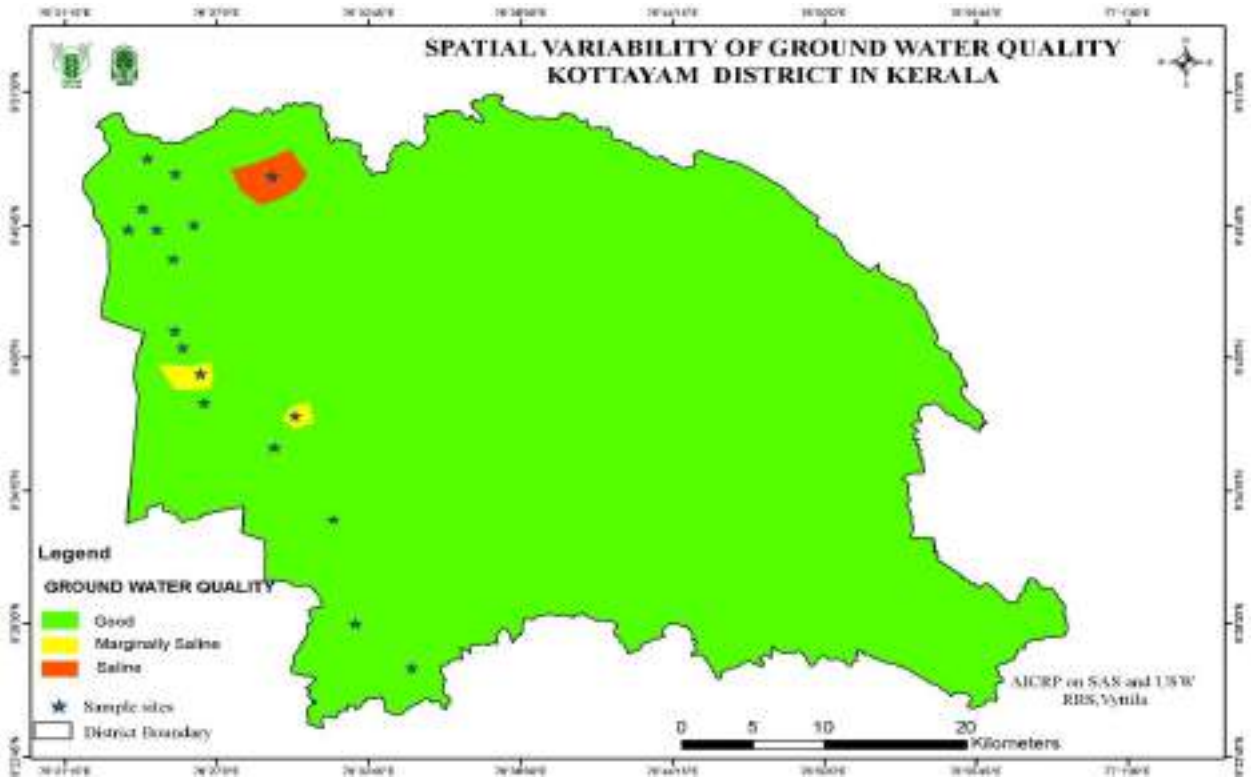

Fig 5e:Spatial distribution of ground water quality for irrigation purpose for Kottayam district

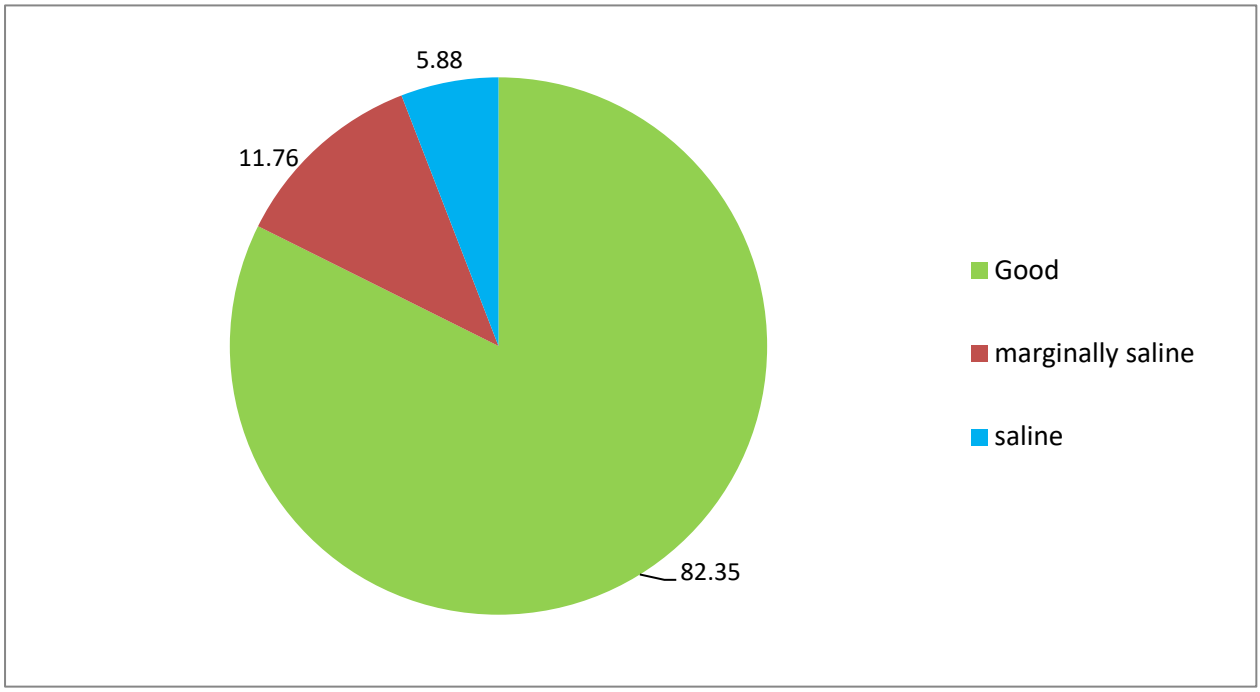

Fig 5f. Groundwater quality distribution for irrigation purpose in Kottayam

Chapter VII

Ground water quality of Idukki district

The Idukki district is the second largest district in Kerala, after Palakkad, with a total size of 1,971.14 sq miles (5,105.22 km^2). The district makes up 12.9% of Kerala's total land area. The location's latitude and longitude are 9° 51' 0" North and 76° 58' 0". A total of 97% of the Idukki district's land is covered in dense jungle and jagged mountains. This location is 1,200 metres (3,900 ft) above sea level. The groundwater extraction stage of the district is 58.38 % and three blocks namely, Elam Desom, Kattappana, Nedumkandam of the district are semi-critical with stage of groundwater development between 50 to 75% (CGWB, 2019).

The details of ground water data has been collected from Central ground water board (CGWB), for the Idukki districts and were classified according to CSSRI classification. All samples from Idukki districts are good for irrigation (Fig 6a). Spatial variability of EC, SAR, RSC and ground water quality of Alappuzha district were expressed in fig. 6b, 6c, 6d, 6e and 6f respectively.

Table 9: EC, SAR, RSC and ground water quality of Idukki district

Sl No	Locations	EC dS/m	SAR (mmol l^{-1})^1	RSC meq/l	Type of Groundwater (As per CSSRI Classification)
1	Adimali	0.2	1.589	0	Good
2	Chinikuzhi	0.134	0.625	0.38	Good
3	Chittur	0.069	0.489	0.24	Good
4	Karimkunnam	0.27	0.988	0	Good
5	Kumaramangalam	0.084	0.75	0	Good
6	Kulamavu	0.126	0.89	0	Good
7	Elappara	0.154	0.71	0	Good
8	Kumili	0.4	1.155	0.61	Good
9	Vandiperiyar	0.34	1.993	0	Good
10	Kuttikanam	0.077	0.499	0	Good
11	Irattayar	0.43	3.308	0	Good
12	Kattappana	0.36	2.627	0	Good
13	Vandanmedu	0.124	0.902	0	Good
14	Idukki	0.064	0.639	0.23	Good
15	Vellilamkandam	0.069	0.839	0.09	Good
16	Moolamattom	0.092	0.53	0	Good
17	Kaliyar	0.23	1.072	0	Good
18	Koyilkadavu	0.32	1.143	0.09	Good
19	Munnar	0.074	0.784	0	Good
20	Poopara	0.46	1.892	0	Good
21	Nedumkandam	0.37	0.875	0	Good

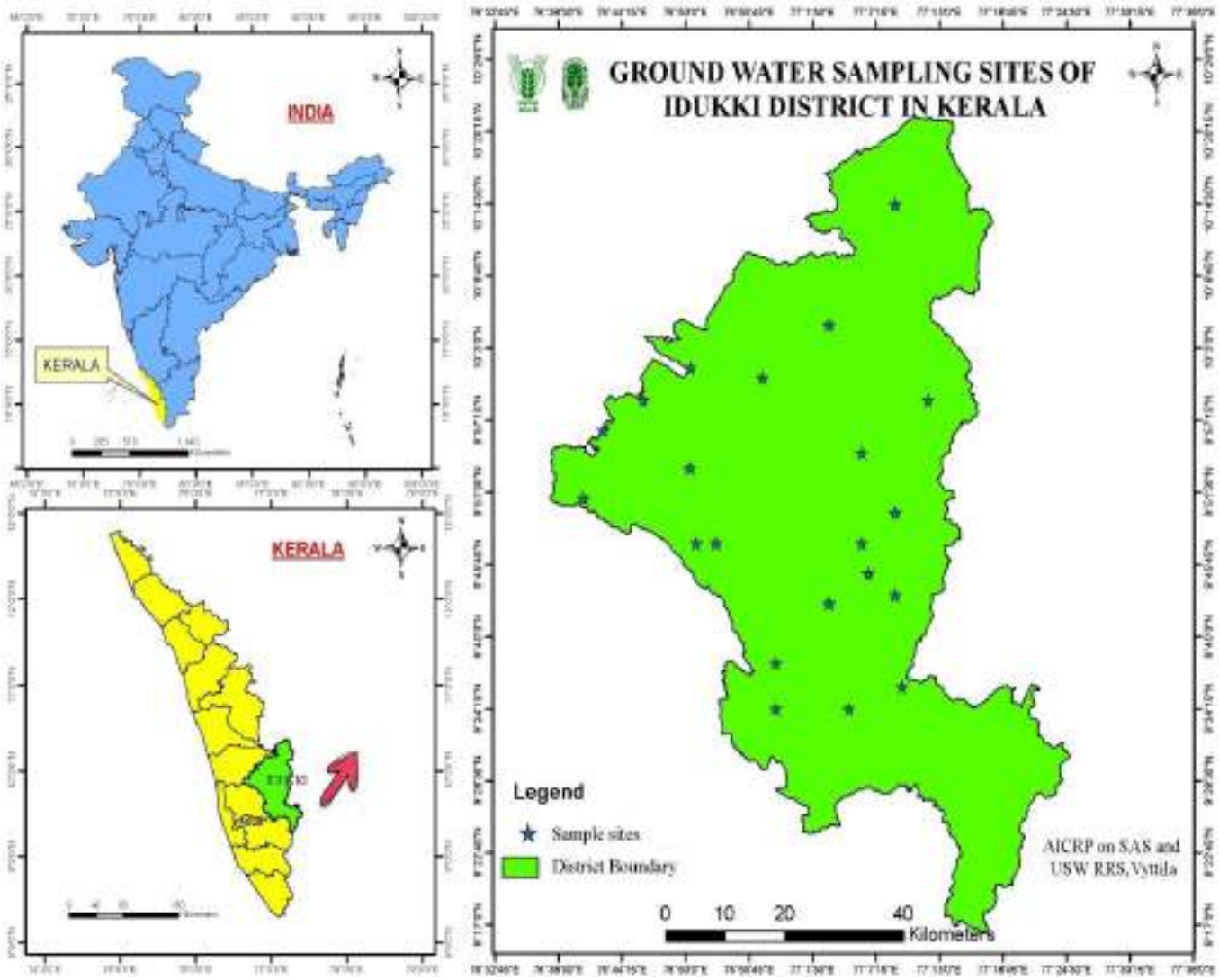

Fig 6a. Ground water sampling sites of Idukki district

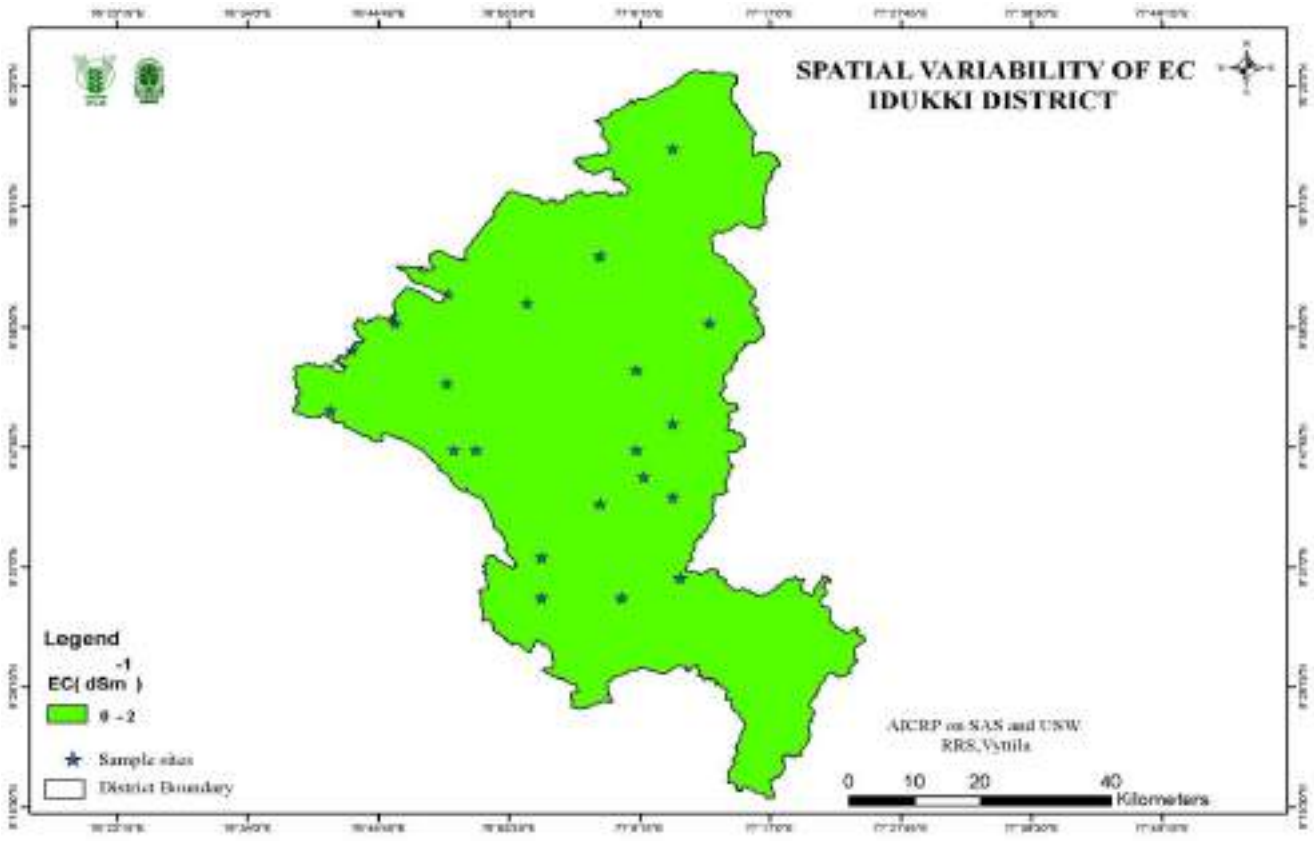

Fig 6b: Spatial variability of electrical conductivity of Idukki district

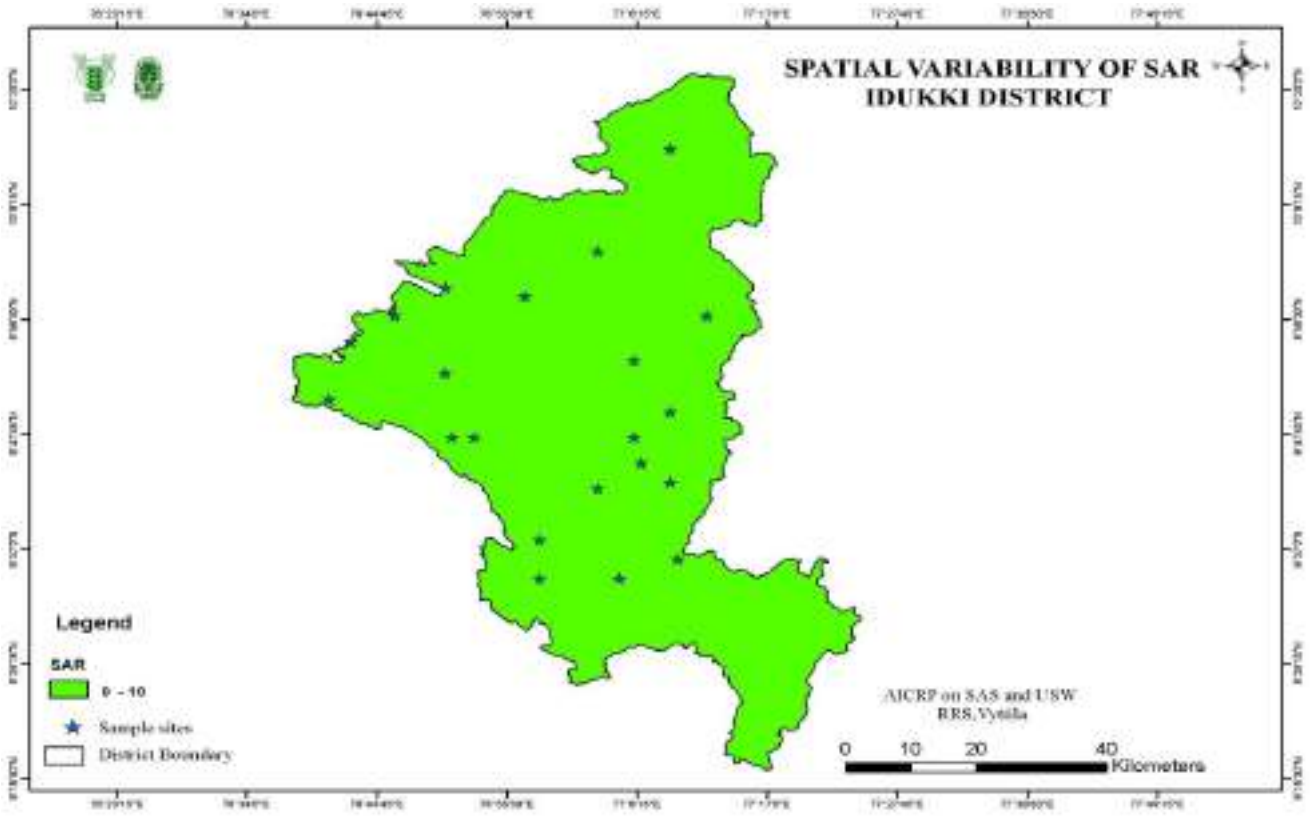

Fig 6c: Spatial variability of SAR of Idukki district

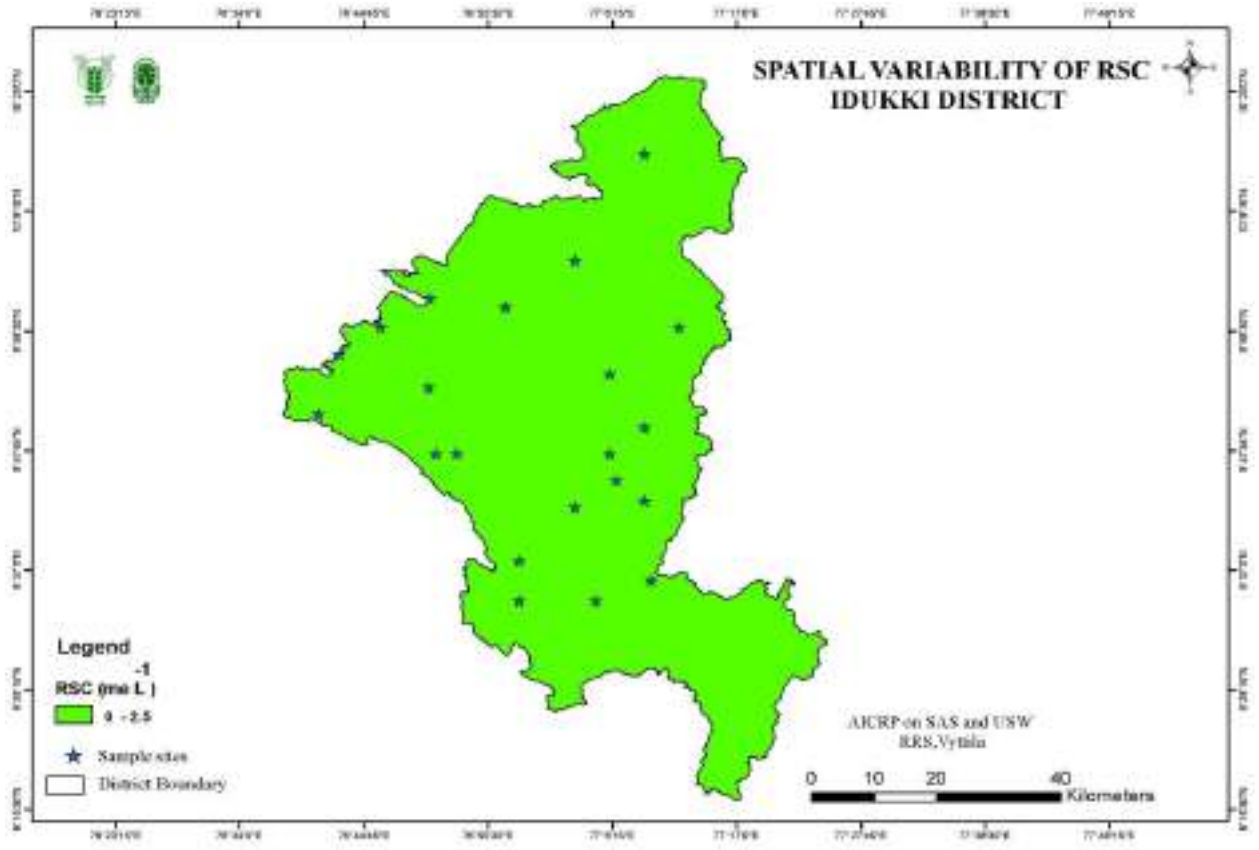

Fig 6d: Spatial variability of RSC of Idukki district

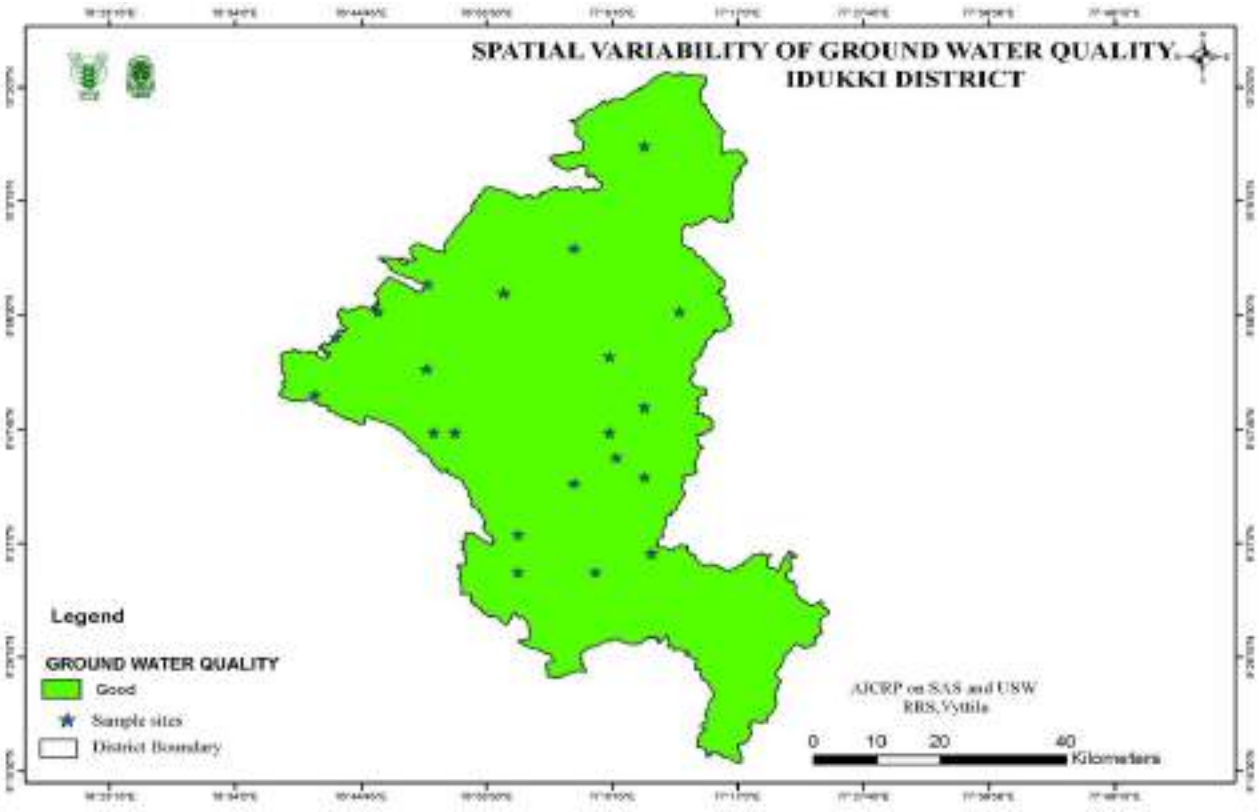

Fig 6e. Spatial variability of ground water quality of Idukki district

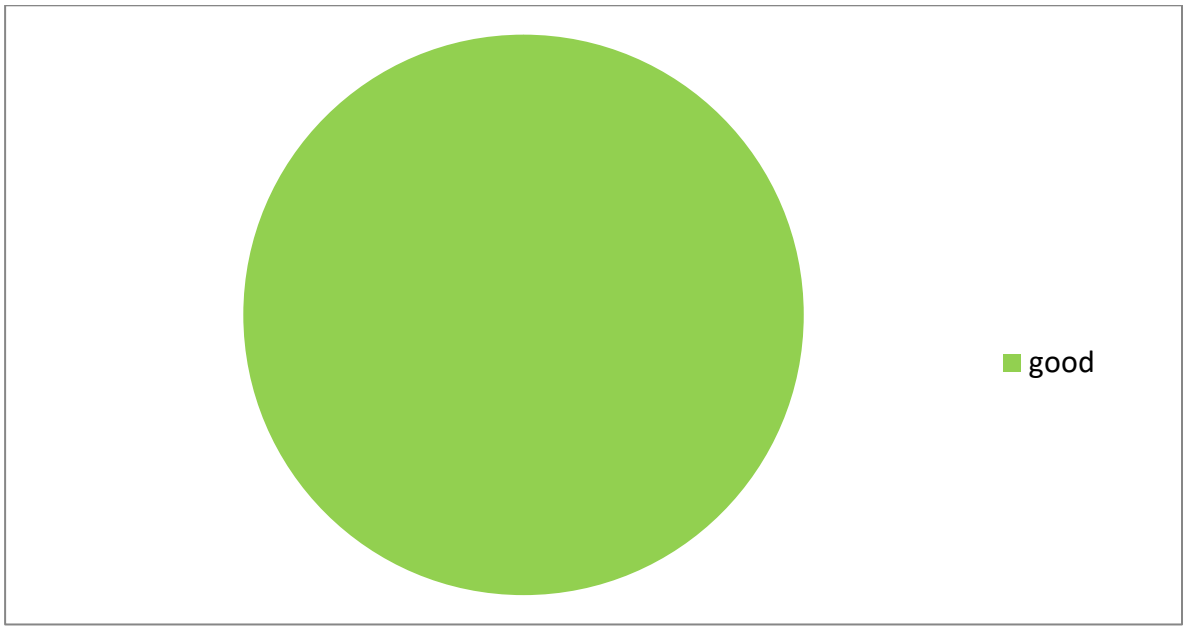

Fig 6f. Groundwater quality distribution for irrigation purpose in Idukki

Chapter VIII

Ground water quality of Ernakulam

The Ernakulam District is situated in Central Kerala in India at 9.98°N 76.28°E. It has an average elevation of 4 m (13 ft) and covers an area of 3,068 km^2 (1,185 sq mi) on the Western Coastal Plains of India. It is surrounded by the Thrissur District to the north, the Idukki District to the east, Alappuzha and Kottayam districts to the south and the Laccadive Sea to the west. The groundwater extraction stage of the district is 43.83% and Parakkadavu block is semi-critical with stage of groundwater development between 60 to 80% (CGWB, 2019)

A total of twenty eight ground water samples were collected from Ernakulam district (fig 7a). Out of this, 75.86%, 20.68% and 3.40% fall under good, high SAR saline and marginally alkali categories of irrigation water quality (Fig. 7e). Spatial variability of EC, SAR, RSC and irrigation water quality of Ernakulam district was given in figures 7b, 7c, 7d, 7e and 7f respectively.

Table 10: EC, SAR, RSC and irrigation water quality of Ernakulam district

Sl No.	Location	EC dS/m	SAR (mmol l^{-1})[1]	RSC meq/l	Type of Groundwater (As per CSSRI Classification)
1	Kumbalangi 1	0.45	0.73	0	Good
2	Kumbalangi 2	0.25	1.31	0	Good
3	Kumbalangi rice field	0.07	1.71	0	Good
4	Chellanum	1.01	1.85	0	Good
5	Ganapathikadu rice field	9	23.07	0	Highly SAR saline
6	Malipuram 1	0.33	1.05	0	Good
7	Malipuram rice field	20	94.09	0	Highly SAR saline
8	Edavanakad	0.37	1.16	0	Good
9	Kuzhupilli	14.6	61.7	0	Highly SAR saline
10	Munambam 1	0.3	1.07	0	Good
11	Munambam 2	0.2	1.11	0	Good
12	Elur	0.37	0.92	0	Good
13	Kothamangalam	0.2	1.34	0	Good
14	Odakkali	0.05	2.24	0	Good
15	Mulanthuruthy	0.08	2.83	0	Good
16	Vadakkekara	0.4	0.97	1.57	Good
17	Poyapalli	20	92.69	0	Highly SAR saline
18	Chirakkakam 1	0.35	0.9	0	Good
19	Chirakkakam 2	0.2	1.42	0	Good
20	Chirakkakam rice field	7.8	30.29	0	Highly SAR saline
21	Poonithura	0.47	0.67	0	Good
22	Edapally 1	0.44	0.96	0	Good
23	Edapally 2	0.48	1.07	1.26	Good
24	Fort Kochi	0.9	0.9	3.02	Good
25	Kanjiramattom	0.08	2.12	0	Good
26	Tripunithura	0.5	0.76	0	Good
27	Irumbanam1	0.35	0.75	0	Good
28	Irumbanam2	0.31	1.26	0	Good

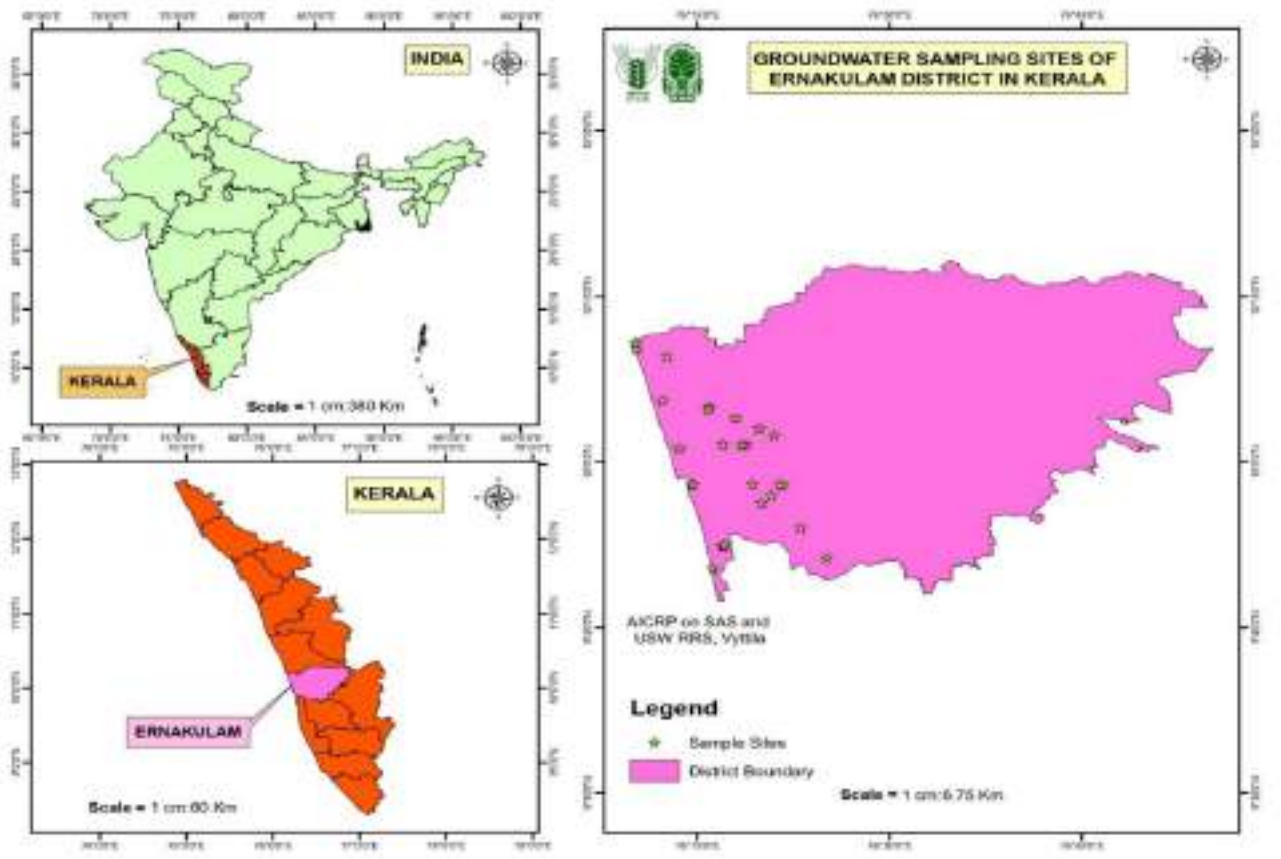

Fig 7a. Ground water samples sites of Ernakulam district in Kerala

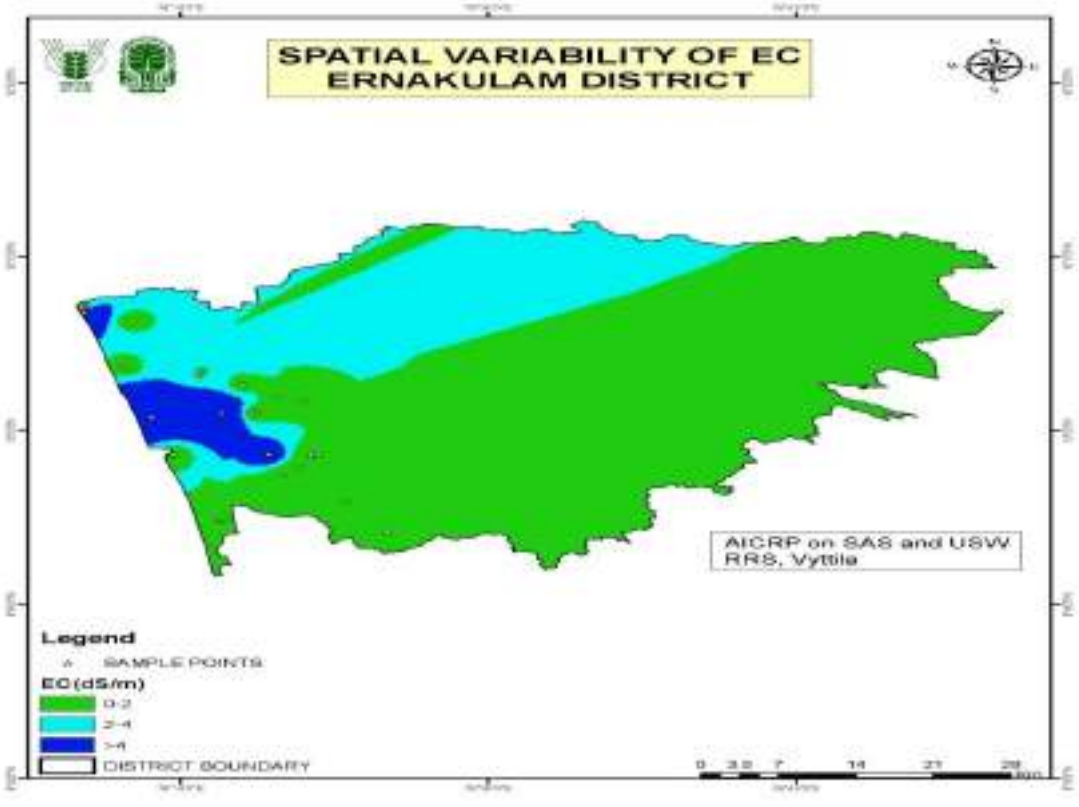

Fig 7b. Spatial variability of EC of Ernakulam district

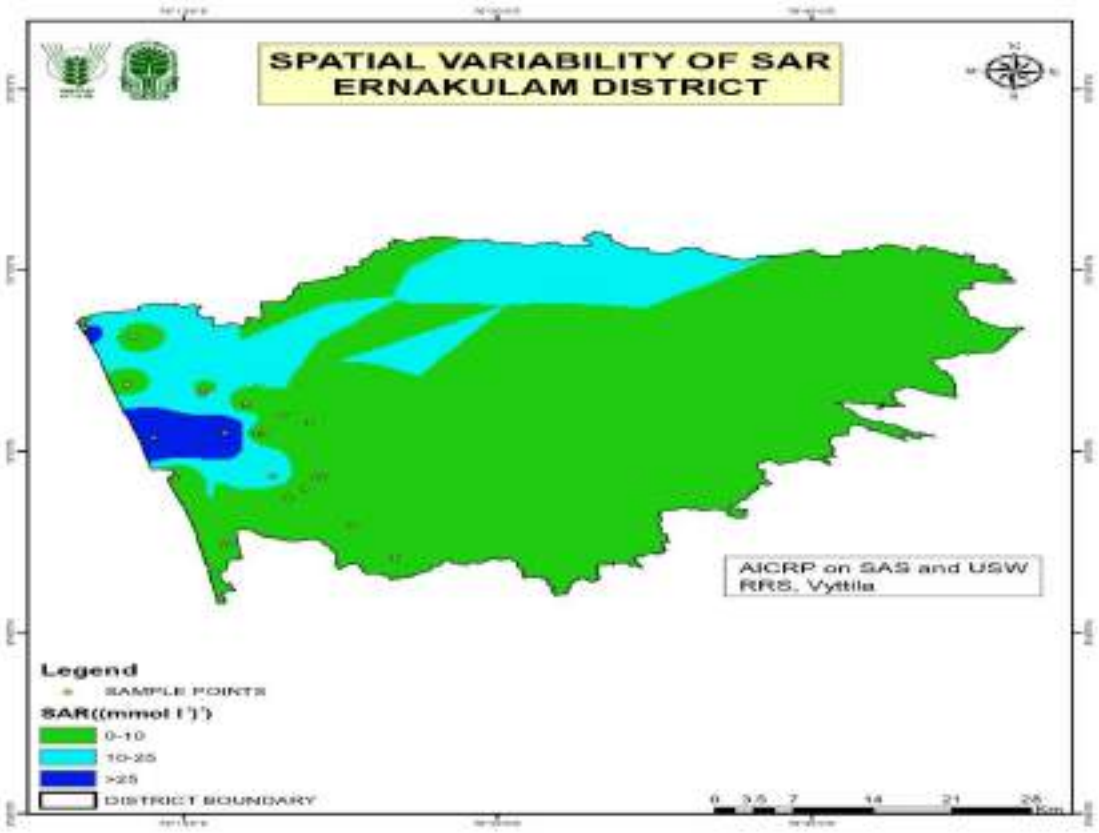

Fig 7c. Spatial variability of SAR of Ernakulam district

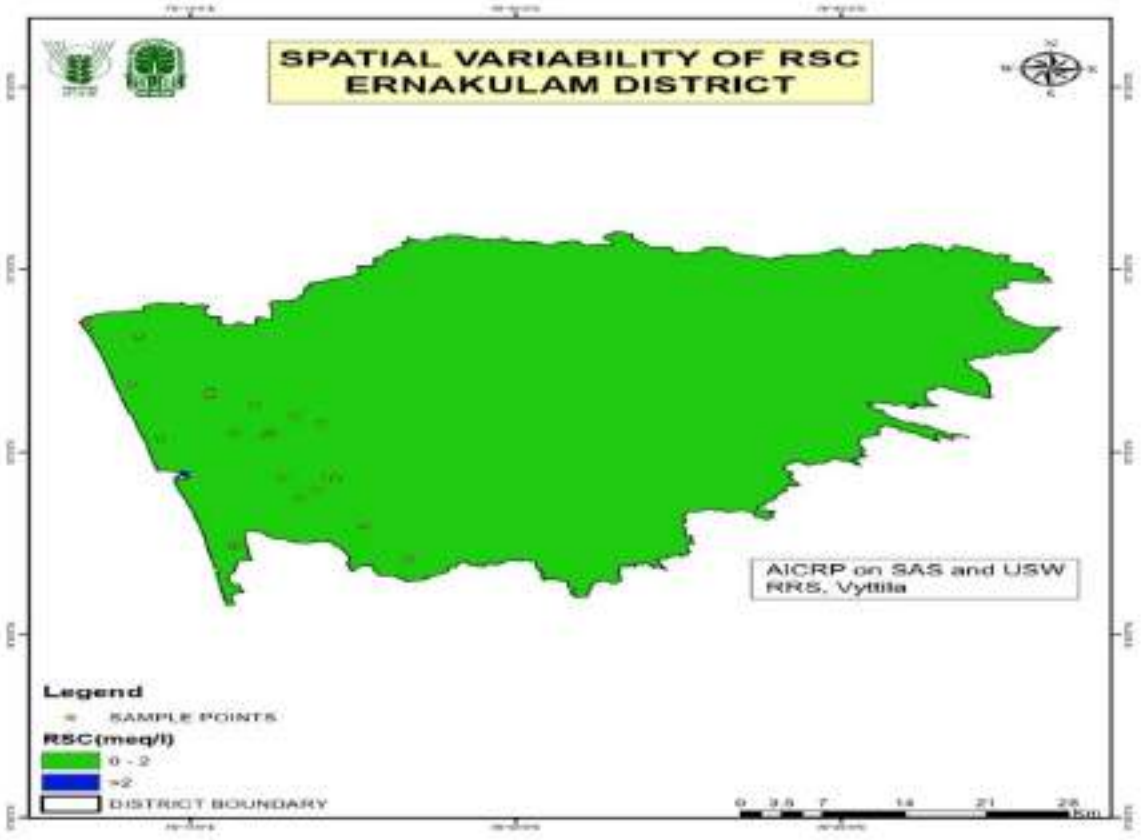

Fig 7d. Spatial variability of RSC at Ernakulam district

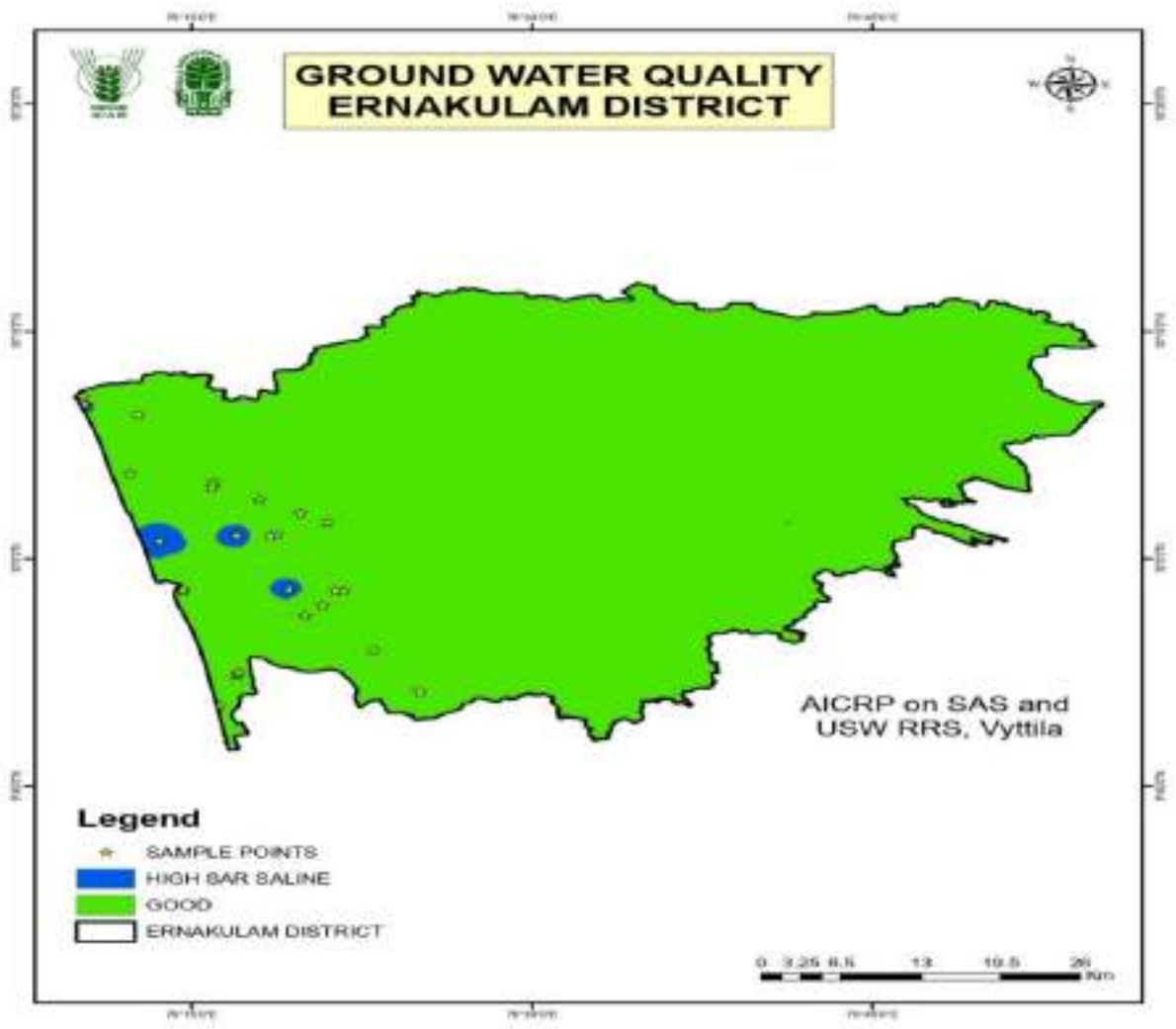

Fig 7e. Spatial distribution of ground water quality for irrigation purpose for Ernakulam district

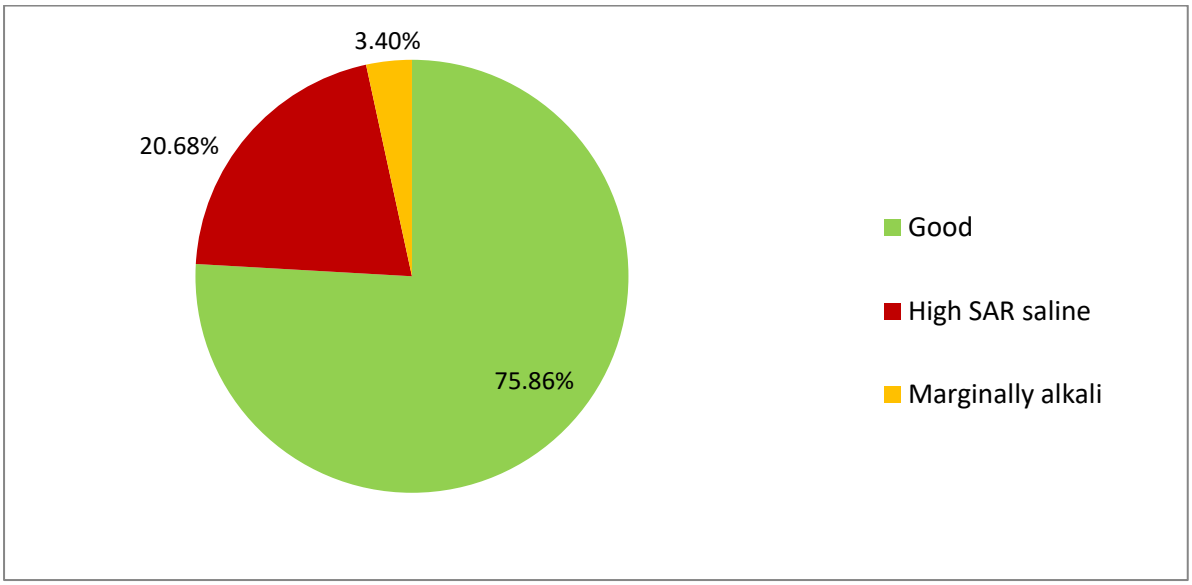

Fig 7f. Groundwater quality distribution for irrigation purpose in Ernakulam

Chapter IX

Ground water quality of Thrissur district

A landlocked city, Thrissur is located on a hillock which is surrounded by Thrissur Kole Wetlands. The Thrissur district shares borders with the Arabian Sea in the west, the Malappuram district in the north, the Palakkad district in the east, and the Ernakulam district in the south. The city is 2.83 metres above sea level on average and is located at 10.52°N 76.21°E. The city is situated in Kerala's central region, extending into the Palakkad Plains. Because of its hilltop location, rainwater may immediately drain out of the city. Geologically, the city is made up of crystalline schists and Archaean gneisses.Thrissur lies near the center of the Indian tectonic plate (the Indian Plate) and is subject to comparatively little seismic or volcanic activity. The predominant topography of the city is Thrissur Kole Wetlands which extends to Malappuram district. The groundwater extraction stage of the district is 57.67% and three blocks namely, Chowannur, Mathilakom, Thalikkulam of the district are semi-critical with stage of groundwater development between 65 to 80% (CGWB, 2019).

A total of thirty three ground water samples were collected from Thrissur district. The location map of the sampling points was presented in Fig 8a. Out of this, 93.93 % falls under good and 4.76 % falls under marginally saline categories of irrigation water quality (Fig 8b, 8c, 8d, 8e and 8f).

Table 11: EC, SAR, RSC and water quality of Thrissur district

Sl. No.	Location	**EC**	**SAR**	**RSC**	**Type of Groundwater** (As per CSSRI Classification)
		dS/m	(mmol l^{-1})[1]	meq/l	
1	Azhikode 1	0.36	0.83	0.47	Good
2	Azhikode 2	0.09	0.43	0	Good
3	Eriyad 1	0.22	0.22	0	Good
4	Eriyad 2	0.2	0.56	0	Good
5	Logamalleswaram	0.35	1.03	0.32	Good
6	Kodungallur	1.1	4.25	0.01	Good
7	Methala	0.21	0.43	0	Good
8	Padakkulam 1	0.42	0.74	0	Good
9	Padakkulam 2	0.17	0.46	0	Good
10	Karupadanna 1	0.22	0.56	0	Good
11	Karupadanna 2	0.12	1.78	0	Good
12	Thekkumkara	0.04	1.15	0.27	Good
13	Poyya 1	0.04	0.93	0.2	Good
14	Poyya 2	34	91.33	0	Highly SAR saline
15	Mathilakam	0.27	0.68	0	Good
16	Perinjanam 1	0.22	0.49	0.5	Good
17	Perinjanam 2	0.56	1.18	0	Good
18	Edamuttam	0.36	1.23	1.51	Good
19	Triprayar 1	0.38	1	0	Good
20	Triprayar 2	0.15	0.84	0	Good
21	Engandiyur	0.27	0.7	0	Good
22	Manalur	0.04	1.36	0.48	Good
23	Enammavu 1	25	70.1	0	Good
24	Enammavu 2	0.22	0.83	0	Good
25	Mullassery	0.2	0.83	0	Good
26	Pavaratty	0.24	0.43	0	Good
27	Chavakkad	0.16	0.47	0	Good
28	Kottapadi	0.92	5.57	1.43	Good
29	Punnayoor	0.06	0.77	0.43	Good
30	Chemmannur	0.14	1.34	0	Good
31	Akalad	0.19	0.46	0	Good
32	Kattoor	0.07	1.16	0.09	Good
33	Krishnamkotta	0.07	0.75	0	Good

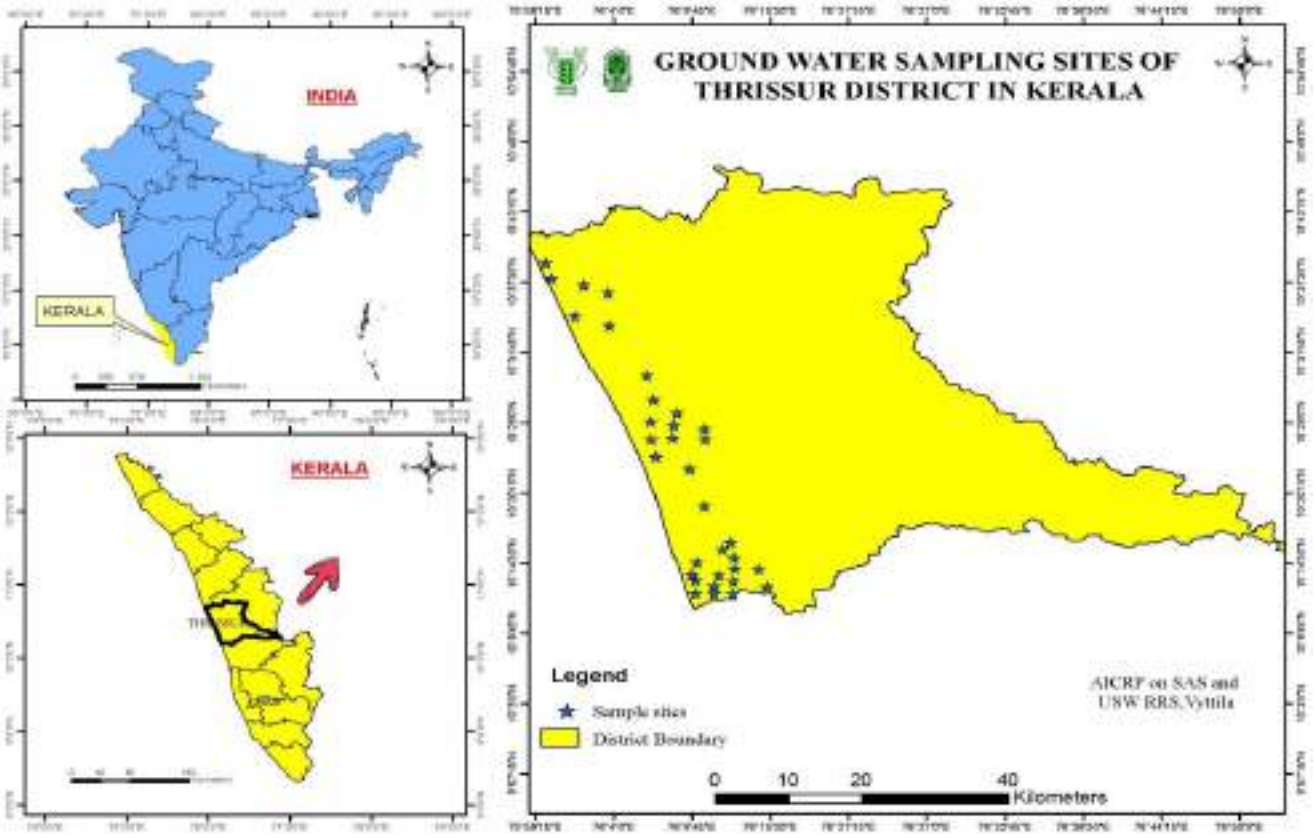

Fig 8a:Ground water sampling sites of Thrissur district

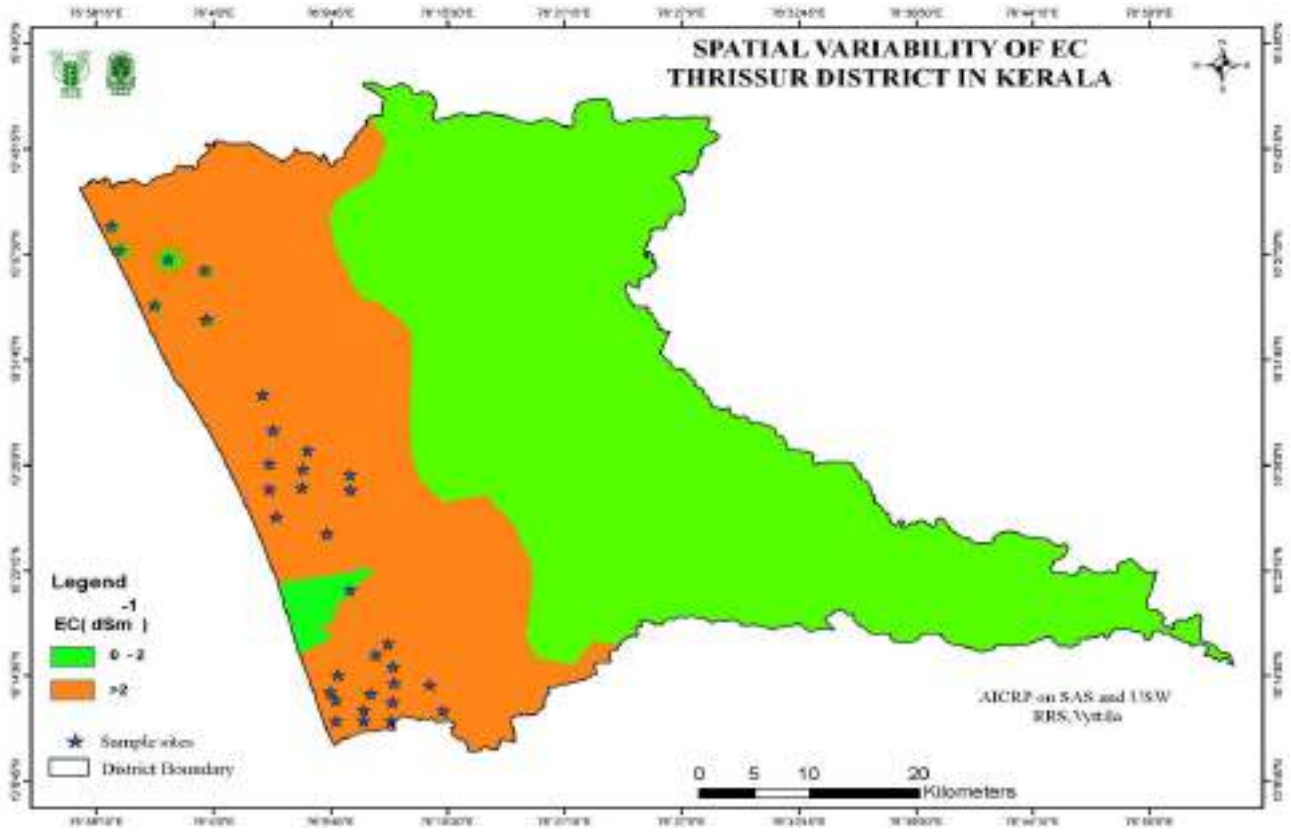

Fig 8b: Spatial variability of electrical conductivity of Thrissur district

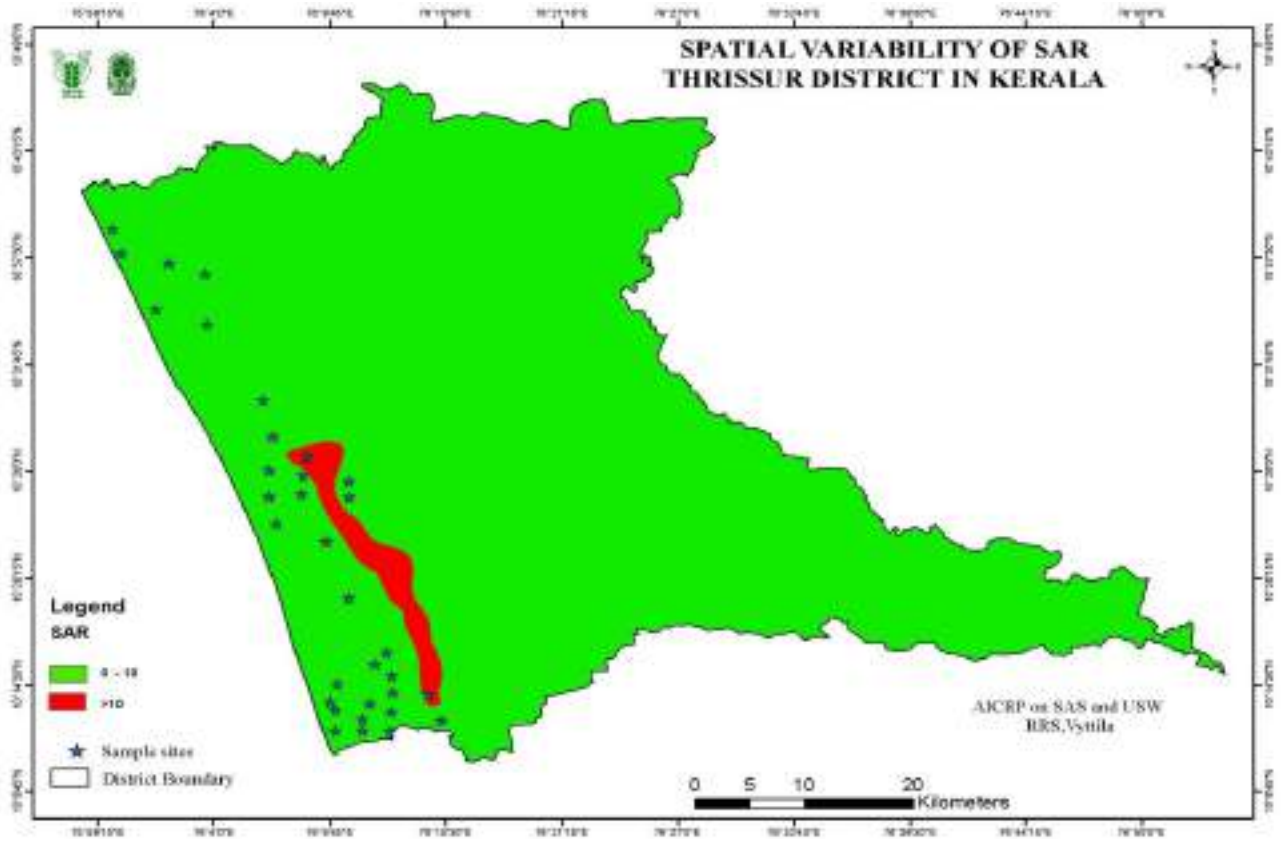

Fig 8c: Spatial variability of SAR of Thrissur district

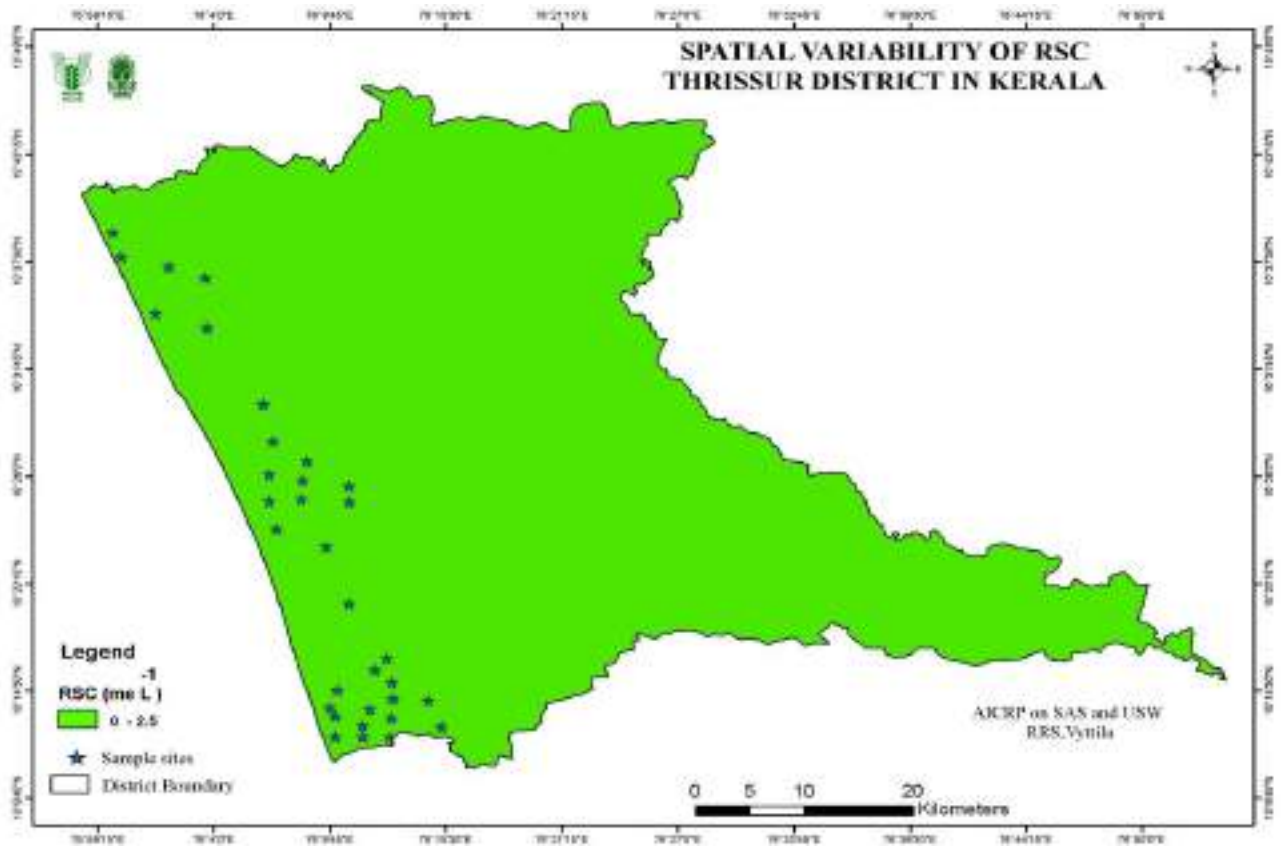

Fig 8d: Spatial variability of RSC of Thrissur district

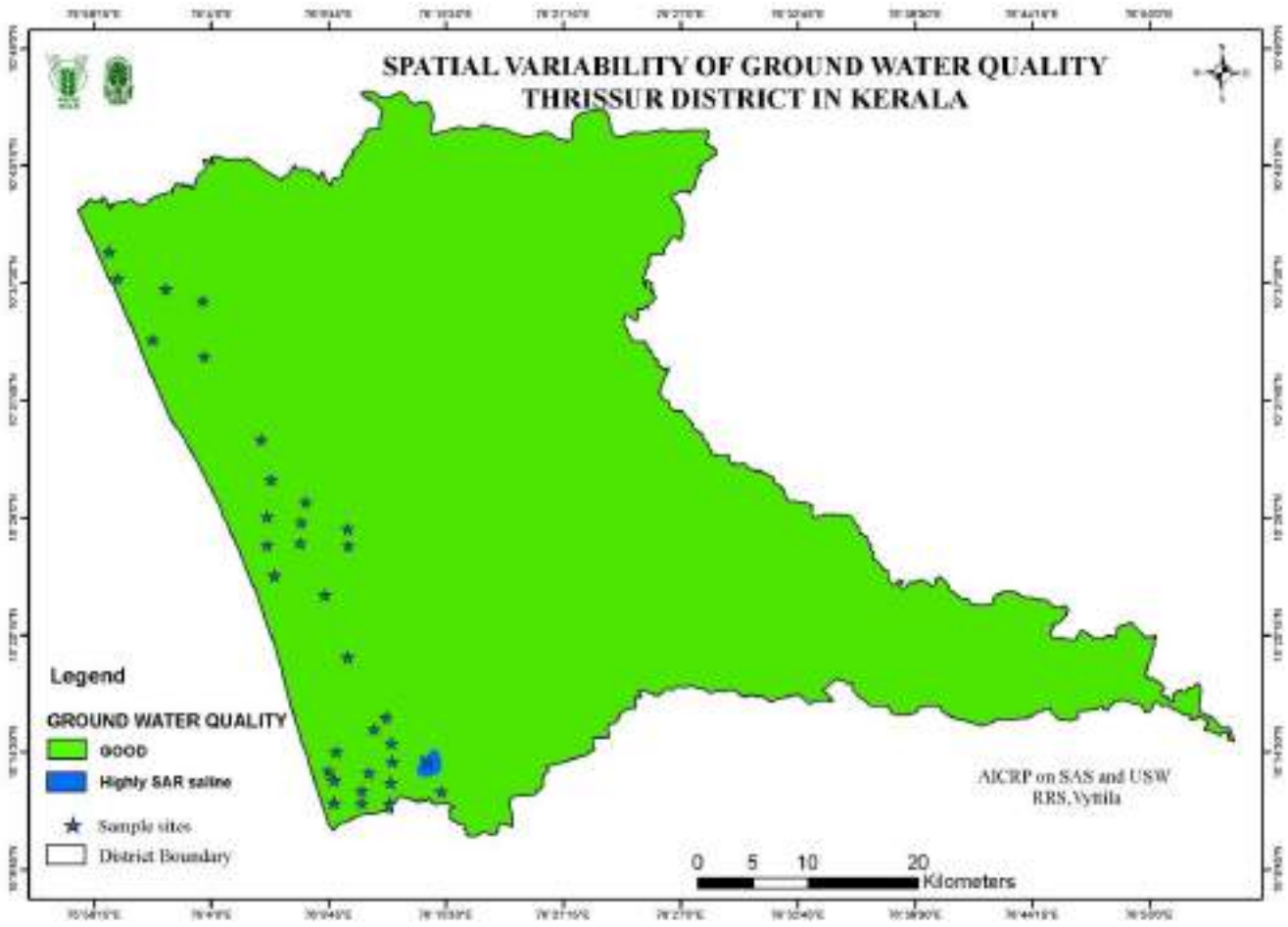

Fig 8e: Spatial distribution of ground water quality for irrigation purpose for Thrissur district

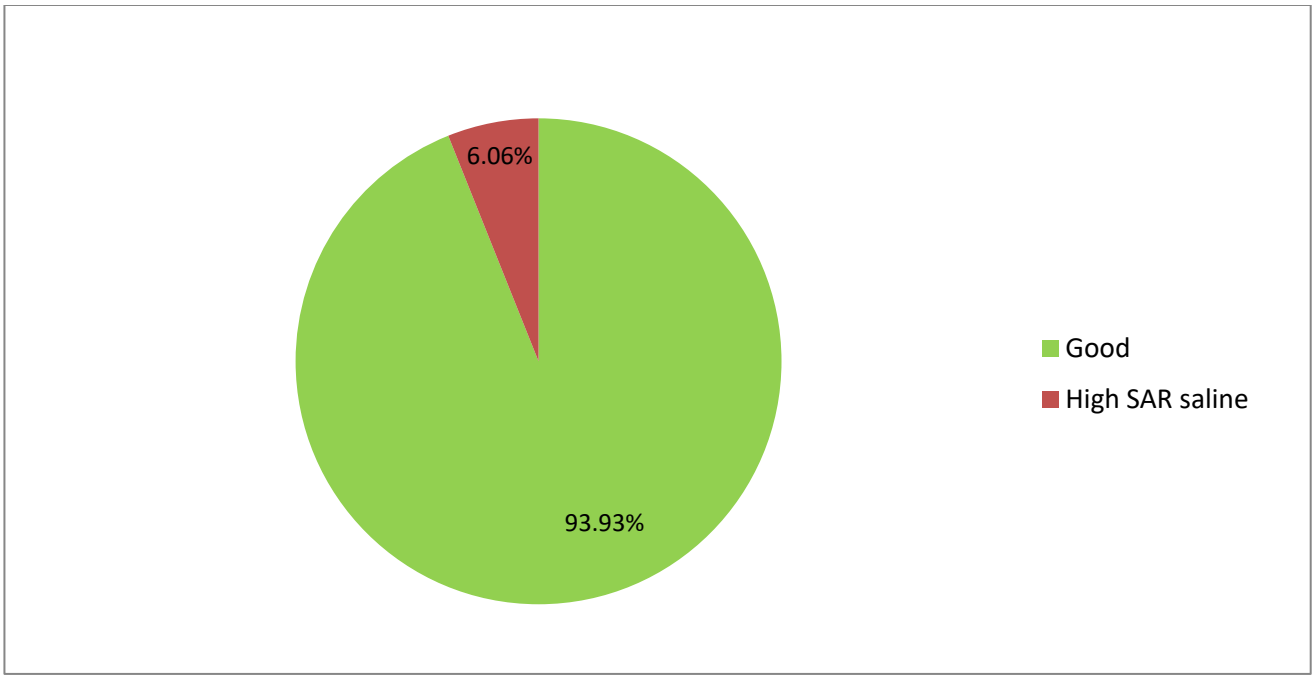

Fig 8f. Groundwater quality distribution for irrigation purpose in Thrissur district

Chapter X

Ground water quality of Palakkad district

Palakkad, known as the Granary of Kerala, is a huge area of rich plains dotted with mountains, rivers, streams, and forests which is located at 10.775°N 76.651°E. The Palakkad Gap, a 40-kilometer mountain gap known as Kerala's northern entryway, provides access to this region at the base of the Western Ghats. The pass served as a commercial route between the east and west coasts of peninsular India and served as a connection between Kerala and the neighbouring state of Tamil Nadu. Palakkad has a tropical wet and dry climate. Temperatures remain moderate throughout the year, with the exception being March and April, the hottest months. A very high amount of precipitation is received in Palakkad, mainly due to the South-West monsoon. July is the wettest month, and the total annual rainfall is around 83 inches (210 cm). The groundwater extraction stage of the district is 56.20 % and two blocks namely, Pattambi, Thrithala of the district are semi-critical, Malampuzha is critical and Chittur is over exploited with stage of groundwater development between 65 to 80% (CGWB, 2019).

The details of ground water data has been collected from Central ground water board (CGWB), for the Palakkad district and was classified according to CSSRI classification (Fig 9a). In case of Palakkad, 97% falls under good quality and remaining 3% was marginally alkaline in nature. The spatial variability maps of EC, SAR, RSC and water quality of the district were depicted in Fig 9b, 9c, 9d, 9e and 9f respectively.

Table 12 : EC, SAR, RSC and water quality of the Palakkad district

Sl No	Location	EC	SAR	RSC	Type of Groundwater (As per CSSRI Classification)
		dS/m	(mmol l^{-1})[1]	meq/l	
1	Agali	0.83	2.738	0	Good
2	Alanallur	0.23	1.321	0	Good
3	Chavadiyur	0.68	1.246	0.8	Good
4	Mannarghat	0.4	1.214	0	Good
5	Kumaramputhur	0.1	0.632	0.2	Good
6	Alathur	0.8	1.197	0	Good
7	Vadakkancherry	0.67	1.523	0	Good
8	Kuzhalmannam	0.72	2.082	0	Good
9	Chalisseri	0.18	1.505	0	Good
10	Kalladikode	0.09	1.504	0	Good
11	Kanjikode	0.98	3.553	3.3	Good
12	Karimpuzha	0.05	0.799	0	Good
13	Ottapalam	0.42	3.5	0	Good
14	Chemmampathi	1.51	2.125	0	Good
15	Gopalapuram	0.6	2.028	0	Good
16	Kozhinmparaja	0.71	2.01	0	Good
17	Meenakshipuram	1	1.759	1.4	Good
18	Meenkara	0.71	0.734	0.2	Good
19	Nadupeni	1.38	5.834	0.5	Good
20	Mankara	0.28	1.194	0.1	Good
21	Mundur	0.23	0.943	0.6	Good
22	Palakkad	0.72	1.592	0.4	Good
23	Pudhunagaram	0.6	1.977	1.9	Good
24	Kodavayur	0.23	1.72	1.3	Good
25	Kollengode	1.34	2.91	1.6	Good
26	Nenmara	0.67	1.132	0.3	Good
27	Adiparanda	0.26	0.697	0.9	Good
28	Koppam	0.27	1.74	0	Good
29	Pattambi	0.29	1.191	0	Good
30	Chullimade	0.27	0.945	0.6	Good
31	Shornur	0.17	0.842	0.4	Good
32	Tavalam	0.32	0.847	0	Good
33	Trittala	0.53	1.398	0	Good
34	Cherpulassery	0.33	1.674	0.9	Good

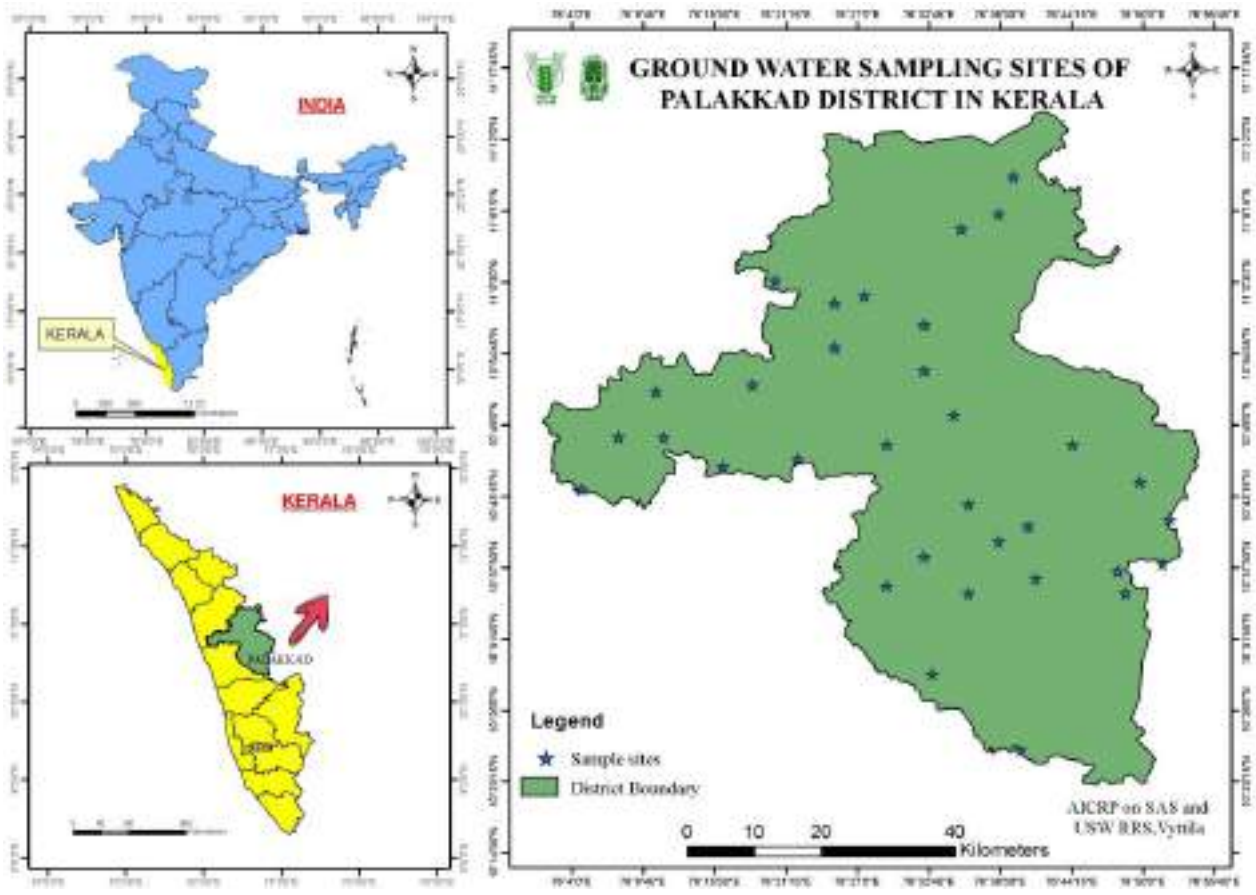

Fig 9a. Ground water sampling sites of Palakkad district

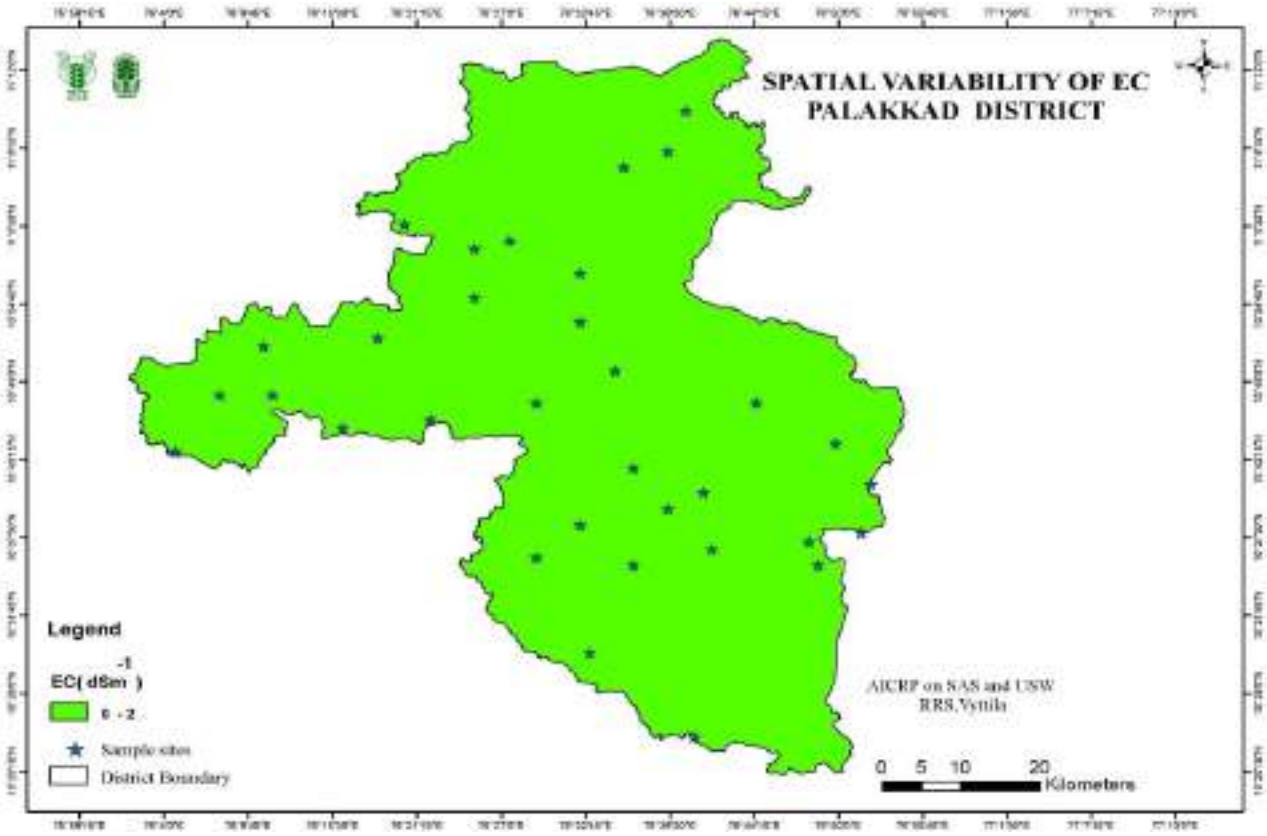

Fig 9b: Spatial variability of electrical conductivity of Palakkad district

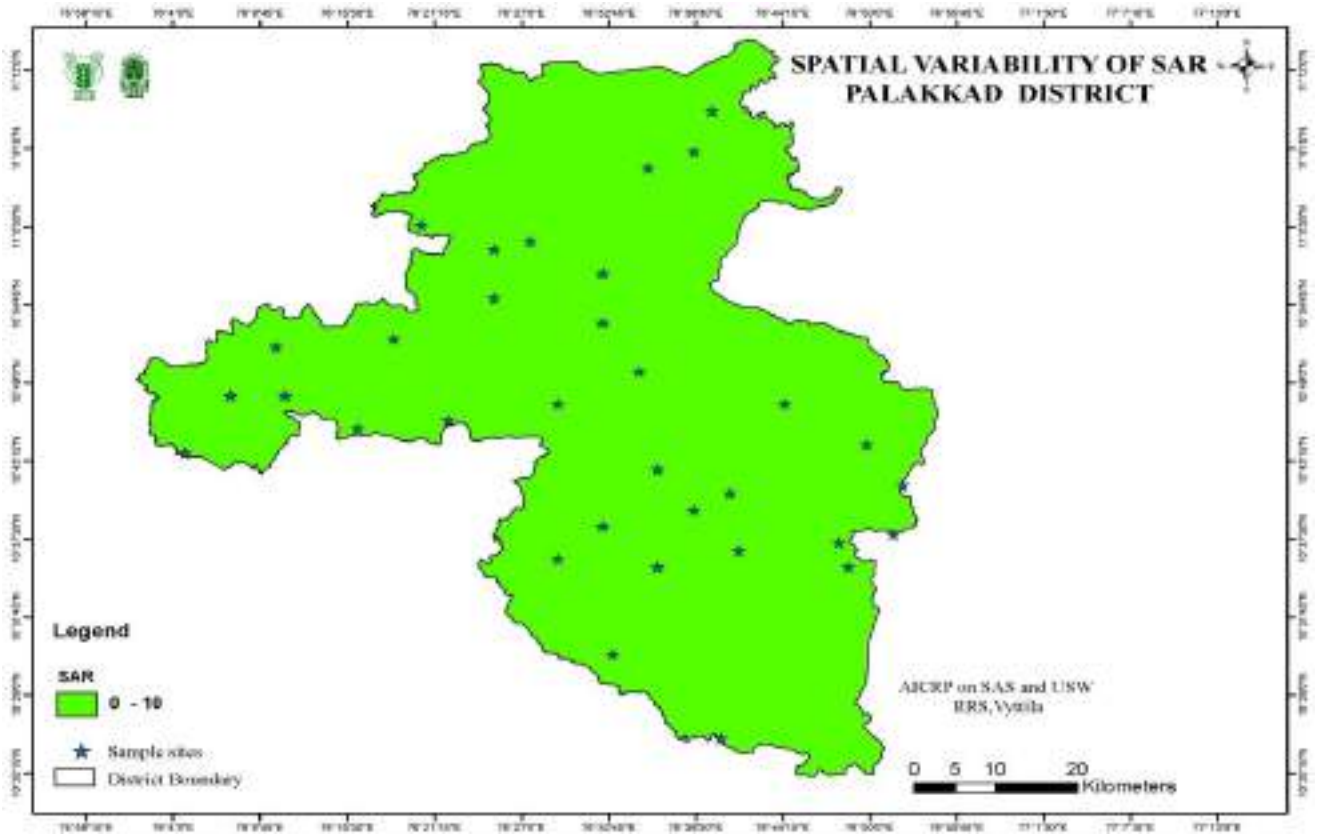

Fig 9c: Spatial variability of SAR of Palakkad district

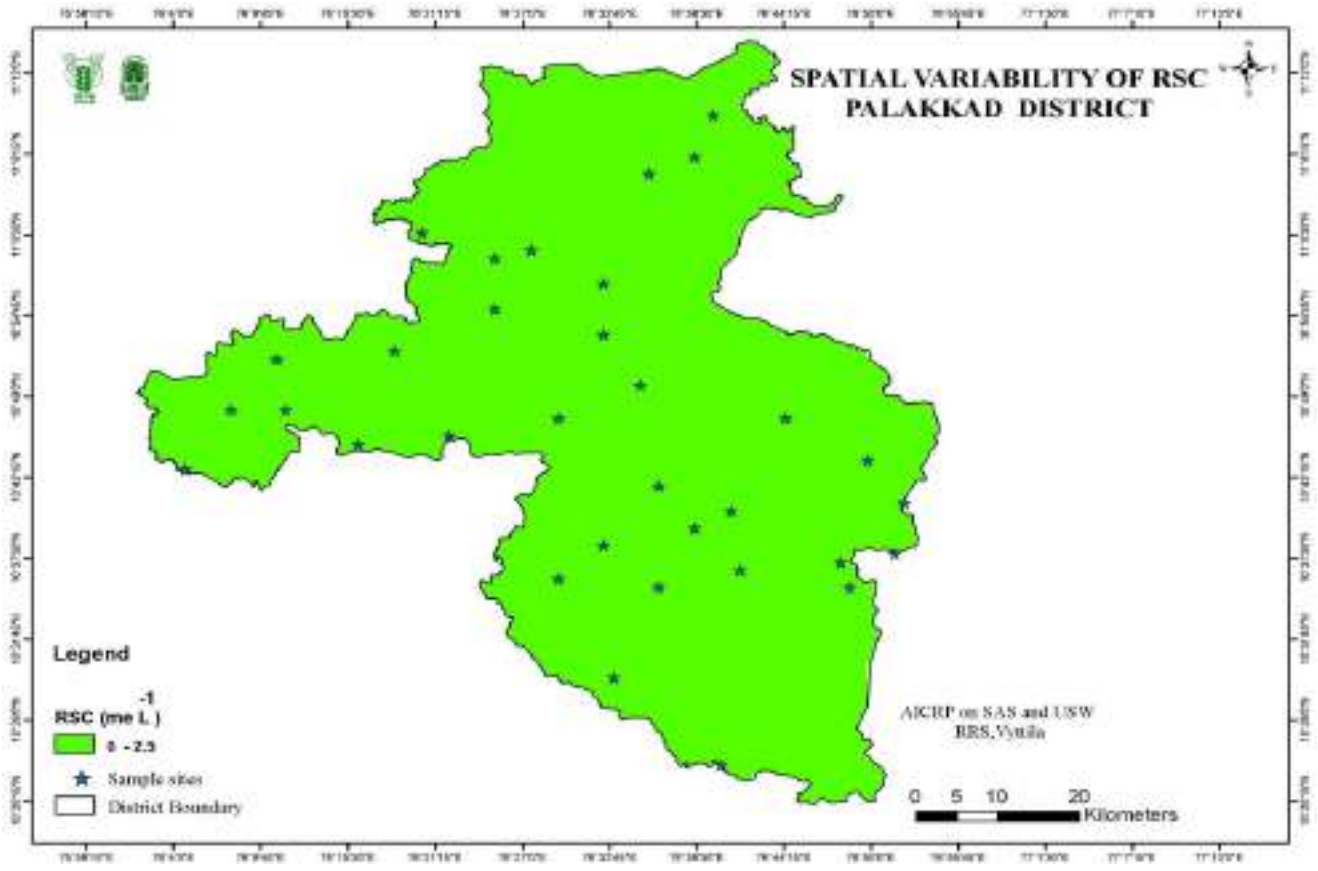

Fig 9d: Spatial variability of RSC of Palakkad district

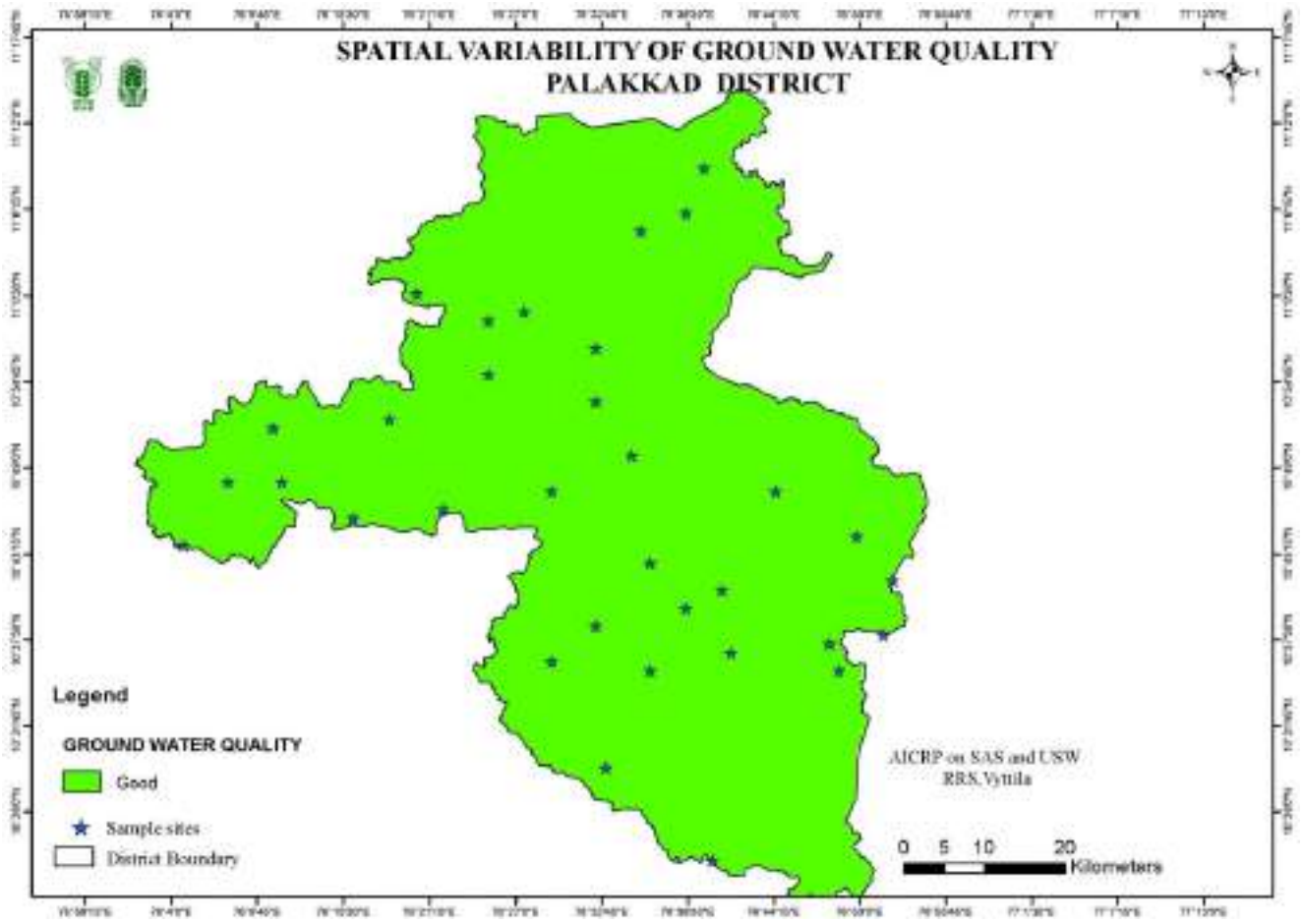

Fig 9e: Distribution of ground water quality for irrigation purpose for Palakkad district

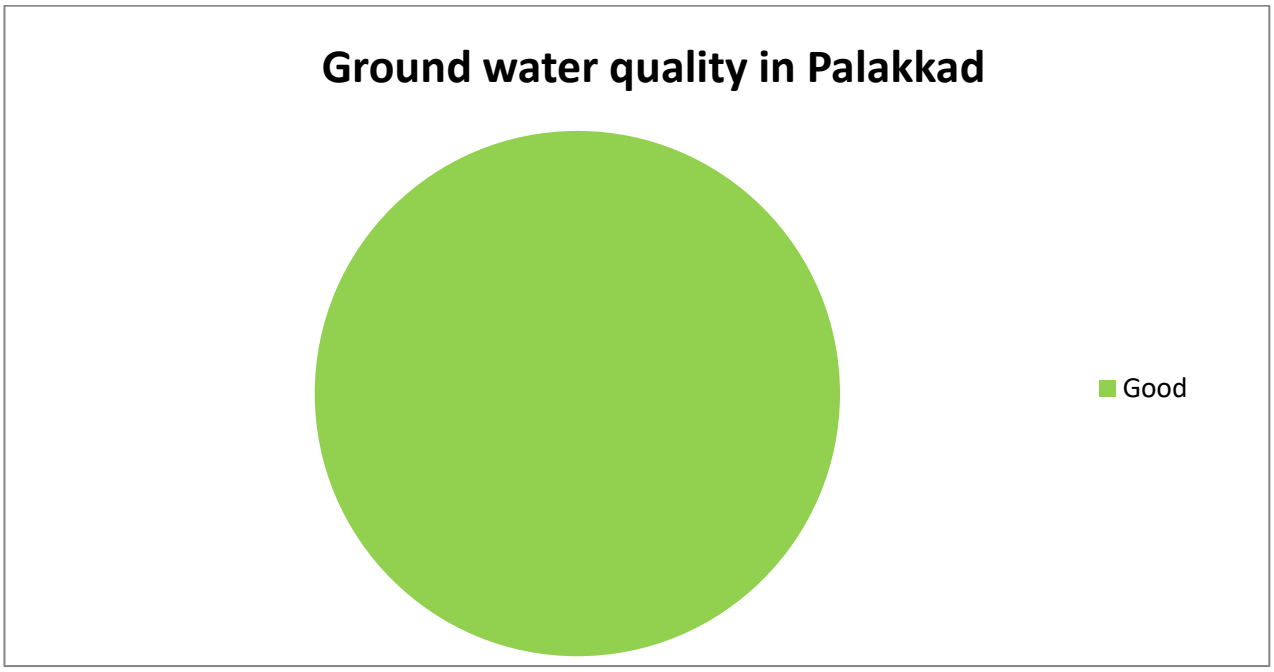

Fig 9f. Groundwater quality distribution for irrigation purpose in Palakkad

Chapter XI

Ground water quality of Malappuram district

Malappuram has a total geographic area of 3,554 km2, which places it third in the state in terms of size, and is bordered by the districts of Kozhikode to the northwest, Wayanad to the northeast, Nilgiri hills to the east, Palakkad to the southeast, Thrissur to the southwest, and the Arabian Sea to the west. A total of 9.15% of the state's land area is contained within the district. On the map, the district is situated between 10°N and 12°N latitude and 75°E and 77°E longitude. Malappuram has a coastal area (lowland) bordered by the Arabian Sea on the west, a midland in the centre, and a hilly portion (highland), bounded by the Western Ghats on the east, just like other regions of Kerala. The groundwater extraction stage of the district is 67.22 % and seven blocks namely, Kondotty, Kuttippuram, Malappuram, Thanur, Thriurangadi, Tirur, Vengara of the district are semi-critical with stage of groundwater development between 60 to 85% (CGWB, 2019).

A total of twenty ground water samples were collected from Malappuram district (Fig 10a). Out of the total ground water samples collected, 35 % and 65 % fall under good and marginally alkaline categories of irrigation water quality respectively. The spatial variability maps of EC, SAR, RSC and water quality of Malappuram district were depicted in Fig 10b, 10c, 10d 10e, and 10f respectively.

Table 13: EC, SAR, RSC and water quality of Malappuram district

Sl. No.	**Location**	**EC**	**SAR**	**RSC**	**Type of Groundwater** (As per CSSRI Classification)
		dS/m	(mmol l^{-1})[1]	meq/l	
1	Tanur	0.39	1.52	3.85	Marginally alkali
2	Tavannur cllg-1	0.17	0.31	3.79	Marginally alkali
3	Perumpakadavu	0.35	1.21	2.08	Good
4	Purathur	0.48	0.54	13.27	Marginally alkali
5	Mangalam	0.77	1.18	1.88	Good
6	Chamravattom	0.25	0.45	6.46	Marginally alkali
7	Maranchery	0.18	0.59	1.32	Good
8	Tavannur cllg -2	0.12	0.58	2.39	Good
9	Thalakkadathur	0.16	1.01	0.64	Good
10	Thirurangadi	0.21	0.61	2.38	Good
11	Koyilandi	0.72	1.3	8.05	Marginally alkali

12	Krishnapuram	0.39	0.93	1.72	Good
13	Thirunavaya	0.57	0.92	10.54	Marginally alkali
14	Malappuram	1.05	3.55	18.82	Marginally alkali
15	Ariyallur	0.22	0.32	3.6	Marginally alkali
16	Tirur	0.33	0.86	1.64	Good
17	Ponnani	0.56	0.48	12.75	Marginally alkali
18	Kanjiramukku	0.65	1.6	3.71	Marginally alkali
19	Vylathur	0.41	0.76	5.94	Marginally alkali
20	Parappanangadi	0.8	0.79	6.27	Marginally alkali

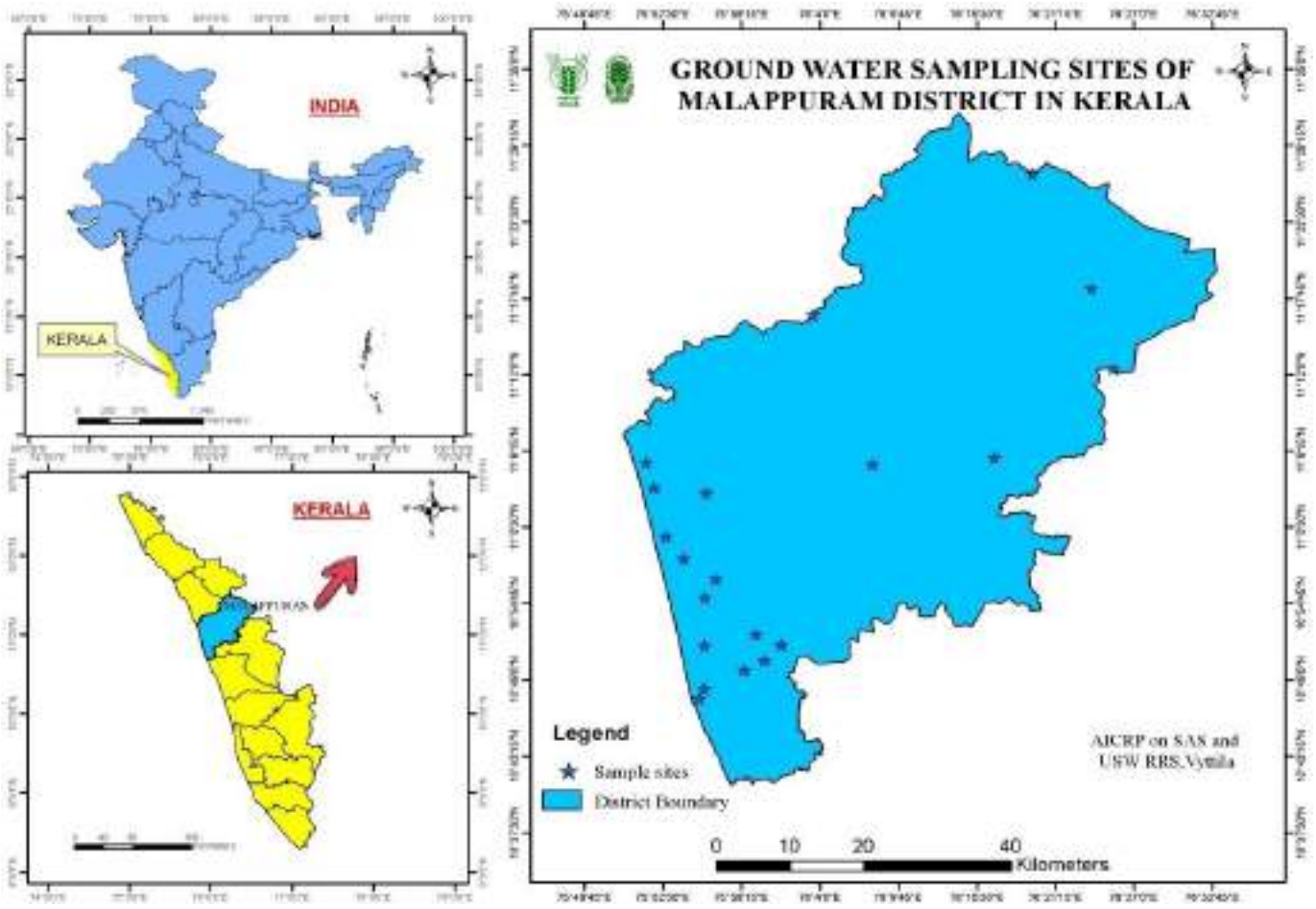

Fig 10a. Ground water sampling sites of Malappuram district

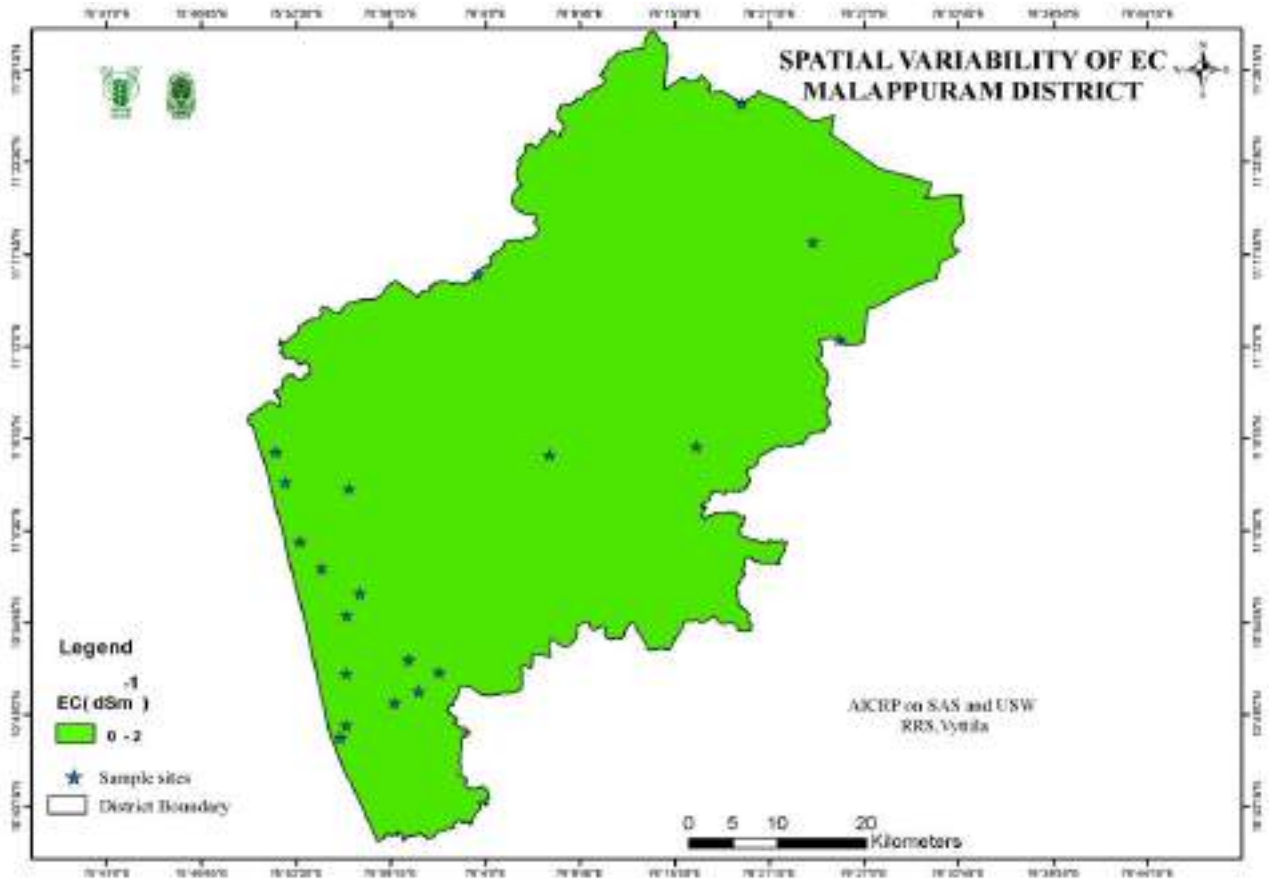

Fig 10b: Spatial variability of electrical conductivity of Malappuram district

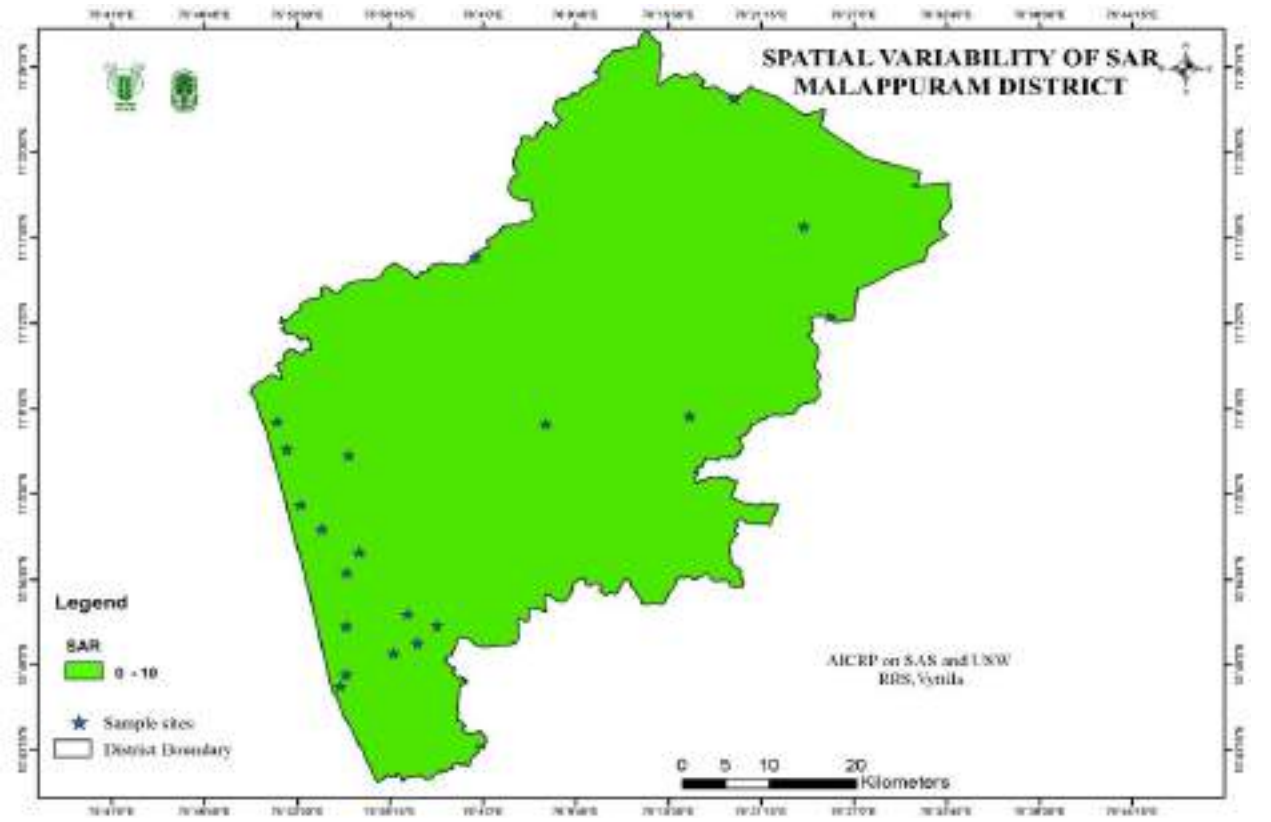

Fig 10c: Spatial variability of SAR of Malappuram district

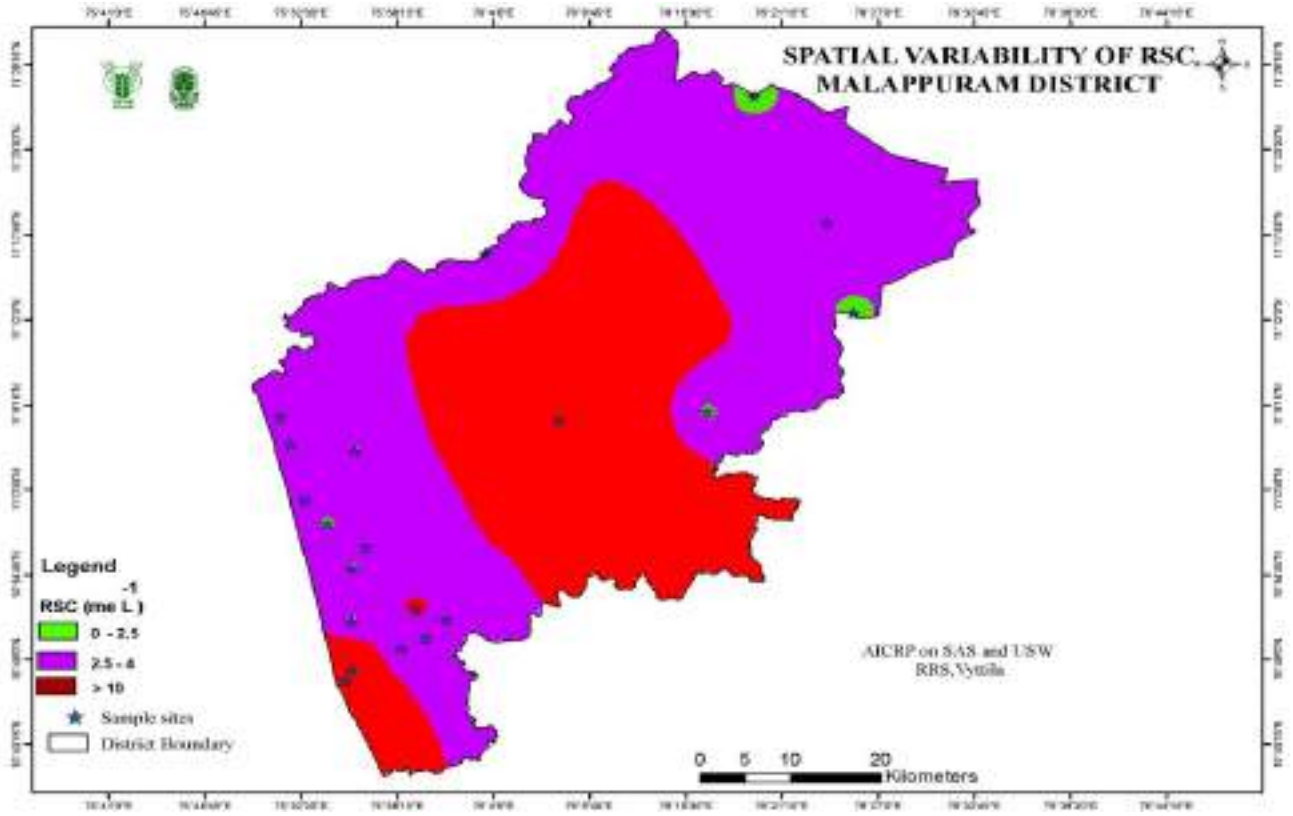

Fig 10d: Spatial variability of RSC of Malappuram district

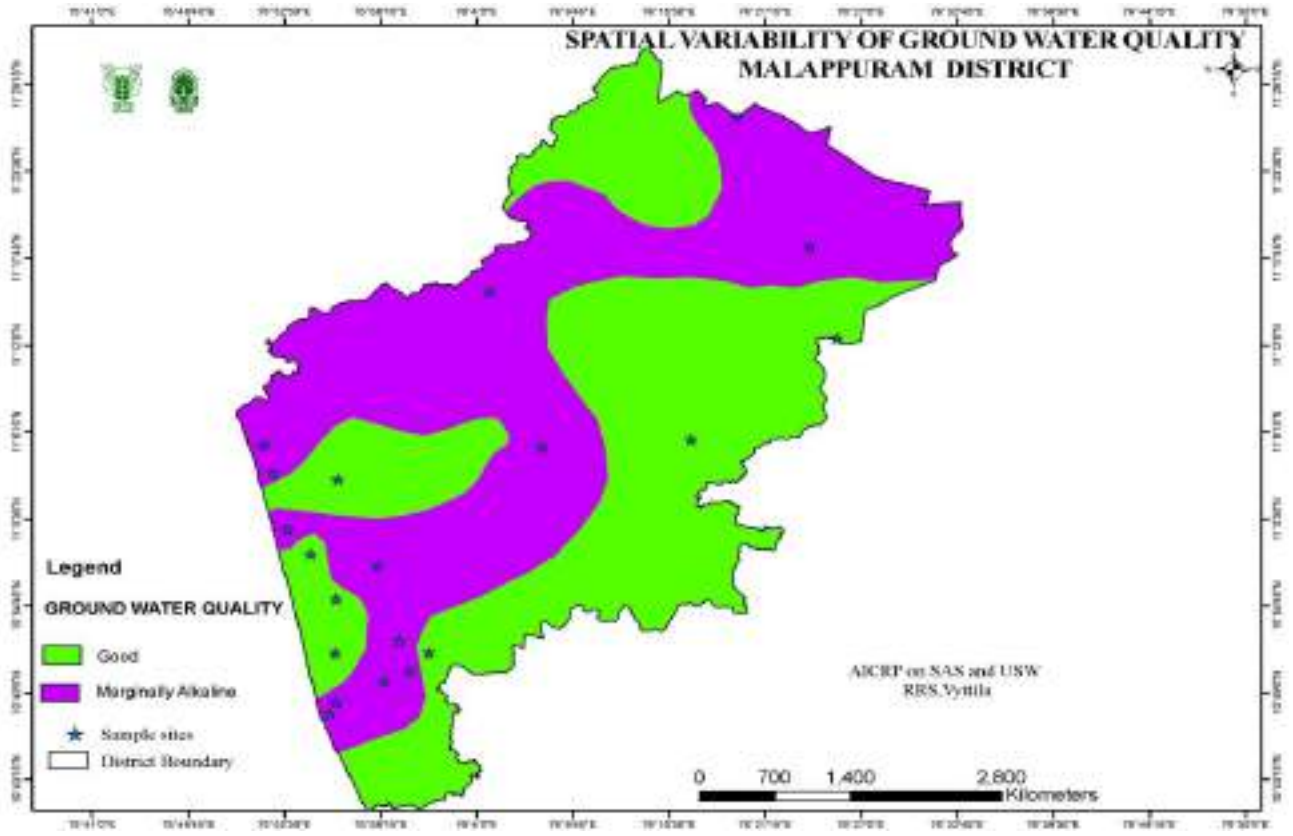

Fig 10e: Spatial distribution of ground water quality for irrigation purpose for Malappuram district

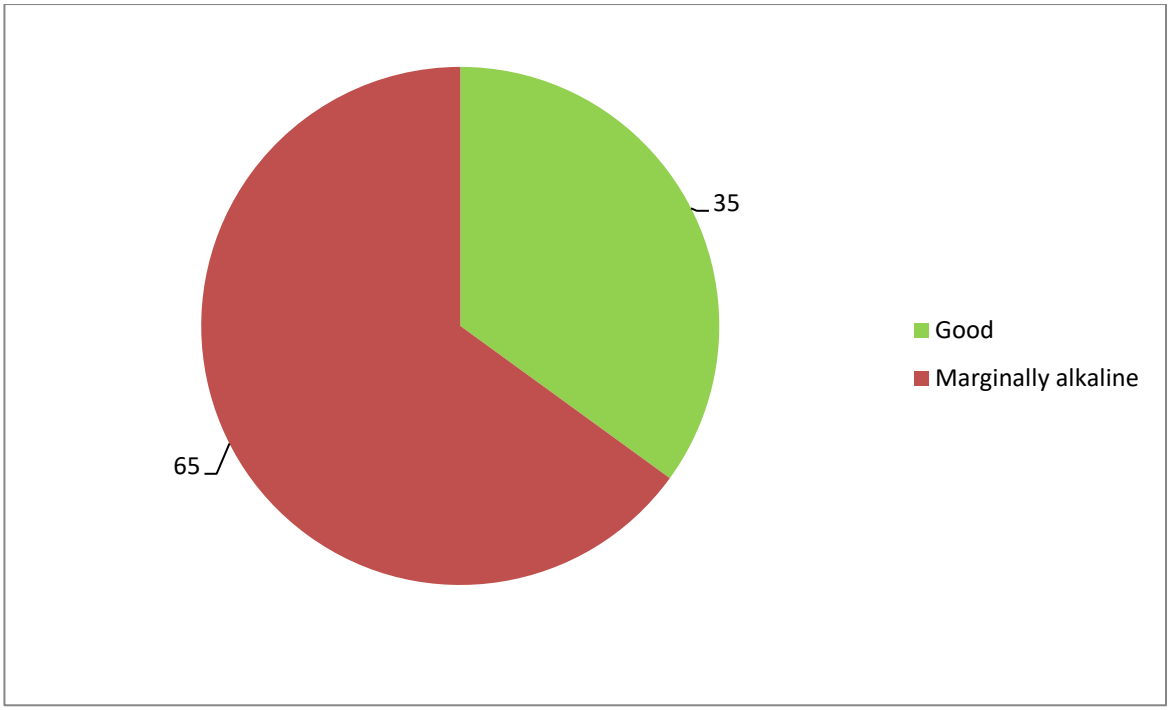

Fig 10 f. Groundwater quality distribution for irrigation purpose in Malappuram

Chapter XII

Ground water quality of Kozhikode district

The district of Kozhikode is located at 11.25°N 75.77°E on India's southwest coast. The district is bounded on the North by the district of Kannur, the East by the district of Wayanad, the South by the district of Malappuram, and the West by the Arabian Sea. The district's topography divides it into three distinct areas: the lateritic midland, the rocky highlands formed by the steep Western Ghats, and the sandy coastal belt. The rocky highlands cover 637.65 sq. km. of the overall area of 2344 sq. km., followed by the lateritic midlands at 1343.50 sq. km. and the sandy coastal belt at 362.85 sq. km. The groundwater extraction stage of the district is 58.02 % and two blocks namely, Ballussery and Kunnamangalam of the district are semi-critical (CGWB, 2019).

A total of nineteen ground water samples were collected from Kozhikode district (Fig 11a). Out of the total ground water samples collected, 73.68 % and 26.31 % fall under good and marginally alkaline categories of irrigation water quality respectively. The spatial variability maps of EC, SAR, RSC and water quality were depicted in Fig 11b,11c, 11d,11e and 11f respectively.

Table 14: EC, SAR, RSC and water quality of Kozhikode district

Sl. No.	**Location**	**EC**	**SAR**	**RSC**	**Type of Groundwater** (As per CSSRI Classification)
		dS/m	(mmol l^{-1})[1]	meq/l	
1	Melady	0.55	0.36	16.94	Marginally alkali
2	Madhurabazar	0.25	0.66	4.89	Good
3	Kozhikode	0.41	0.28	7.48	Good
4	Mukkali	0.13	0.73	2.69	Marginally alkali
5	Meppayil	0.1	0.82	0.68	Good
6	Chemancheri	0.38	0.4	5.91	Good
7	Koodathumpara	0.16	0.63	2.74	Marginally alkali
8	Moodadi	0.17	0.21	3.94	Marginally alkali
9	Thikkodi	0.14	0.45	1.82	Good
10	Chorode	0.16	0.48	2.25	Good
11	Karaparamba	0.44	0.44	6.1	Good
12	Payyoli	0.1	0.34	1.78	Good
13	Modernbazar	0.5	0.98	2.94	Marginally alkali
14	Chovayur	0.13	0.52	4.44	Good
15	Kozhikode-1	0.49	0.41	4.56	Good
16	Bepore	0.83	1.39	9.46	Good
17	Elathur	0.38	0.6	1.61	Good
18	Vadakara	0.54	0.69	2.83	Good
19	Vellimadkunnu	0.08	0.37	1.84	Good

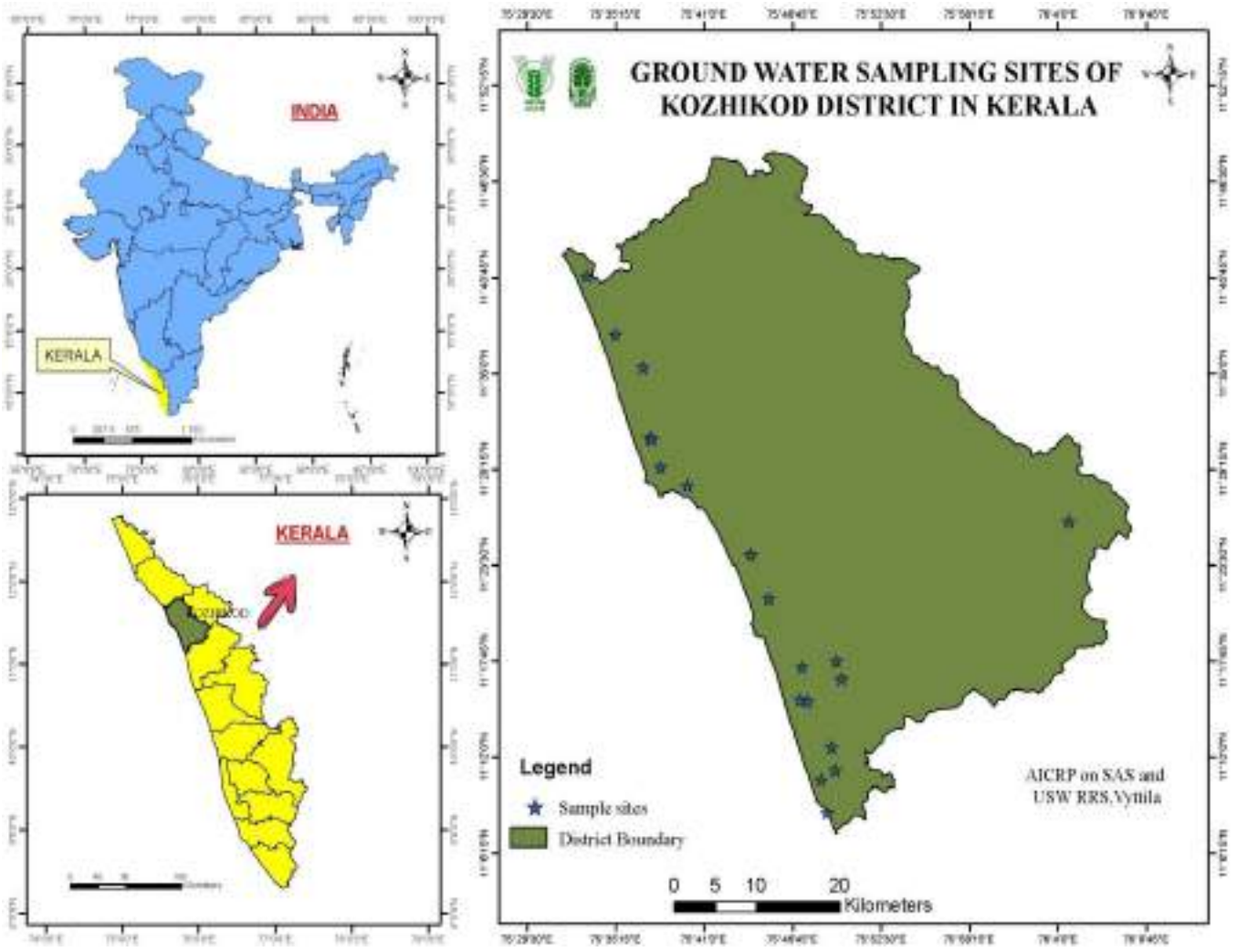

Fig 11a. Ground water sampling sites of Kozhikode district

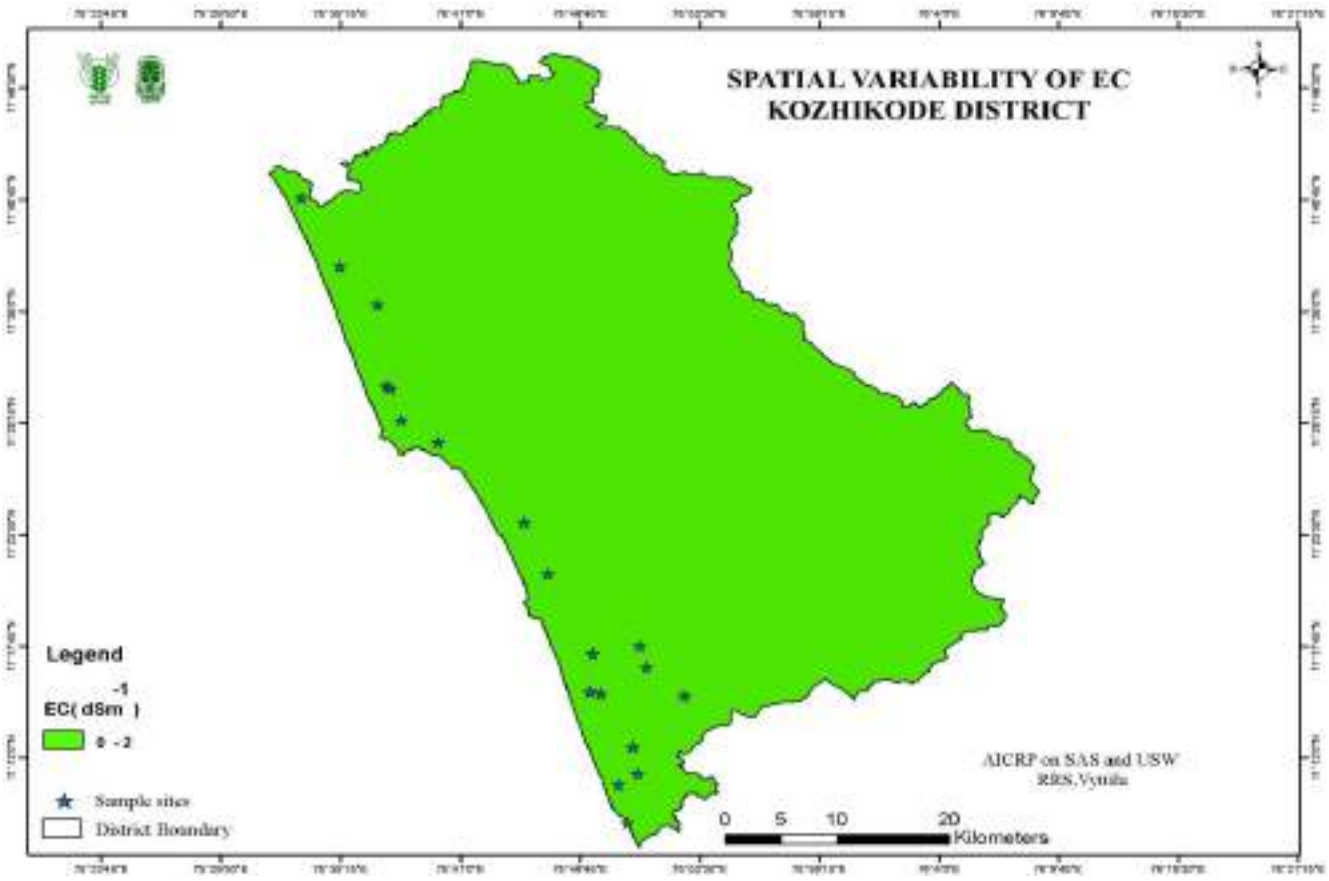

Fig 11b: Spatial variability of electrical conductivity of Kozhikode district

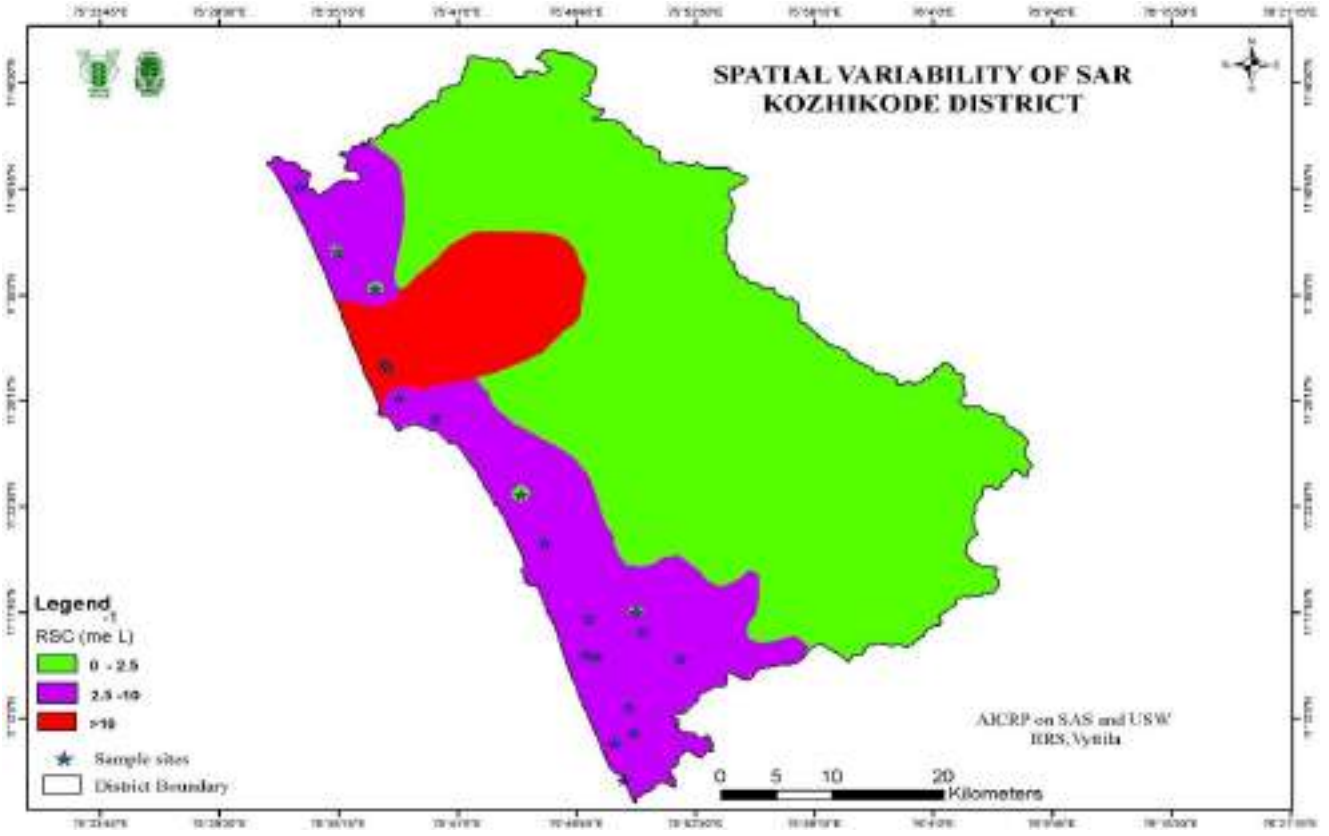

Fig 11c: Spatial variability of SAR of Kozhikode district

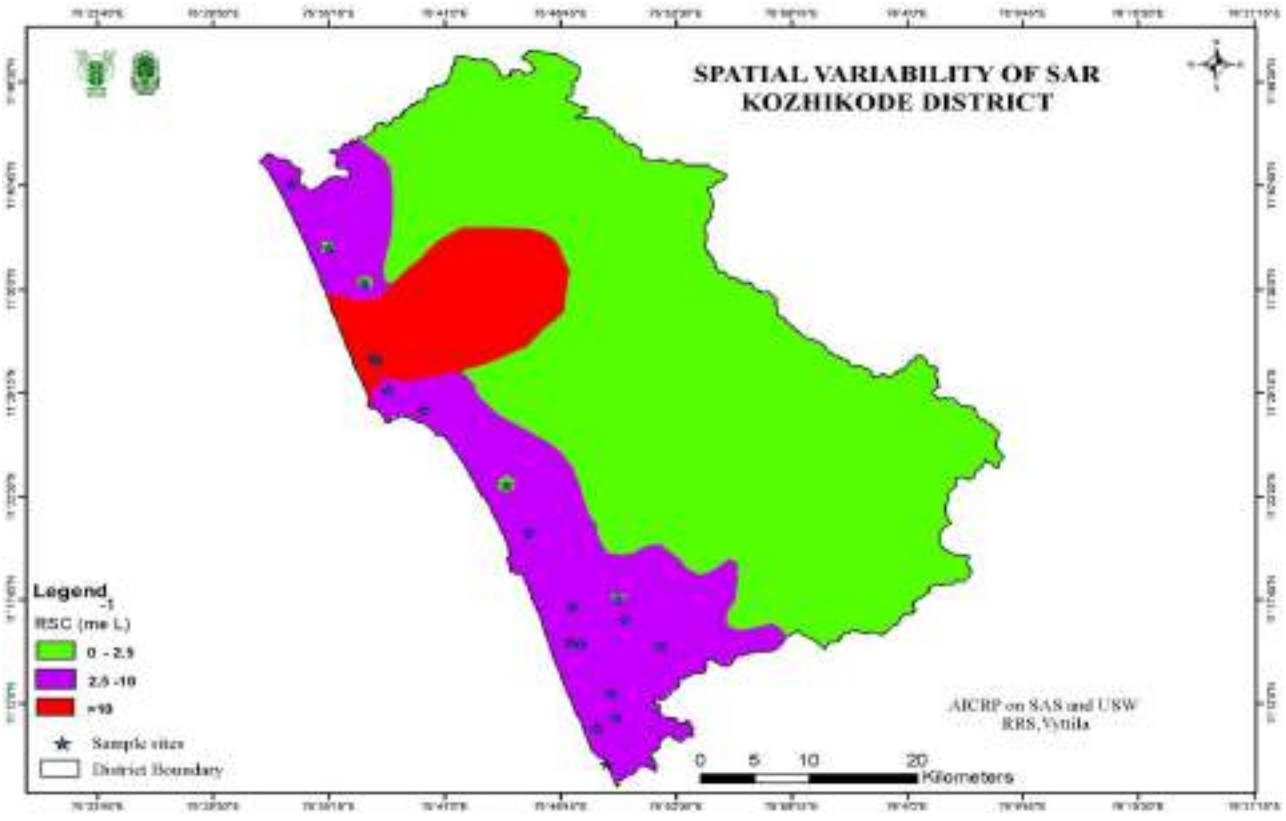

Fig 11d: Spatial variability of RSC of Kozhikode district

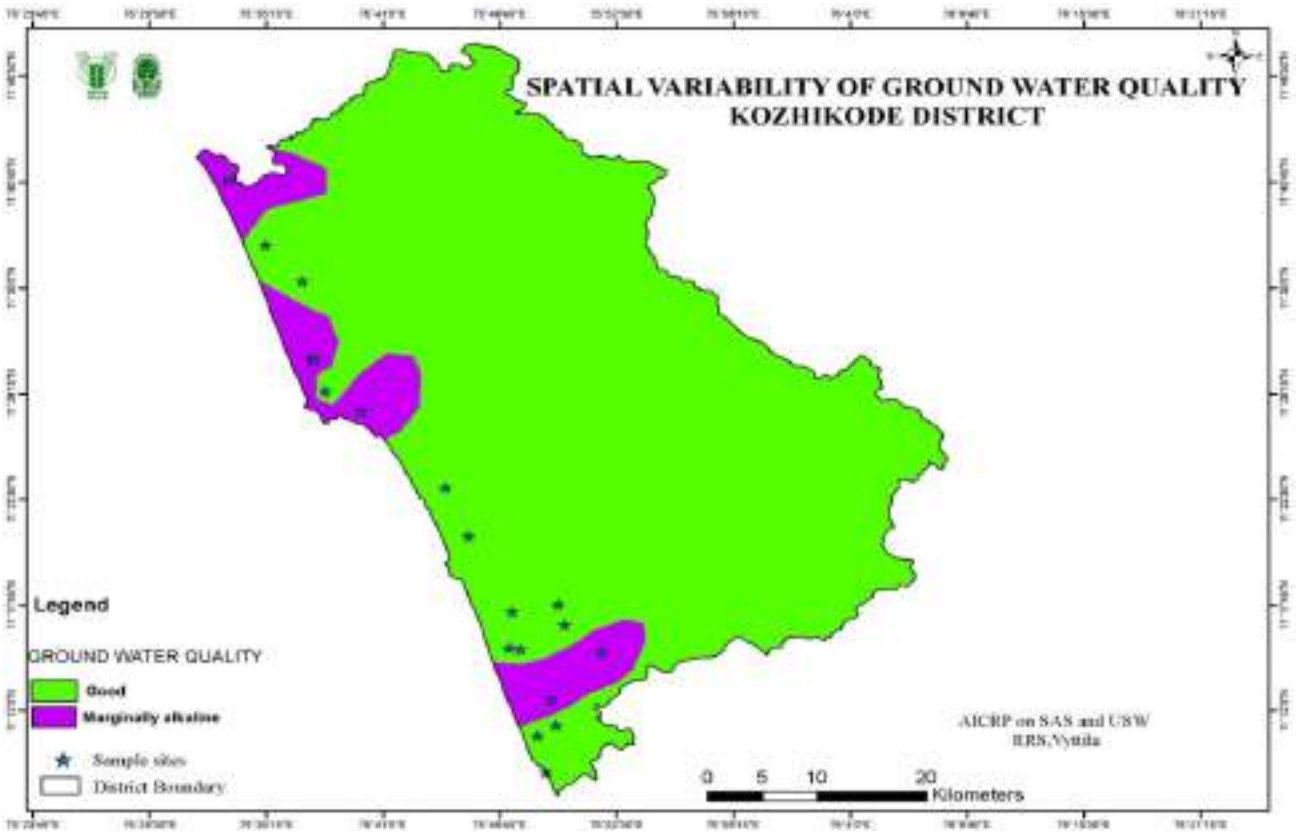

Fig 11e: Spatial variability of ground water quality of distribution of ground water quality for irrigation purpose for Kozhikode district

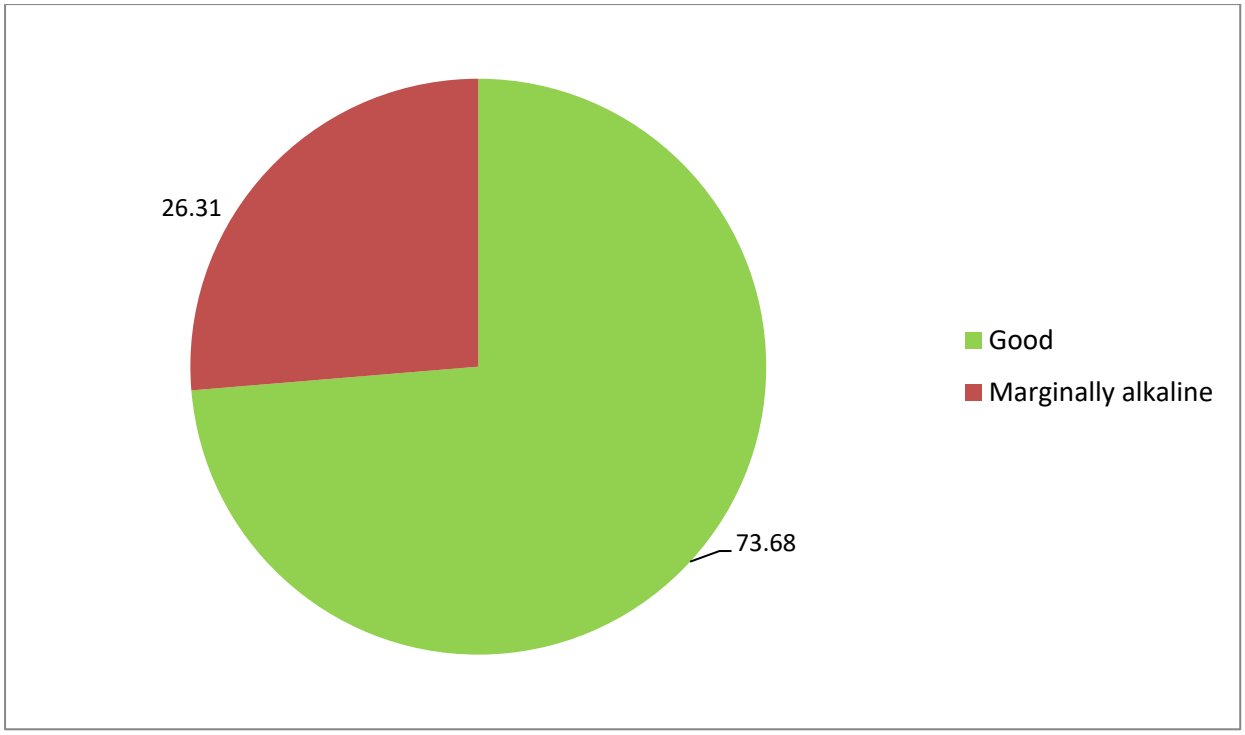

Fig 11f. Groundwater quality distribution for irrigation purpose in Kozhikode district

Chapter XIII

Ground water quality of Wayanad district

The district of Wayanad, which has Kalpetta as its administrative centre, is located in the state of Kerala's northeastern region. Wayanad is situated between 11. 27 and 15. 58 north latitude and 75. 47 and 70. 27 east longitude and has a total size of 2132 sq km. Nestled among the mountain of the Western Ghats, lies Wayanad, one of the loveliest hill stations of Kerala. This green paradise, located at a distance of about 76 km from the seashores of Kozhikkod, lies at a height of 700 to 21000 m. above sea level, on the north eastern part of the state. The mean average rainfall in this district is 2322 mm. Lakkidy, Vythiri and Meppadi are the high rainfall areas in Wayanad. Annual rainfall in these high rainfall areas ranges from 3,000 to 4,000 mm. High velocity winds are common during the southwest monsoon and dry winds blow in March/April. High altitude regions experience severe cold. The groundwater extraction stage of the district is 24.51% (CGWB, 2019).

The details of ground water data has been collected from central ground water board (CGWB), for the Wayanad and were classified according to CSSRI classification (Fig.12a). All samples from Wayanad district is good for irrigation. The spatial variability maps of EC, SAR, RSC and water quality were depicted in Fig 12b, 12c, 12d, 12e and 12f respectively.

Table 15: EC, SAR, RSC and water quality of Wayanad district

Sl. No.	**Location**	**EC**	**SAR**	**RSC**	**Type of Groundwater** (As per CSSRI Classification)
		dS/m	$(\text{mmol } l^{-1})^1$	meq/l	
1	Ambalavayal	0.23	1.73	0	Good
2	Chenad	0.13	0.49	0.34	Good
3	Perikallur	0.35	3.25	0	Good
4	Pulpally	0.21	2.17	0	Good
5	SulthanBathery	0.44	1.46	0	Good
6	Vaduvanchal	0.15	0.62	0	Good
7	Minangadi	0.21	1.43	0	Good
8	Muthanga	0.71	2.04	0	Good
9	Noolpuzha	0.16	0.5	0.68	Good
10	Muthanga	0.71	2.04	0	Good
11	Kalpetta	0.35	1.86	0	Good
12	Vyttiri	0.18	0.95	0	Good
13	Padinjarattara	0.19	1.37	0	Good
14	Tirunelly	0.13	0.56	0.3	Good
15	Kamblakat	0.16	0.92	0.12	Good
16	Koroth	0.08	0.38	0	Good
17	Mananthody	0.37	1.17	0.36	Good

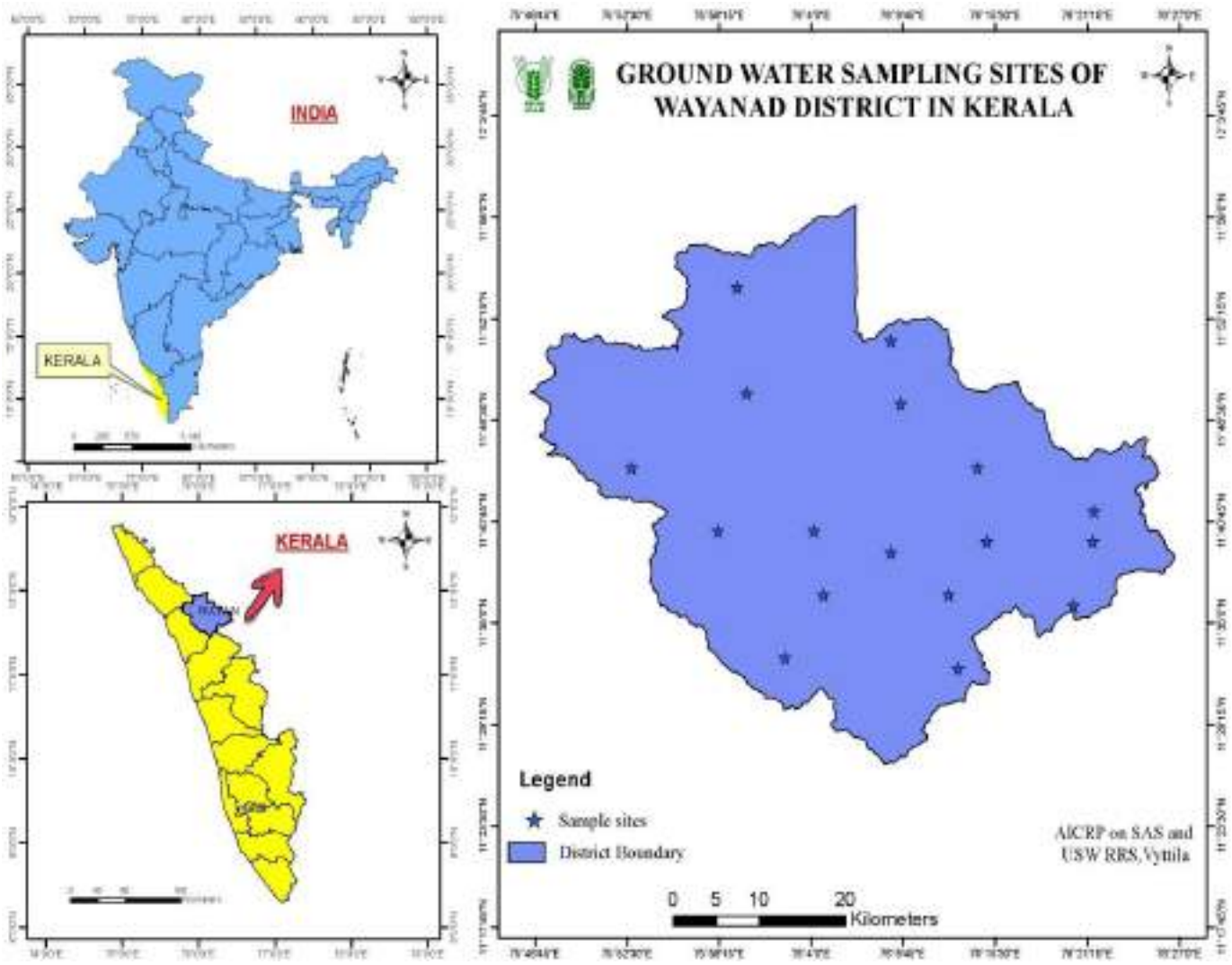

Fig 12a: Ground water sampling sites of Wayanad district

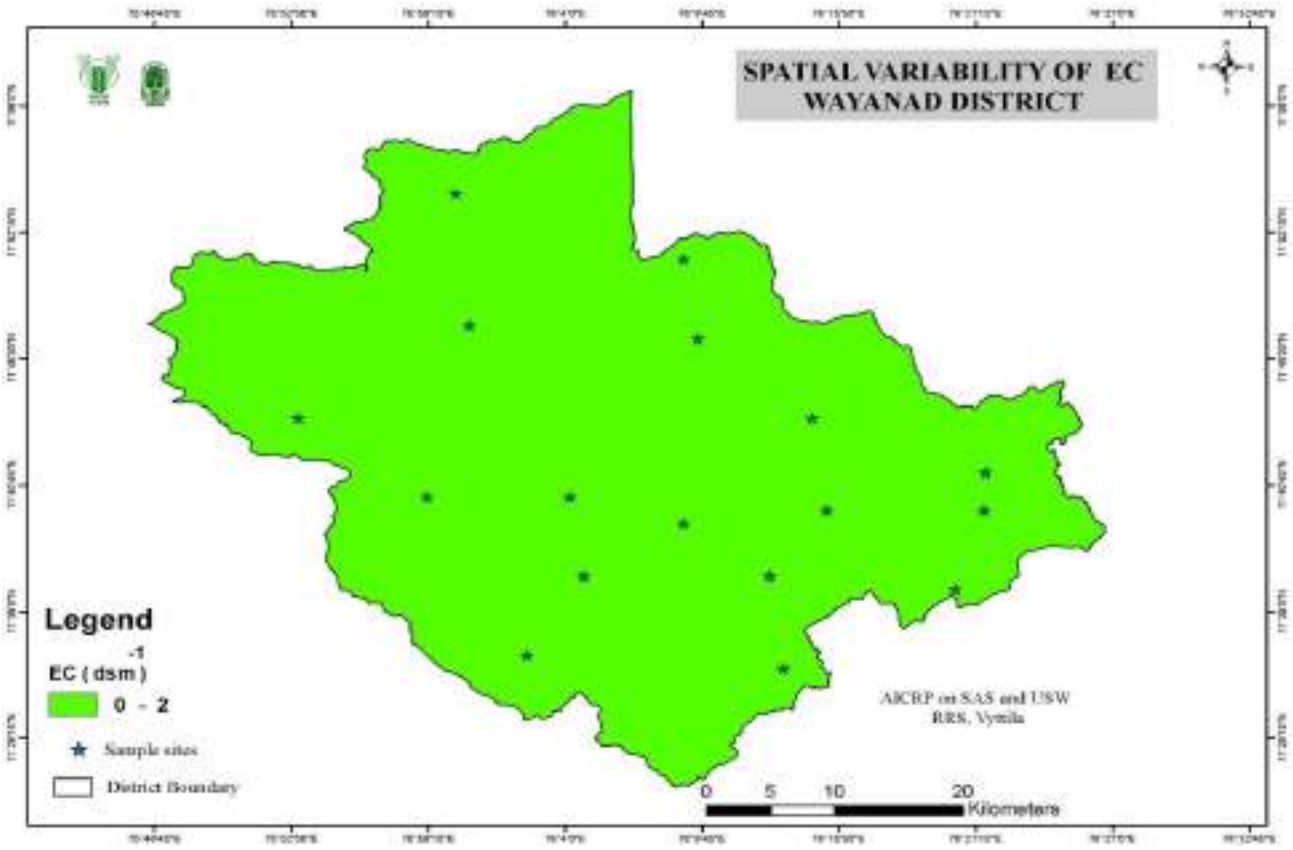

Fig 12b: Spatial variability of electrical conductivity of Wayanad district

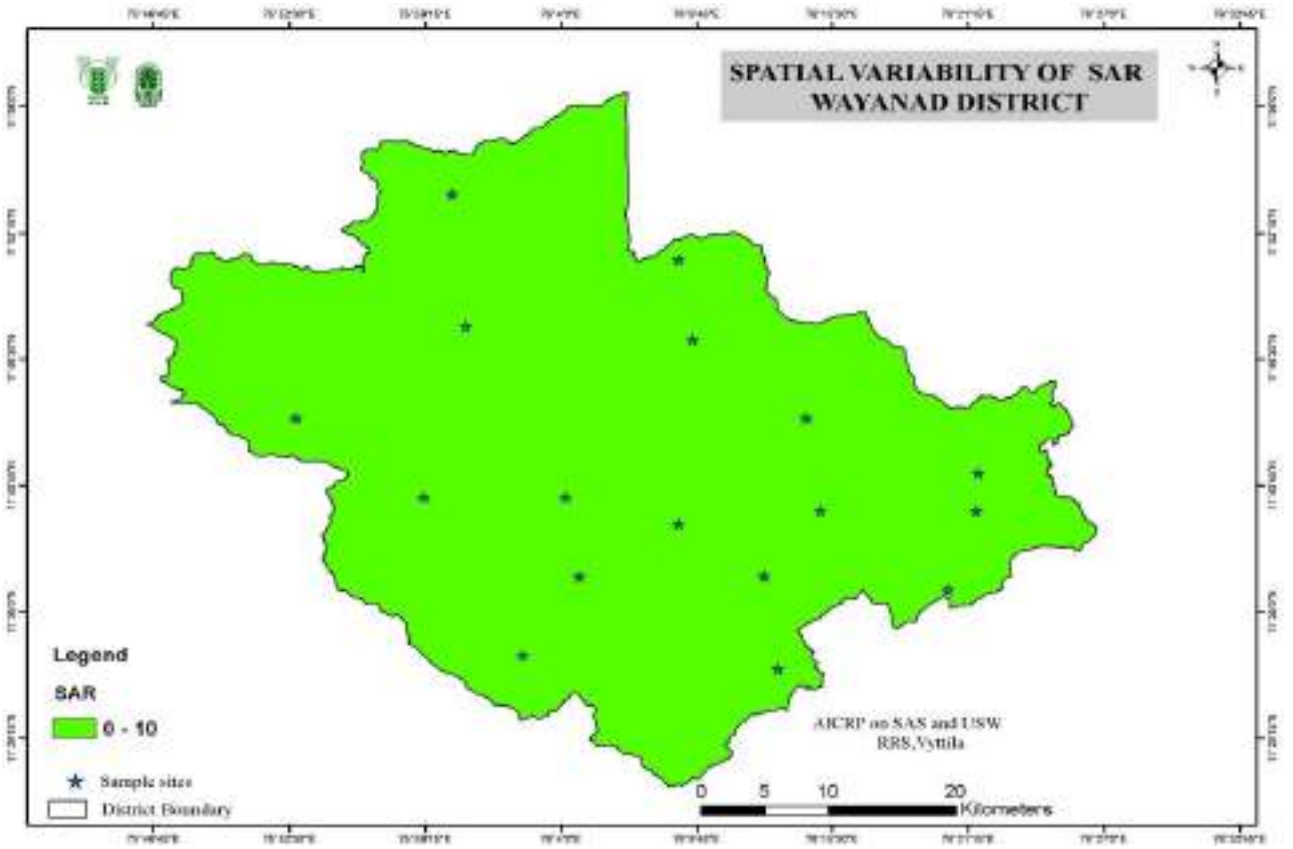

Fig 12c: Spatial variability of SAR of Wayanad district

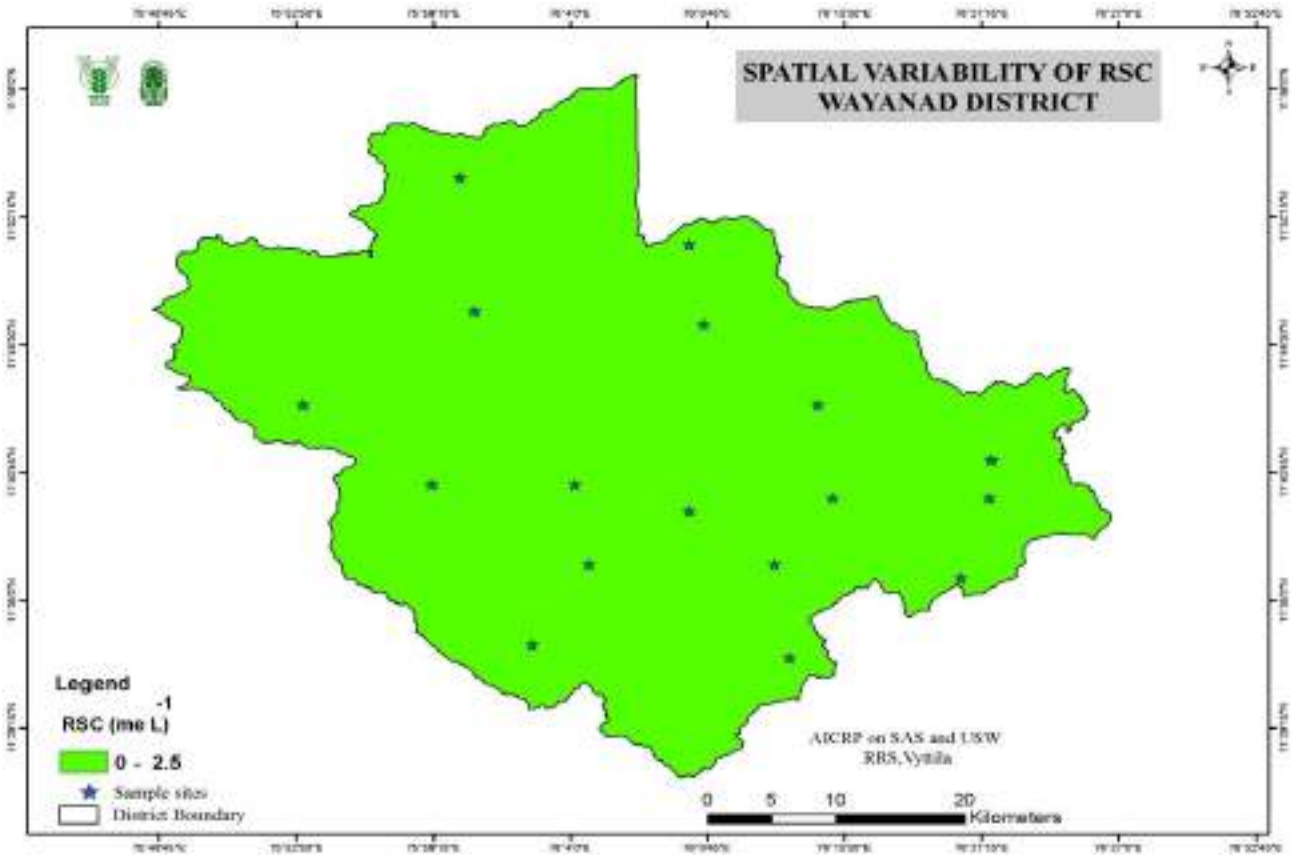

Fig 12d: Spatial variability of RSC of Wayanad district

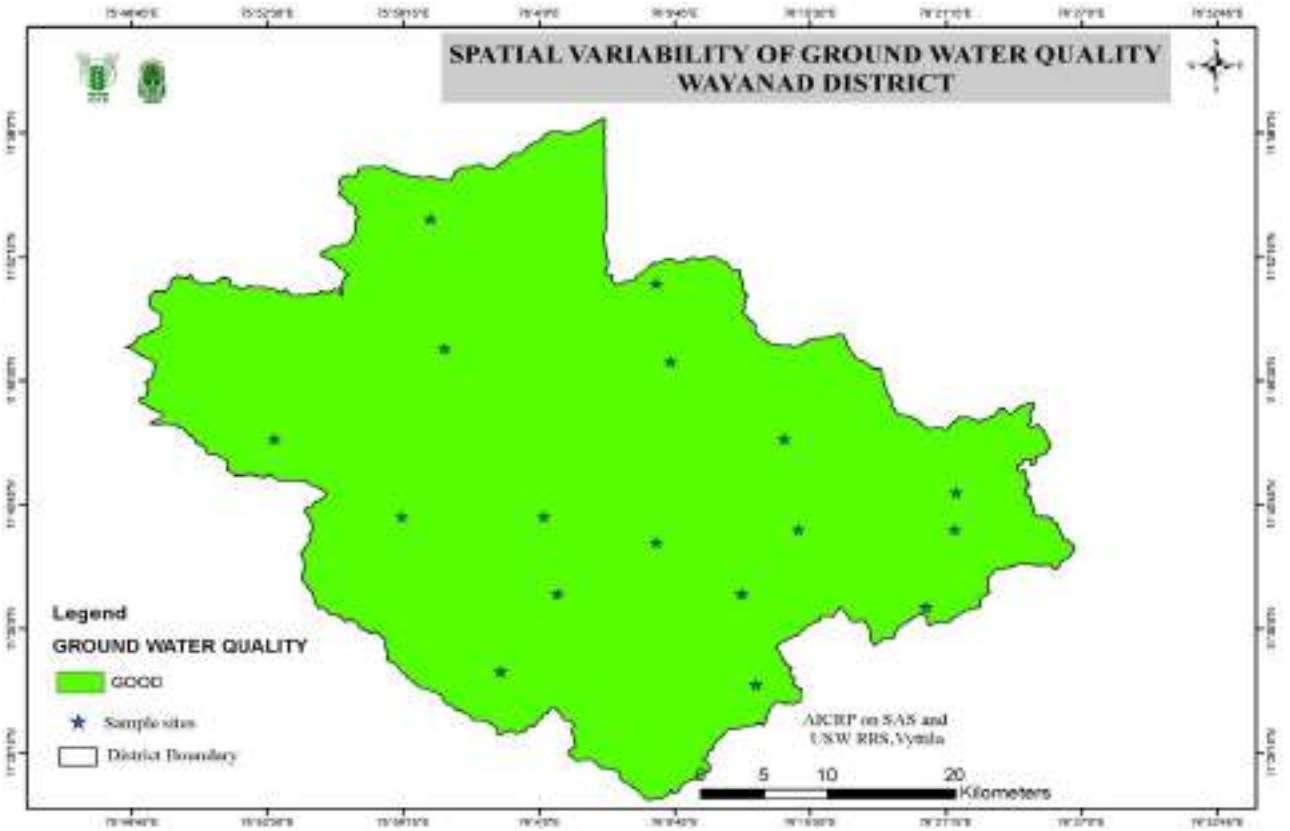

Fig 12e: Spatial distribution of ground water quality for irrigation purpose for Wayanad district

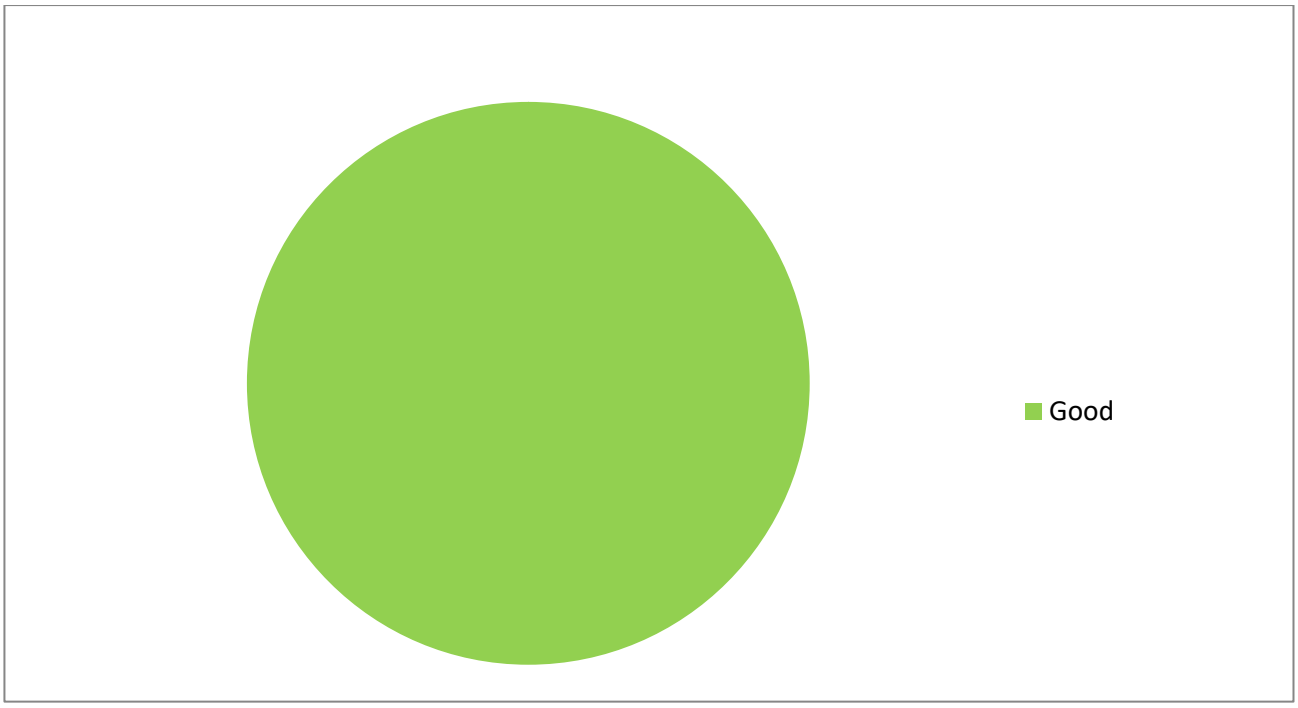

Fig 12 f. Groundwater quality distribution for irrigation purpose in Wayanad

Chapter XIV

Ground water quality of Kannur district

Along the Laccadive Sea's coast, Kannur is elevated by 1.02 metres, or 3.3 feet, and its coastline is sandy. Kannur is located at 11.8689°N 75.3555°E in the east of the Laccadive Sea, west of the Kodagu and Wayanad regions of the Western Ghats, south of Kasargod and Mangalore, and north of Kozhikode**.** The annual average rainfall is 3,438 millimetres or 135 inches, around 68 per cent of which is received in summer. The groundwater extraction stage of the district is 45.54 % and three blocks namely, Kannur, Panur, Thalassery of the district are semi-critical with stage of groundwater development between 65 to 80% (CGWB, 2019).

A total of fifteen ground water samples were collected from Kannur district. The location map of the sampling points was presented in Fig 13a. The spatial variability maps for EC, SAR, RSC and ground water quality of Kannur district was depicted in Fig. 13b, 13c, 13d, 13e and 13f respectively. Out of the total ground water samples collected, 60.00 % falls under good category for irrigation. The rest 26.66 % and 13.33 % were marginally alkaline and high alkali categories of irrigation water quality respectively.

Table 16: EC, SAR, RSC and ground water quality of Kannur district

Sl. No.	**Location**	**EC**	**SAR**	**RSC**	**Type of Groundwater** (As per CSSRI Classification)
		dS/m	$(mmol\ l^{-1})^1$	meq/l	
1	Alavil	0.11	1	1.5	Good
2	Valapattanam	0.49	1.34	0.4	Good
3	Payangadi	0.43	0.27	3.9	Marginally alkali
4	Cheleri	0.02	1.09	0.7	Good
5	Ramantali	0.04	1.02	0.7	Good
6	Thalassery	0.55	0.67	2.4	Good
7	Chaladi	0.21	0.73	1	Good
8	Payyanur	0.2	0.42	1	Good
9	Edakkad	0.21	0.4	5.1	Marginally alkali
10	Kannapuram	0.51	0.53	2.8	Good
11	Kaipad-1	23	46.53	15.3	High SAR saline
12	Kaipad-1 well	1.7	2.86	3.3	Marginally alkali
13	Kaipad-2-valiyathuruthy	37	67.9	0	High SAR Saline
14	Kaipad-3-chemmenchery	33	64.37	0	High SAR Saline
15	Kaipad-2- well	9.6	18.88	6.2	High SAR saline

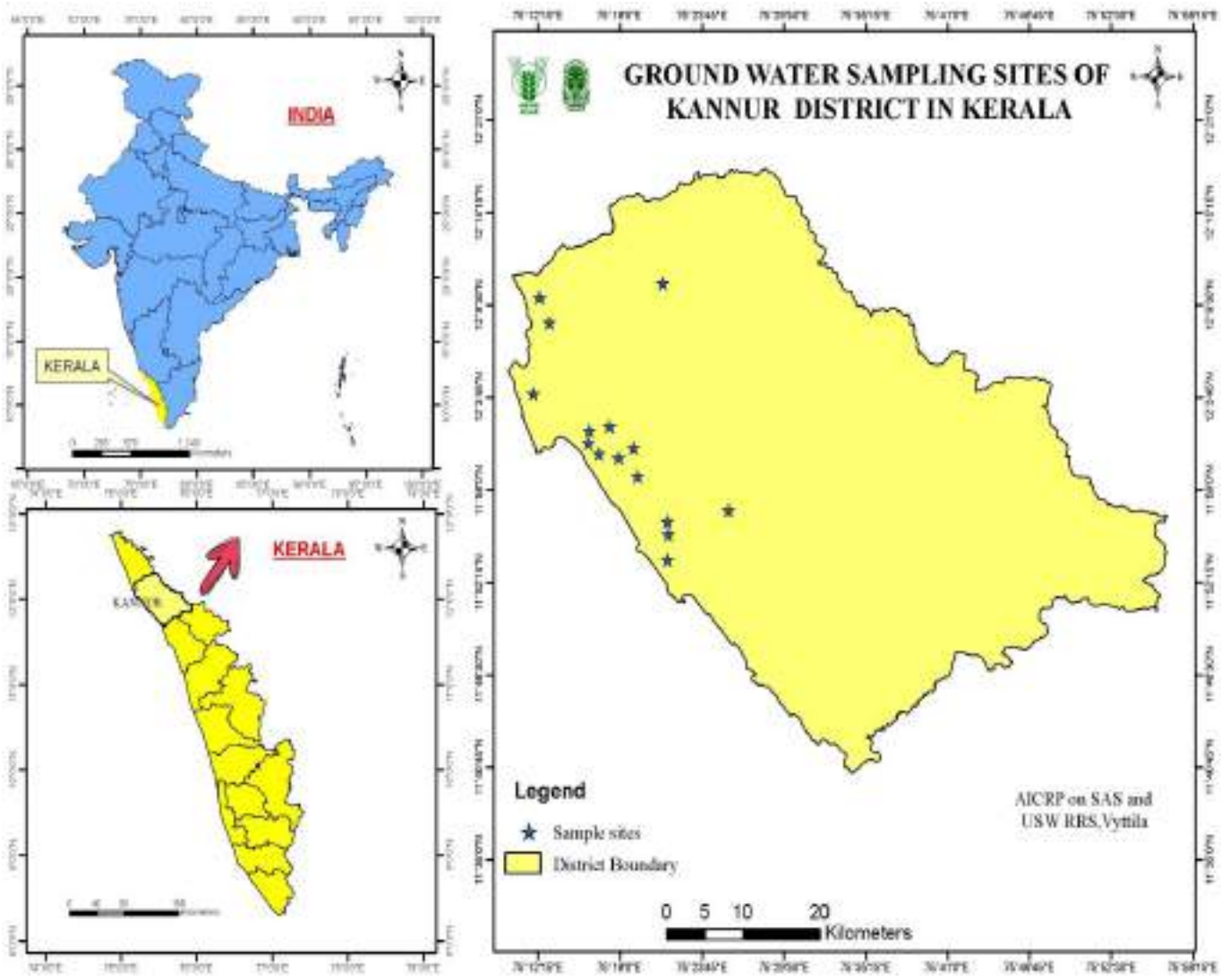

Fig 13a: Ground water sampling sites of Kannur district

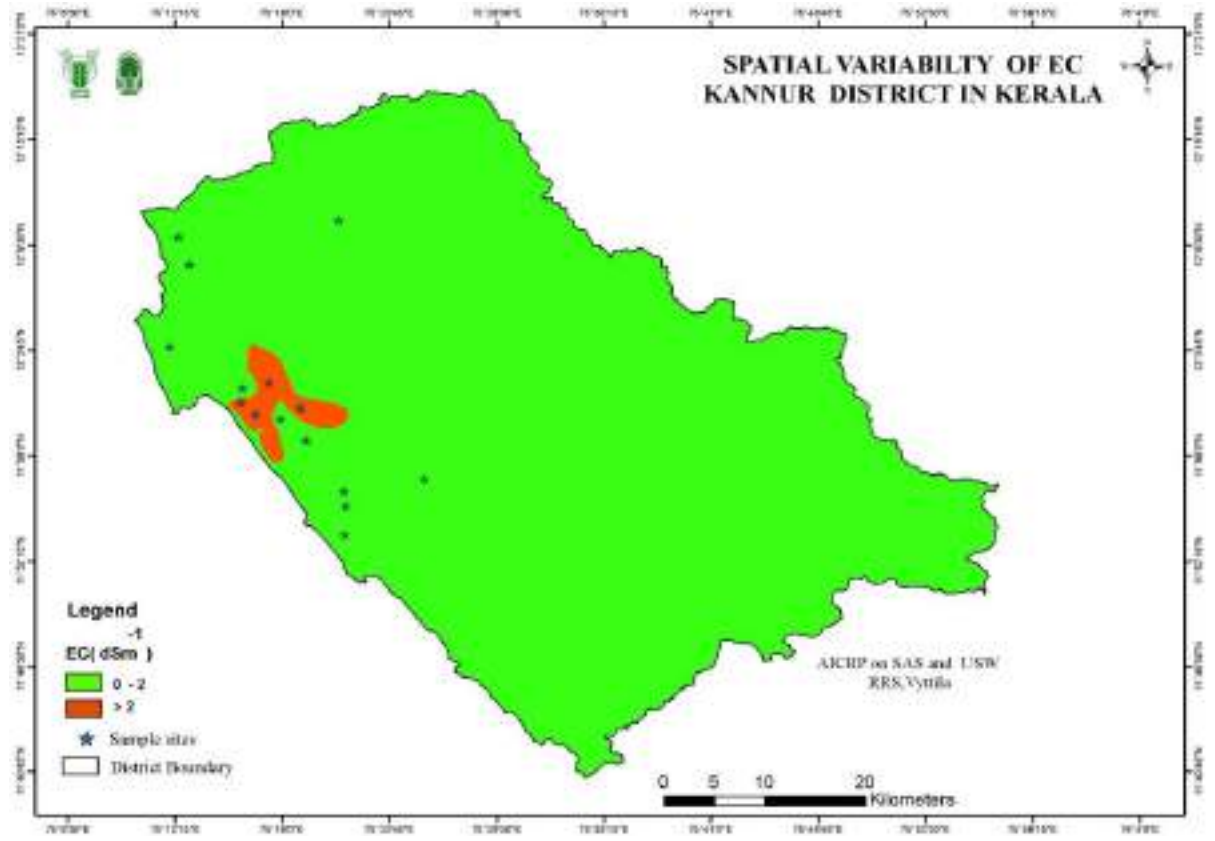

Fig 13b: Spatial variability of electrical conductivity of Kannur district

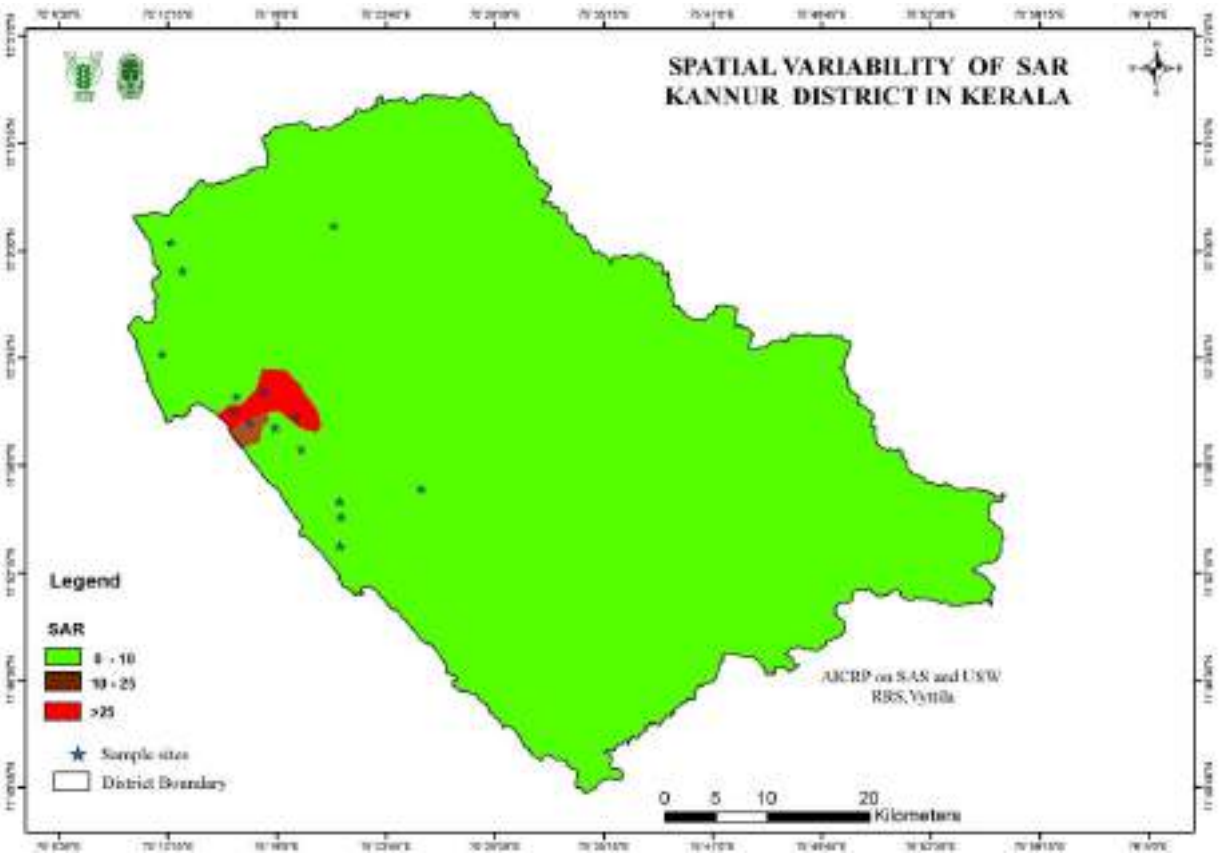

Fig 13c: Spatial variability of SAR of Kannur district

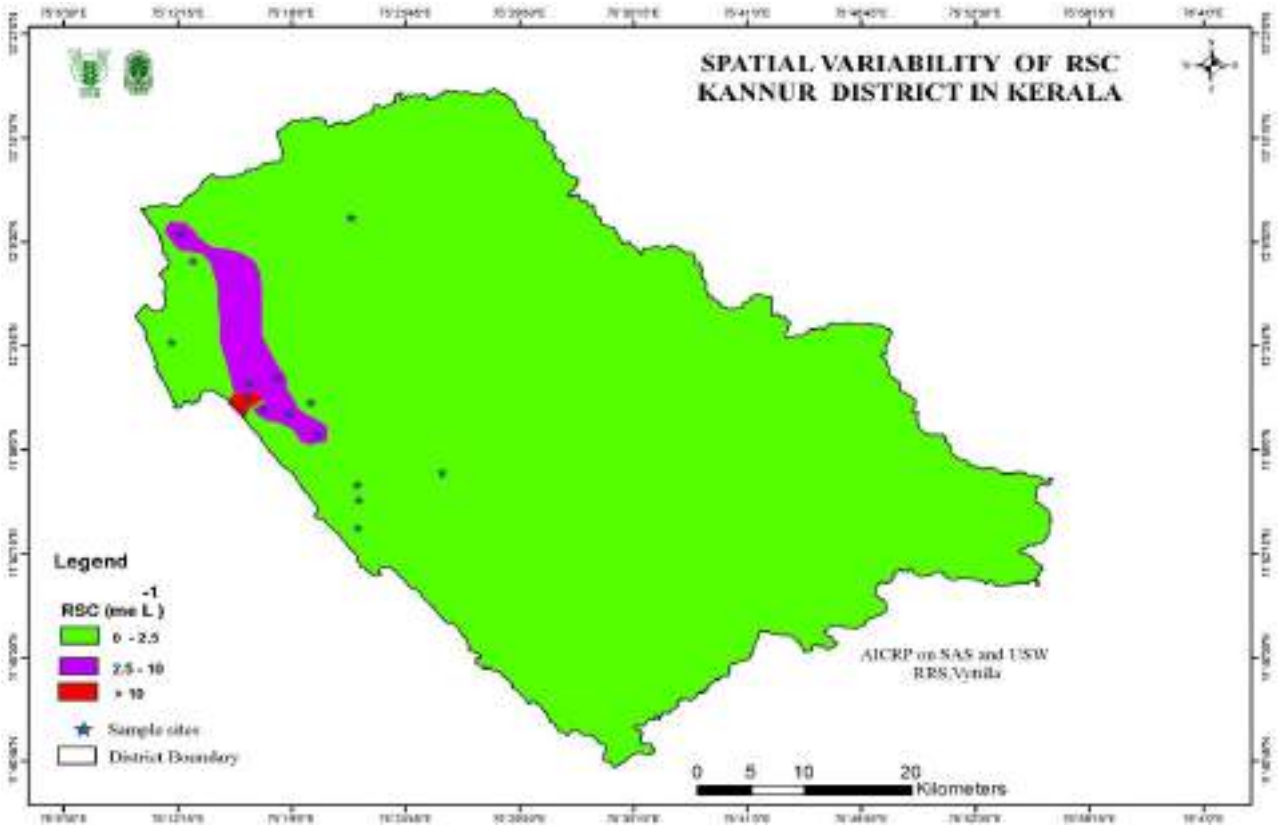

Fig 13d: Spatial variability of RSC of Kannur district

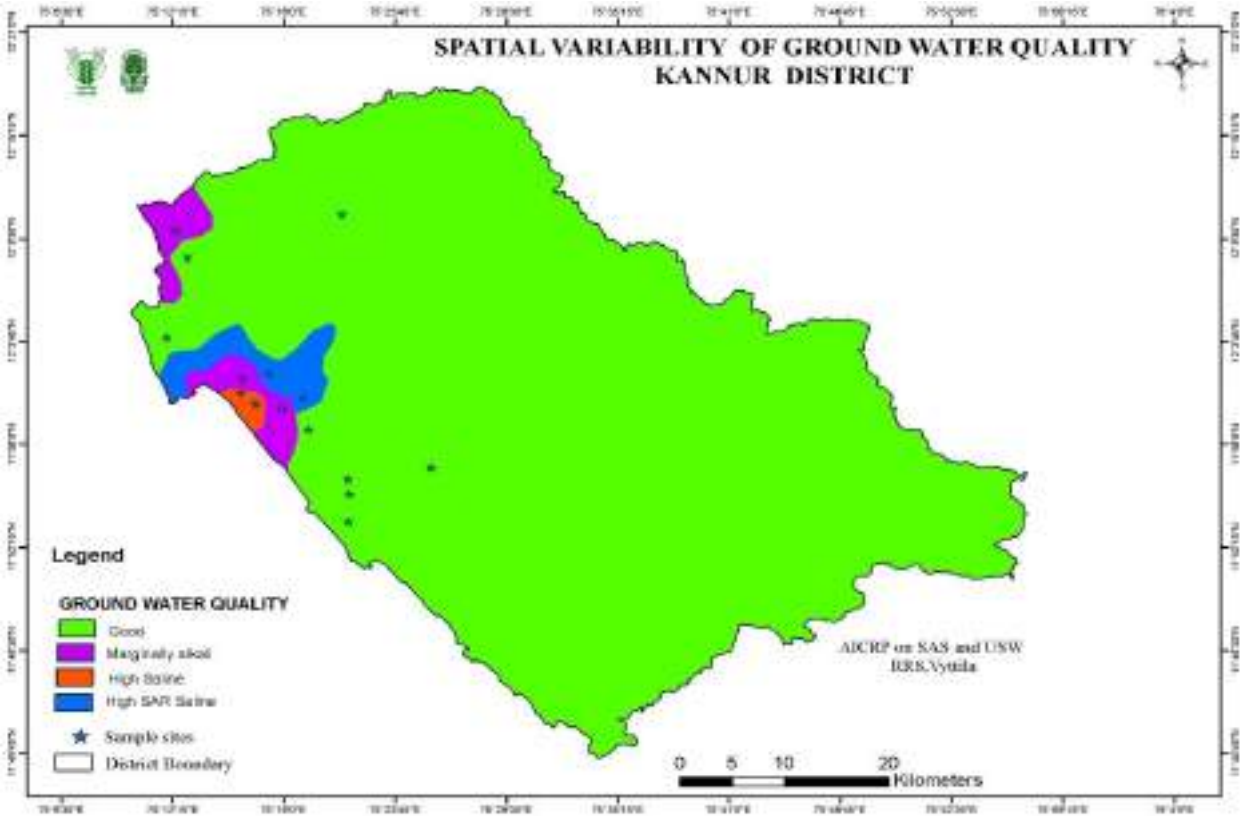

Fig 13e. Spatial distribution of ground water quality for irrigation purpose for Kannur district

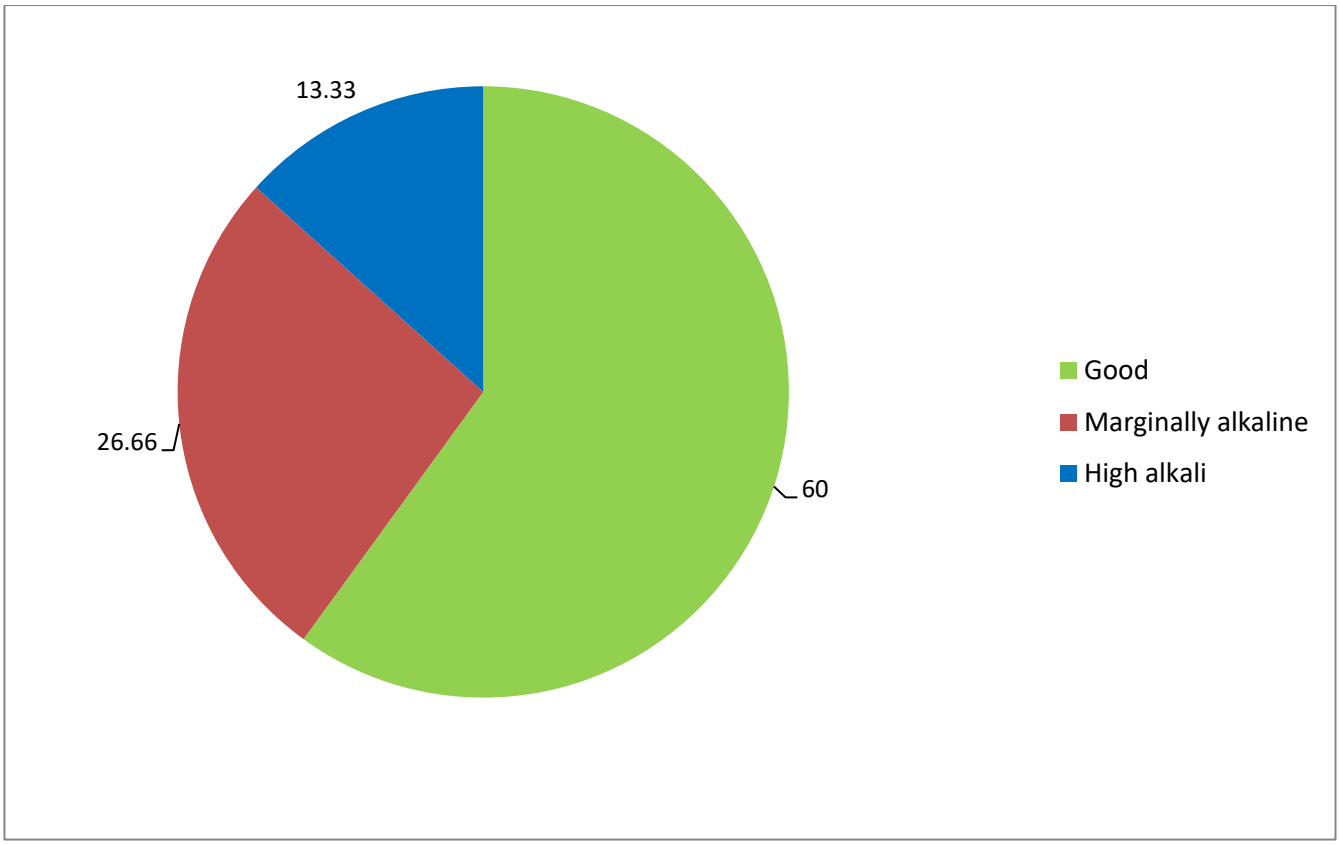

Fig 13f. Groundwater quality distribution in Kannur district

Chapter XV

Ground water quality of Kasargod district

The Kasargod district is located in Kerala State's farthest north. Kasargod has an average elevation of 19 metres and is situated at 12.5°N 75.0°E. (62 feet). The geography of Kasaragod can be summed up as lowlands bordering the sea on the west, an undulating section of midland, and the forested highlands near the Western Ghats on the east. The groundwater extraction stage of the district is 79.64 % and three blocks namely, Kanhangad, Karadka, Manjeswar of the district are semi-critical Kasaragod is critical with stage of groundwater development between 60 to 85% (*CGWB, 2019).

A total of twenty six ground water samples were collected from Kasargod district. The location map of the sampling points is presented in Fig 14a. Out of the total ground water samples collected, 76.92 % and 23.07 % fall under good and marginally alkaline categories of irrigation water quality respectively. The spatial variability maps for EC, SAR, RSC and ground water quality of Kasargod district is depicted in Fig. 14b, 14c, 14d, 14e and 14f respectively.

Table 17: EC, SAR, RSC and ground water quality of Kasargod district

Sl. No.	Location	EC	SAR	RSC	Type of Groundwater (As per CSSRI Classification)
		dS/m	$(mmol\ l^{-1})^1$	meq/l	
1	Mogral	0.12	0.61	0.86	Good
2	Melparamba	0.24	1.38	1.21	Good
3	Mavungal	0.06	0.86	1.18	Good
4	Bekal	0.07	0.8	1.01	Good
5	Trikaripur	0.04	0.77	1.48	Good
6	Thoyammel	0.15	0.43	0.79	Good
7	Elambachi	0.2	0.98	2.1	Good
8	Chamundikunnu	0.12	0.89	1.62	Good
9	Kovval	0.11	0.72	1.45	Good
10	Udinoor central	0.09	0.51	1.63	Good
11	Uppala	0.16	1.01	3.71	Marginally alkali
12	Kallikkadavu	0.08	0.87	0.53	Good
13	Anangoor	0.23	0.55	4.34	Marginally alkali
14	Pullur	0.05	0.92	1.04	Good
15	Kannadipara	0.06	0.83	1.17	Good
16	Udma	0.08	0.7	2.72	Marginally alkali
17	Kasargod	0.27	0.8	0.83	Good
18	Kanhangad coast	0.19	0.35	2.07	Good
19	Putheriyadukkam	0.08	0.55	1.05	Good
20	Nileshwar	0.25	0.28	2.87	Good
21	Kanhangad town	0.2	0.85	2.56	Good
22	Pannikunnu	0.21	0.62	1.82	Good
23	Coa, Padanakkad	0.23	0.29	1.46	Good
24	Cpcri, kasargod	0.08	0.64	0.8	Good
25	Rars, pilicode	0.11	0.82	4.97	Marginally alkali
26	Kannankai	3.8	10.28	0	Good

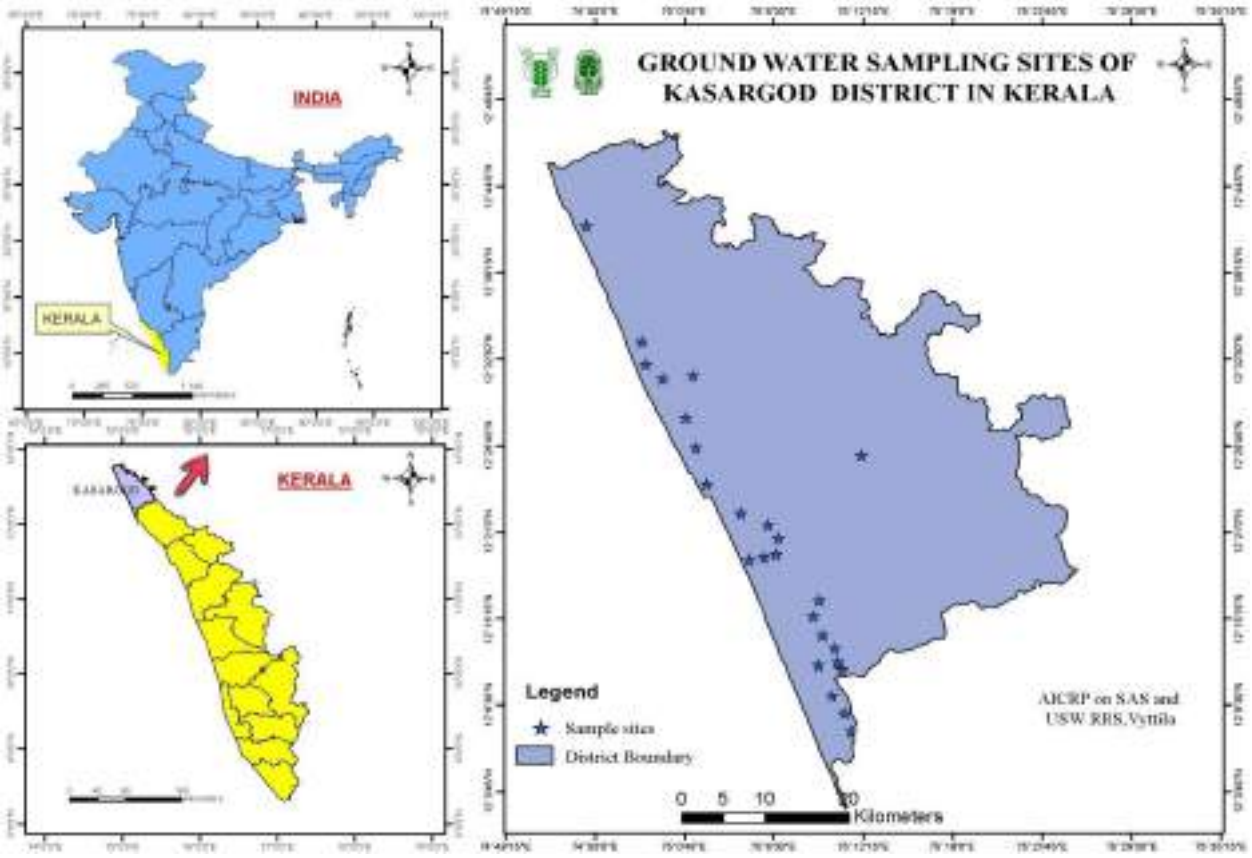

Fig 14a: Ground water sampling sites of Kasargod district

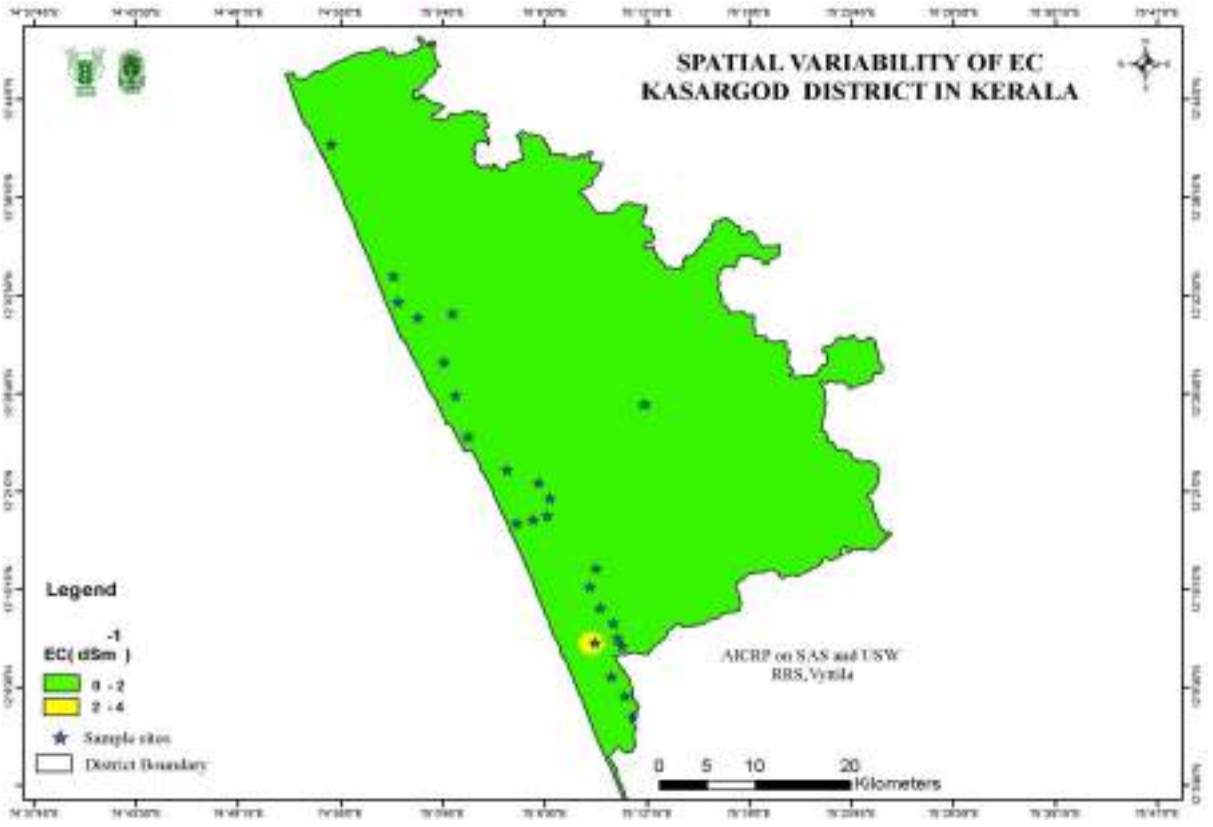

Fig 14b: Spatial variability of electrical conductivity of Kasargod district

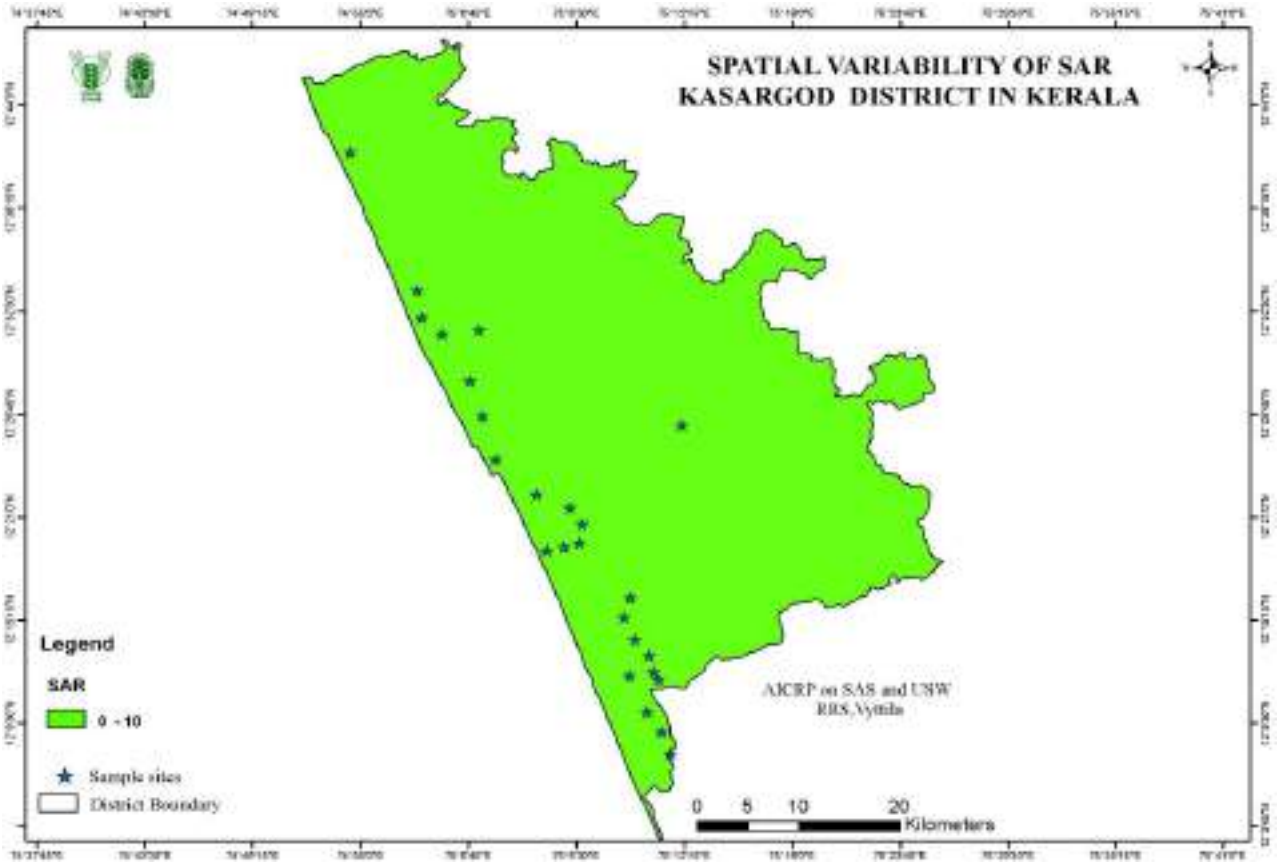

Fig 14c: Spatial variability of SAR of Kasargod district

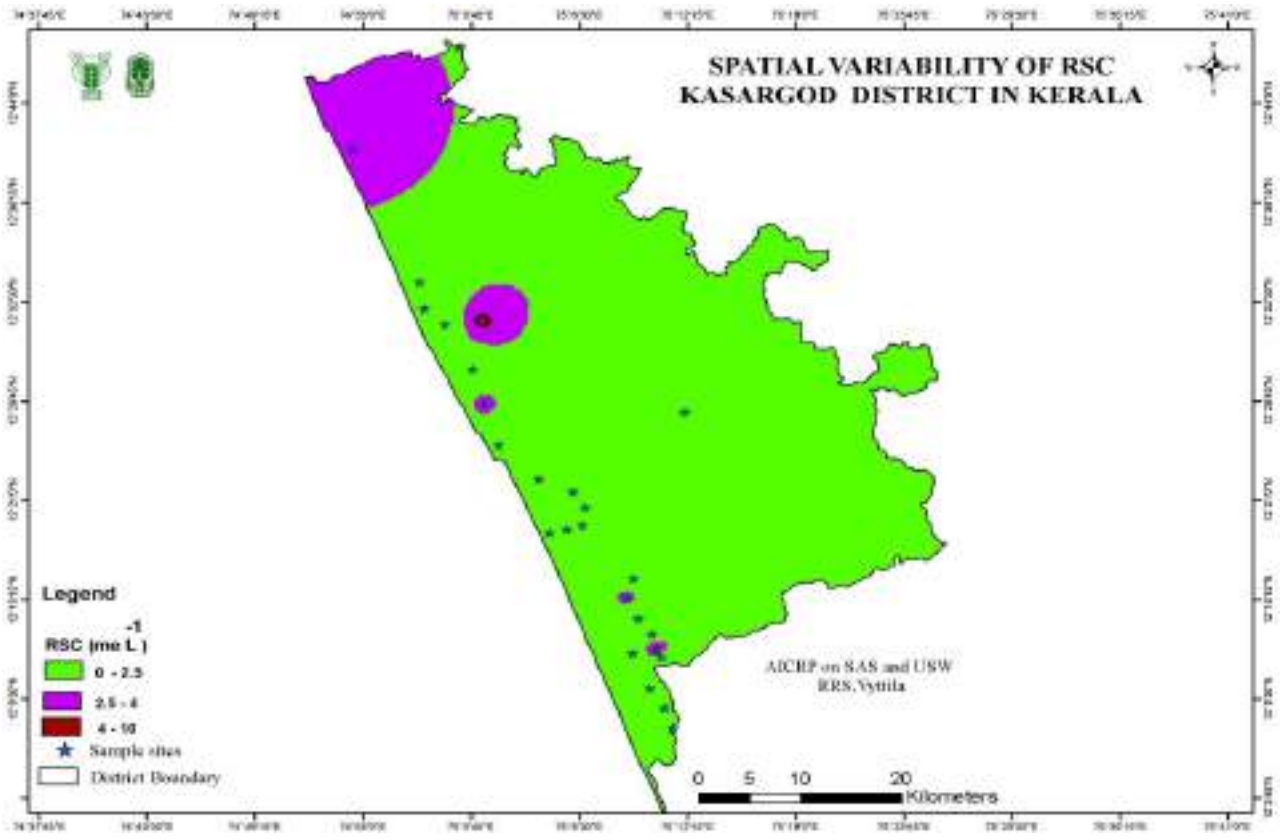

Fig 14d: Spatial variability of RSC of Kasargod district

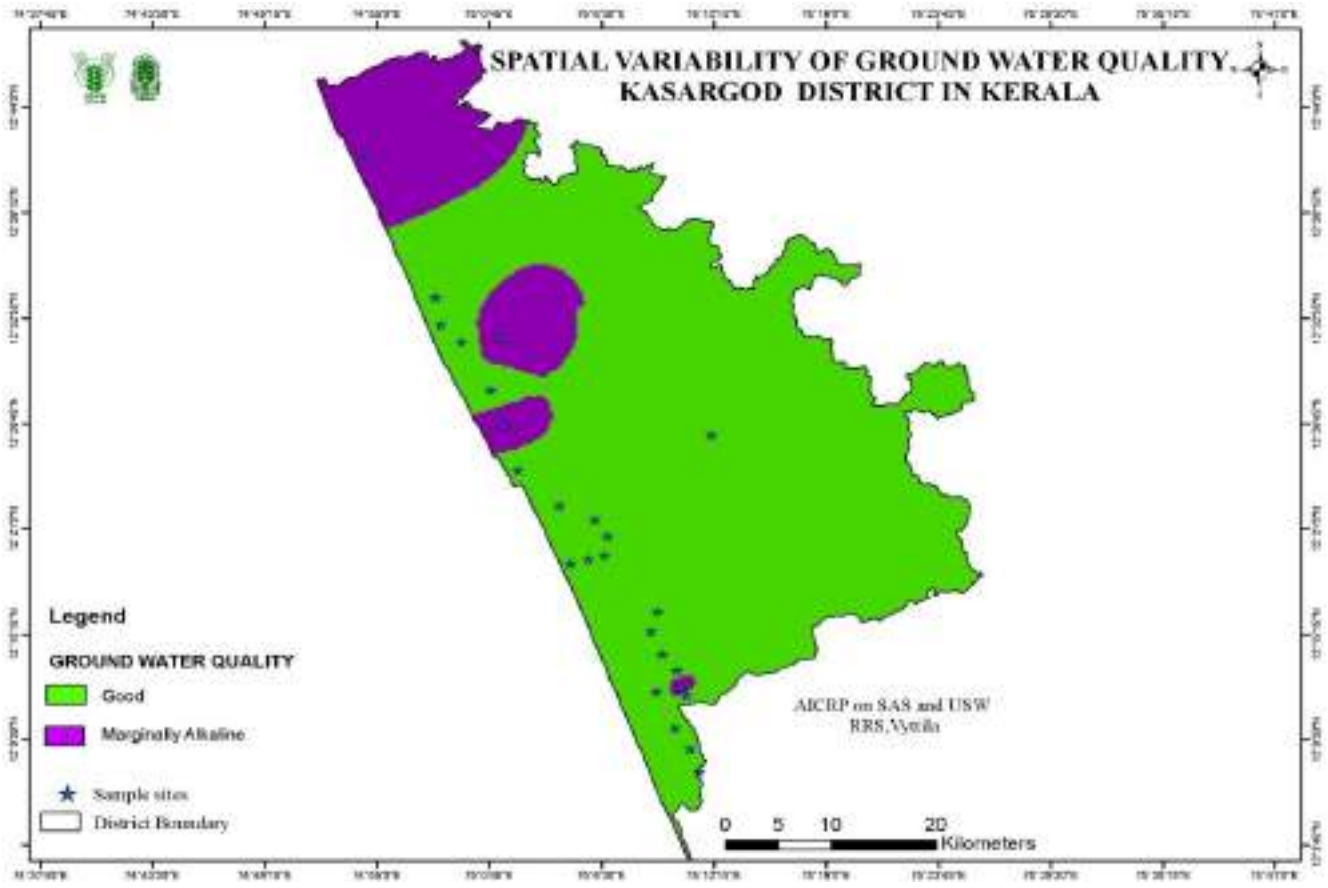

Fig 14e. Spatial distribution of ground water quality for irrigation purpose for Kasargod district

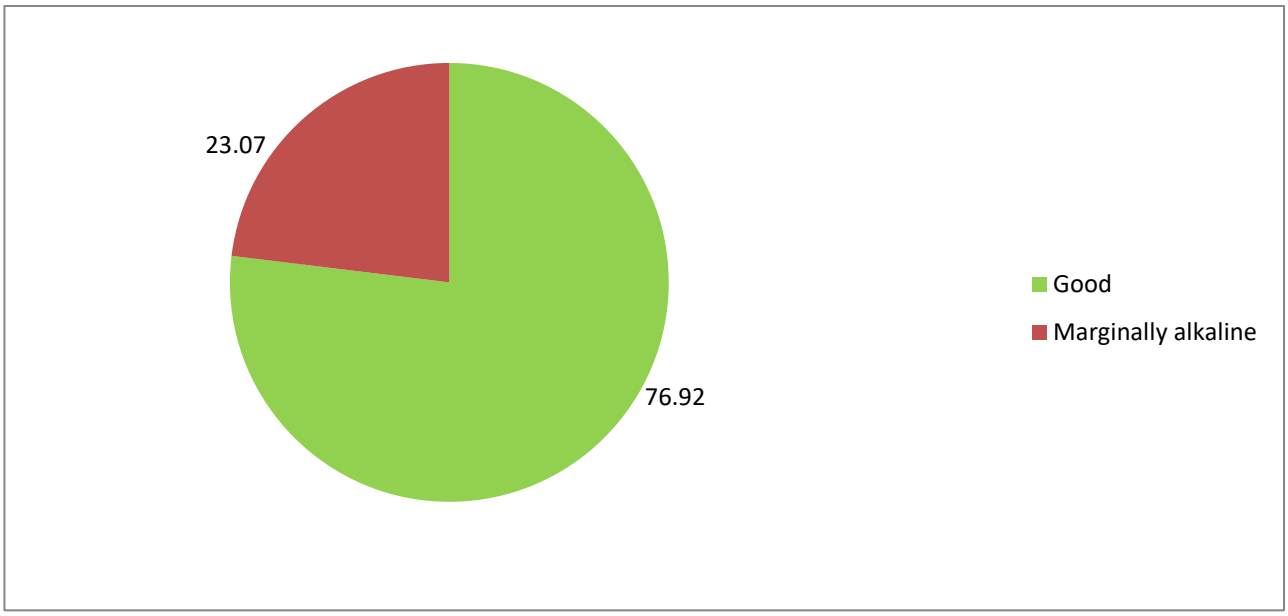

Fig 14 f. Groundwater quality distribution for irrigation purpose in Kasargod

Chapter XVI

Groundwater quality for Irrigation Purpose for State of Kerala

The data on ground water samples of 14 districts of Kerala revealed some of the general observations.

Out of 350 samples of ground water analyzed, 305 were in good category, four each in marginally saline and saline category respectively. Twenty five samples were marginally alkaline, 10 samples were high SAR saline and two samples were alkali in nature (fig. 16a, 16b, 16c, 16d). As a whole in Kerala, 87.15 %, 1.14 %, 1.14 %, 2.86 %, 7.14 % and 0.57 % fall under good, marginally saline, saline, high SAR saline, marginally alkaline and alkaline category of ground water quality respectively (Fig 15). The ground water data of Idukki, Palakkad and Wayanad districts obtained from Central Ground Water Board revealed that all the water samples of the three districts were grouped under good quality for irrigation. It might be due to absence of sea shore and back water in those districts. The major reason for salinity/alkalinity in a small percent of samples is due to saline water intrusion from back waters. The presence of sea coast and back water lagoons is responsible for the poor quality of water in some locations near the sea/backwater

Table 18 : Classification of ground water samples in Kerala for irrigation

Sl No.	District	Good (%)	Marginally saline (%)	Saline (%)	High SAR saline (%)	Marginally alkali (%)	Highly alkaline (%)
1	Thiruvanathapuram	89.47	2.63	7.89			
2	Kollam	95.23	4.76				
3	Pathanamthitta	100.00					
4	Kottayam	82.35	11.76	5.88			
5	Alappuzha	87.50				7.14	5.35
6	Ernakulam	75.86			20.68	3.40	
7	Idukki	100.00					
8	Thrissur	93.93			6.06		
9	Palakkad	97.00				3.00	
10	Kozhikode	73.68				26.31	
11	Kannur	60.00				26.66	13.33
12	Wayanad	100.00					
13	Malappuram	35.00				65.00	
14	Kasargod	73.07	3.86			23.07	

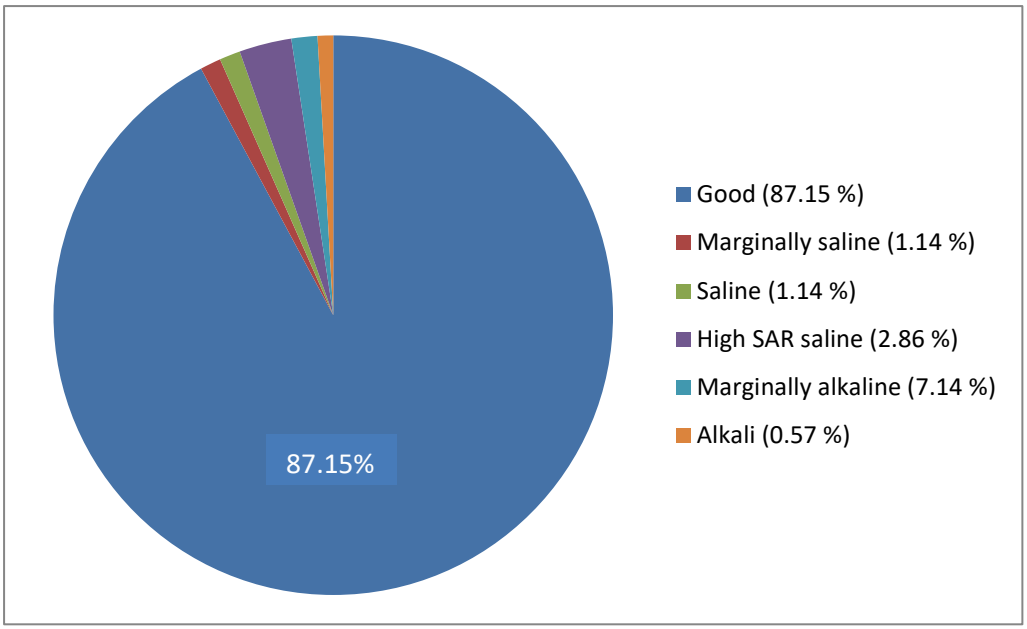

Fig 15. Classification of ground water samples in Kerala for irrigation

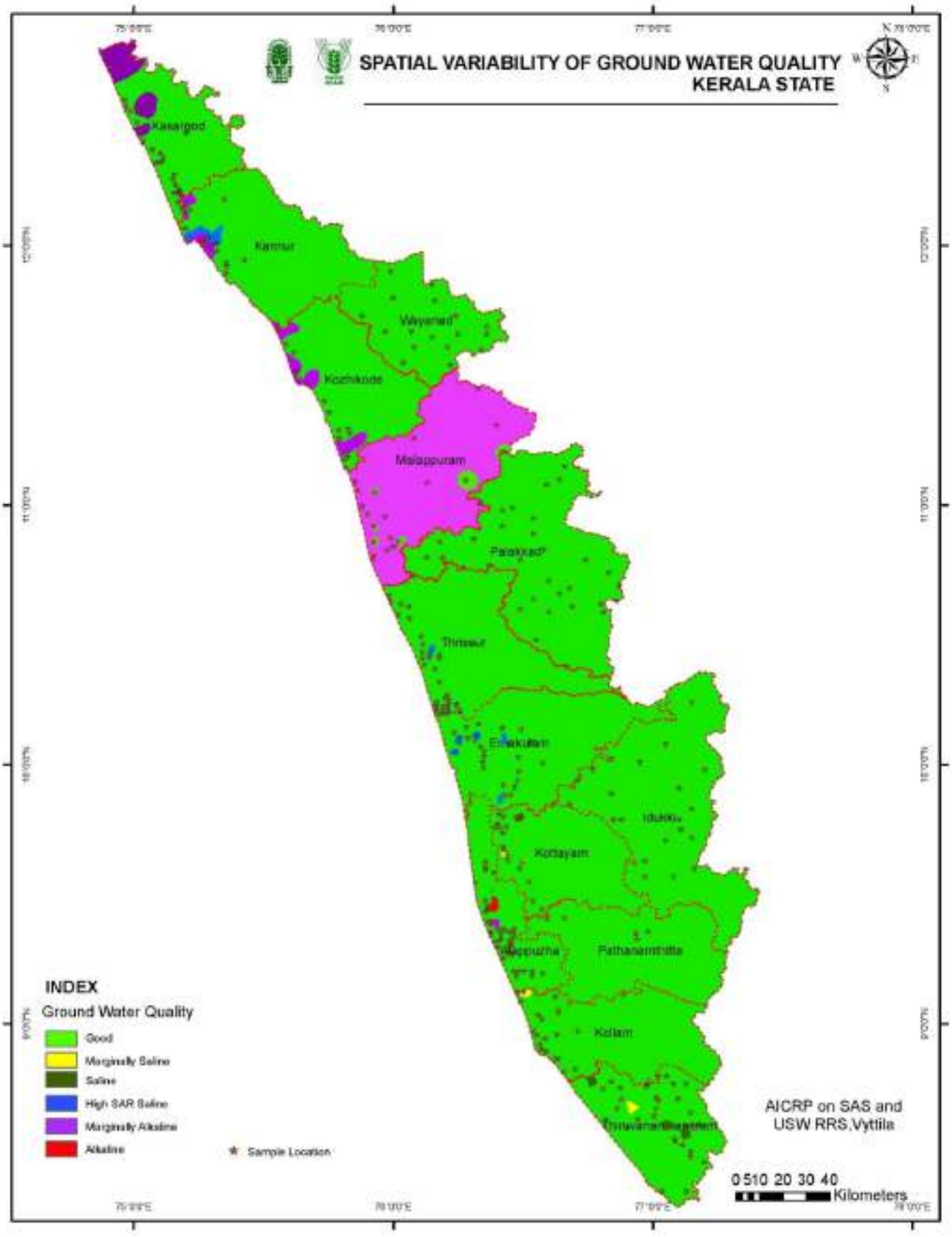

Fig 16a. Spatial variability of ground water quality in Kerala state

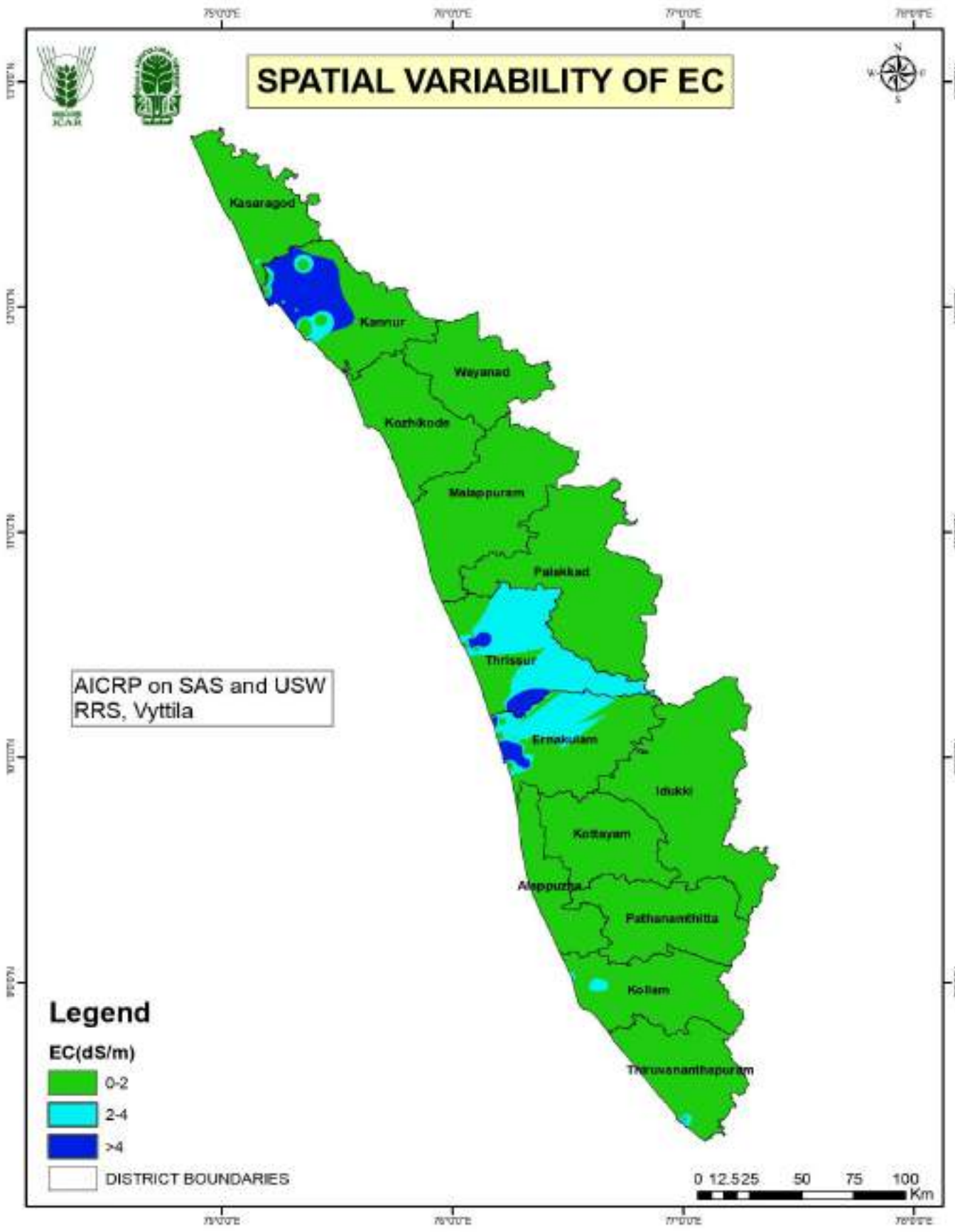

Fig 16b. Spatial variability of EC in Kerala state

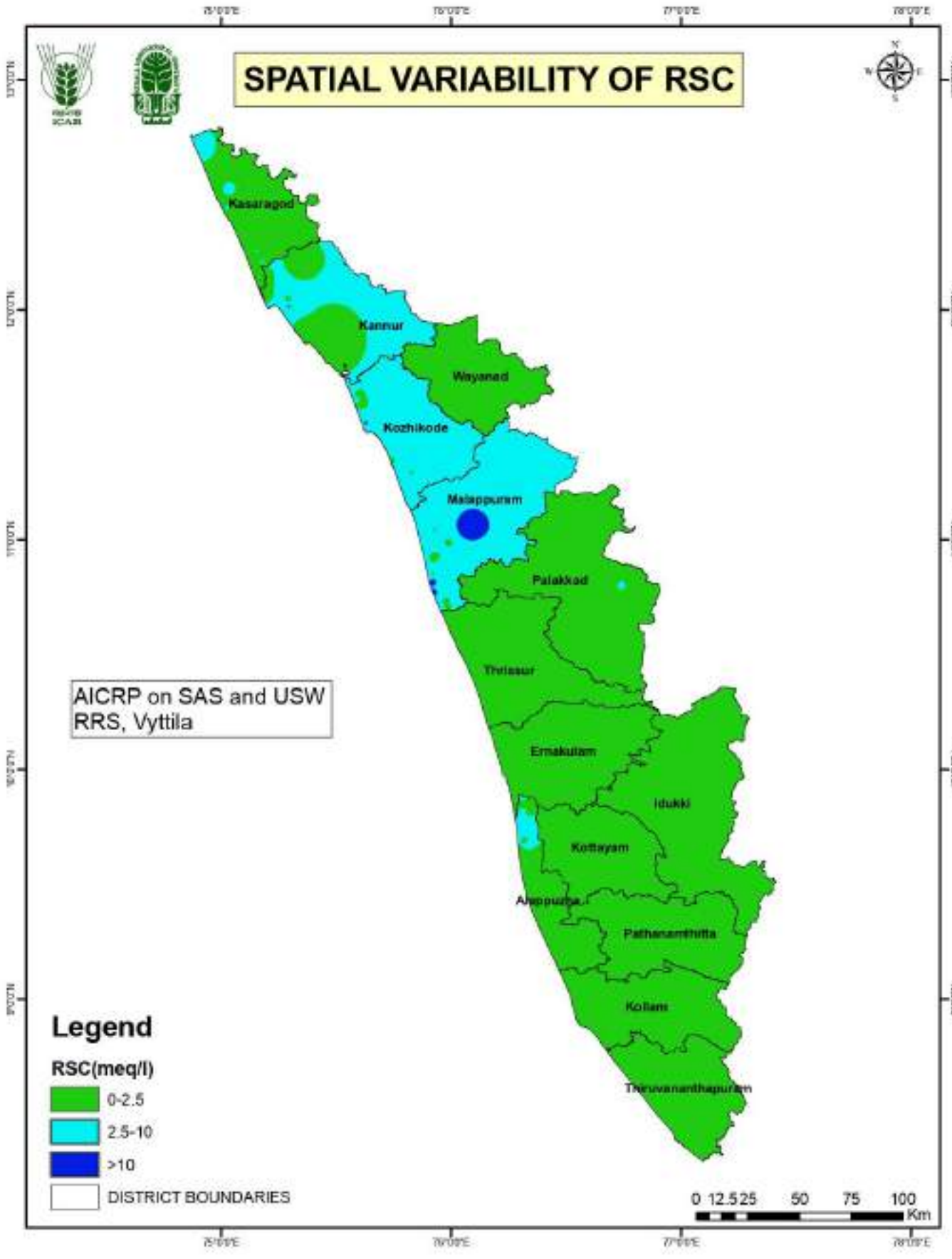

Fig 16c. Spatial variability of RSC in Kerala state

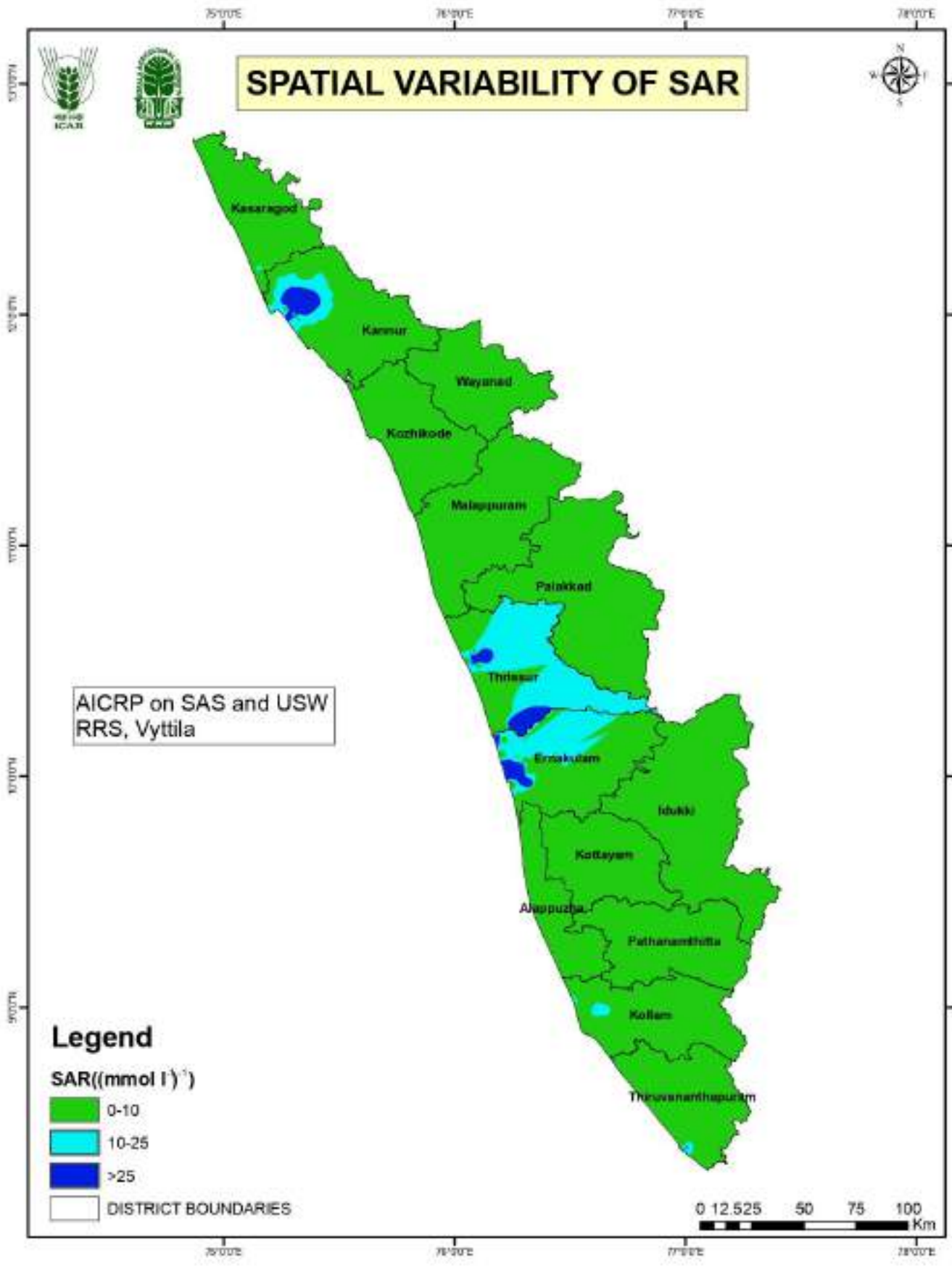

Fig 16d. Spatial variability of SAR in Kerala state

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