GROUNDWATER QUALITY IN COASTAL DISTRICTS OF TAMIL NADU

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FOREWORD

The quality of ground water is at risk due to over exploitation of ground water and sea water intrusion particularly in coastal districts of Tamil Nadu. Coastal districts are always under threat due to excessive pumping of ground water, which induces a flow of the water towards the inland. Availability of fresh water has always been a prime consideration in fostering the socio-economic growth of the people. Rapid urbanization coupled with industrialization has resulted in increased demand of ground water. Dependence on ground water is increasing continuously in order to supplement the domestic, agricultural and industrial requirements. In the last two decades, there is a paradigm shift from development to management of ground water.

AICRP on "Management of salt affected soils and use of poor quality irrigation water in Agriculture" being operated at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirapalli over the years has generated enormous data on various aspects of ground water. This data has been utilized to prepare ground water quality maps depicting their extent and characteristics.

This book deliberates ground water quality in Kanyakumari, Tirunelveli, Thoothukudi, Pudhukottai, Ramanathapuram, Nagapattinam, Thiruvarur, Thanjavur, Cuddalore, Villupuram, Thiruvallur and Chengalpattu district of Tami lNadu and other suitable strategies for proper management of poor quality water in coastal districts of Tamil Nadu. This book will be useful to scientists, planning and development agencies and all those interested in management of soils and ground water in salt affected environment for formulating scientifically viable implementable strategies for efficient management of ground water resources in coastal districts of Tamil Nadu.

The scientists involved in ground water quality survey in coastal districts of Tamil Nadu deserve appreciation for their efforts.

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PREFACE

Groundwater water utilization has increased significantly during the last two decades. The unplanned and indiscriminate use of this vital resource has resulted in declining water level and water quality deterioration in certain areas. The apparent stress on groundwater resources is more often a management issue at this need to be addressed in a holistic manner for its long-term sustainability through an integrated approach. Groundwater quality mapping is an essential step towards the effective management of groundwater resources in coastal districts of Tamil Nadu. The book entitled "Ground water quality in coastal districts of Tamil Nadu" is a step towards achieving the ultimate goal of district wise management of groundwater resources in coastal areas of Tamil Nadu state.

We thank the team members of All India Coordinated Research Project on Salt affected soils and use of poor quality irrigation water in Agriculture at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirapalli for their efforts to bring out this book containing data and information pertaining to various aspects of Groundwater quality in coastal areas of Tamil Nadu. We are sure this book will be of immense use to planners, policy makers, researchers and user involved in groundwater sector.

AUTHORS

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CONTENT

1. INTRODUCTION

India has a very long coast line of 7500 km length which is the backbone of its national economy. Three out of the four metros, the major industrial hubs, about one fourth of the country's population and the most fertile agricultural land are situated in this area. More than 100 rivers, including 14 major and 44 medium rivers discharge into the sea along the entire length of the coast. The coastal zone is the most industrialized area in the country. This is the region where natural calamities like tsunami; cyclones *etc.,* frequently affect the normal life. The coastal region occupies some of the most potential aquifer systems of the country also. The coastal aquifers of India ranges from that of Jurassic to recent and is seen almost all along the coast right from Gujarat to West Bengal. Some of the aquifers especially the Tertiary to recent ones are highly potential and are developed extensively. The small island aquifers of Lakshadweep are highly sensitive since fresh water is seen floating as a thin lens over sea water here. The problems of ground water quality are also complex in the coastal area. Some of them are sea water intrusion, salinity from the aquifer (in situ) material, groundwater pollution, global warming and its impact on entire coastal ecosystem including coastal aquifers.

Ground water is an essential and vital component of our life support system. The ground water resources are being utilized for drinking, irrigation and industrial purposes. There is growing concern on deterioration of ground water quality due to geogenic and anthropogenic activities. The coastal region of India presents a variety of geomorphological units

and landforms developed through several factors like rock types, tectonics, topography, land cover, climate and the fluvial, marine and aeolian actions. These processes also evolved the coastline and left their imprints as major geomorphic features. Various geomorphologic units such as deltas, rocky cliffs, marine deposits, islands, gulfs, lagoons, tidal creeks, beach ridges *etc.,* are encountered along the East and West coasts of the country. The coast line of India covers nine states and the Union Territories of Puducherry and Daman and Diu. Gujarat has the largest share of coast line, followed by Andhra Pradesh. The configurations of East and West coasts differ considerably from each other because of various reasons.

Overexploitation of groundwater and intensive irrigation in major canal commands has posed serious problems for groundwater managers in India. Depletion of water tables, saltwater encroachment, drying of aquifers, groundwater pollution, water logging and salinity, *etc.,* are major consequences of overexploitation and intensive irrigation. It has been reported that in many parts of the country the water table is declining at the rate of 1-2 m/year. At the same time in some canal commands, the water table rise is also reported as result of poor water management in irrigation command. Deterioration in ground water quality by various causes is another serious issue. Increased arsenic content in shallow aquifers of West Bengal reported recently has created panic among the ground water users. Summed together, all these issues are expected to reduce the fresh water availability for irrigation, domestic and industrial uses. If this trend continues unchecked, India is going to face a major water crisis in the

near future. Realizing this, the Government of India has initiated several protective and legislative measures to overcome the ground water management related problems but, due to the lack of awareness and political and administrative will, none of the measures has made any significant impact (Singh *et al.*, 2002).

The utilizable surface water and replenishable ground water resources are of the order of 690 BCM and 432 BCM, respectively. Thus, the total water resources available for various uses, on an annual basis, are of the order of 1122 BCM. The per capita availability of water in India was 1869 cubic meters in 2001; it will be around 1341 /year in 2025 and 1140 cubic meters/year in 2050. The country is approaching to water starved category as per capita water availability is close to 1000 Cubic m/year (GGWB, 2013). Ground water also contributes towards drinking water supply and other various sectors. The rapid development of ground water resources for varied usage has contributed in expansion of irrigated agriculture, overall economic development and in improving the quality of life in India.

In the present assessment, the total annual ground water recharge has been estimated as 432 BCM. Keeping an allocation for natural discharge, the annual extractable ground water resource is 393 BCM. The total current annual ground water extraction (as in March, 2017) is 249 BCM. The average stage of ground water extraction for the country as a whole works out to be about 63%. The extraction of ground water for various uses in different parts of the country is not uniform. Out of the total 6881 assessment units (Blocks/ Mandals/ Talukas/ Firkas) in the country, 1186 units in various States

(17%) have been categorized as 'Over-Exploited' indicating ground water extraction exceeding the annually replenishable ground water recharge. In these areas the percentage of ground water extraction is more than 100 percent. In addition, 313 units (5%) are 'Critical', where the stage of ground water extraction is between 90-100%. There are 972 semi-critical units (14%), where the stage of ground water extraction is between 70% and 90% and 4310 assessment units (63%) have been categorized as 'Safe' where the stage of Ground water extraction is less than 70%. Apart from this, there are 100 assessment units (1%), which have been categorized, as 'Saline' as major part of the ground water in phreatic aquifers is brackish or saline CGWB (2019).

Total Annual Groundwater recharge for the state of Tamil Nadu has been assessed as 20.22 bcm and Annual extractable GroundWater resources as 18.20 bcm. The Annual GroundWater extraction is 14.73 bcm and Stage of Ground Water Extraction as 81%. Out of 1166 firkas, 462 have been categorized as 'Over Exploited', 79 as 'Critical', 163 as 'Semi-Critical', 427 as 'Safe' and 35 firkas have been categorized as 'Saline'. As compared to 2013 estimate, Total Annual Groundwater recharge has decreased from 20.65 to 20.22 bcm and the annual ground water extraction has increased from 14.36 to 14.73bcm. Consequently, there is an increase in the stage of ground water extraction from 77% to 81%. It is a very serious matter in view of most the area of the state has hard rock geology CGWB (2019). Tamil Nadu state is underlined by diverse hydro-geological formations, nearly 73 per cent of the state is occupied by hard rocks, the semi consolidated and consolidated formations are mainly confined in the eastern

part which is the coastal tract. In the hard rock area, ground water is mainly developed through dug wells and dug cum bore wells tapping the weathered zone, the yield of open wells vary from 1-3 lps, whereas in dug wells tapping soft rocks including sedimentary formations, the yield is up to 5 lps (CGWB, 2019).

Ground water quantity and quality are being affected due to over-exploitation of ground water. The Central Ground Water Board (CGWB) has provided spatial distribution of Arsenic (mg/l), EC (micro-Siemens/cm), Fluoride (mg/l), Iron (mg/l) and Nitrate (mg/l) for the country. It is significant contribution and it is quite useful as drinking water issues are concerned. 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. By using the data base available with different agencies in Tamil Nadu *viz.,* State Ground and Surface Water Resources Data Centre (SG & SWRDC) and Soil Testing Laboratories, Department of Agriculture and data generated by Tiruchirappalli centre, groundwater quality map

for the state of Tamil Nadu was prepared by AICRP on "Management of Salt Affected Soils and Use of Saline water in Agriculture", ADAC&RI, Tiruchirappalli which was released during the year 2003-04. It is shown in Fig. 1. (Annual Report, 2003-04). However, the map is good for macro level planning as its scale is 1:250,000. As per map, 73.2% of water samples were of of good quality, 21.1% moderately saline and 5.7% were saline. Micro-level planning for judicious use of ground water for irrigation purpose, mapping of quality parameters at scale of 1: 50,000 is required and the Tiruchirappalli centre undertook groundwater quality survey, characterization and mapping in coastal districts of the state where groundwater quality has remained a serious issue and it affected crop yields adversely. The groundwater quality classification was performed as per criteria mentioned in Table 1.

Table 1: Grouping of low-quality ground waters for irrigation in India

Water quality	**EC_{iw} (dS/m)**	**SAR_{iw} (m mol/L)**	**RSC (me/L)**
A. Good	<2	<10	<2.5
B. Saline			
i. Marginally saline	2-4	<10	<2.5
ii. Saline	>4	<10	<2.5
iii. High-SAR saline	>4	>10	<2.5
C. Alkali water			
i. Marginally alkali	<4	<10	2.5-4.0

ii. Alkali	<4	<10	>4.0
iii. Highly alkali	Variable	>10	>4.0
D. Toxic water	The toxic water has variable salinity, SAR and RSC but has excess of specific ions such as chloride, sodium, nitrate, boron, fluoride or heavy metals such as selenium, cadmium, lead and arsenic *etc.*,		

Source: AICRP (1989)

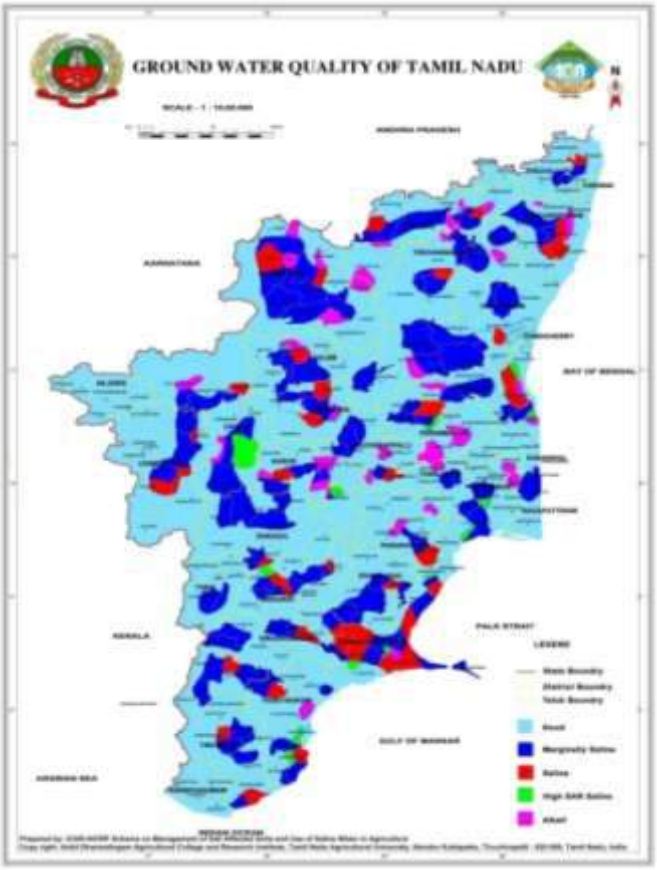

Fig.1. Ground water quality Map of Tamil Nadu (Annual Report, 2003-04-Tiruchirappalli)

The coastline of Tamil Nadu starts from from Chengalpet district in the North to the Kanyakumari district in the South. The coastal area varies between few km to about 30 km. The low lying areas and estuaries are also found close to the coast. Tiruchirappalli centre completed ground water sampling and characterization work for 12 coastal districts of Tamil Nadu *viz.,* Cuddalore, Nagapattinam, Thiruvarur, Thanjavur, Ramanathapuram, Thiruvallur, Villupuram, Pudukottai, Chengalpattu, Tirunelvelli, Thoothukudi and Kanyakumari (Fig.2). Ground water quality maps for these districts are ready and can be used by researchers, irrigation water managers and farmers for better and efficient use of poor quality ground water for irrigation purpose.

1. Kanyakumari
2. Tirunelvelli
3. Thoothukudi
4. Ramanathapuram
5. Pudukottai
6. Thanjavur
7. Nagapattinam
8. Thiruvarur
9. Cuddalore
10. Villupuram
11. Chengapattu
12. Thiruvallur

Fig.2. Coastal districts of Tamil Nadu

2. GROUND WATER QUALITY OF COASTAL DISTRICTS OF TAMIL NADU

Details of survey, analysis, characterization of groundwater samples and classification on basis of irrigation quality criteria, as given in Table.1 for 12 coastal districts of Tamil Nadu are provided in following sections.

2.1. Kanyakumari District

Kanyakumari is the Southernmost district of Tamil Nadu. The district lies between 77^{o} 15' and 77^{o} 36' of the Eastern Longitudes and 8^{o} 03' and 8^{o} 35' of the Northern Latitudes. The district is bound by Tirunelveli district on the North and the East. The South eastern boundary is the Gulf of Mannar. On the South and the South West, the boundaries are the Indian Ocean and the Arabian Sea. On the west and NorthWest, it is bound by Kerala. With an area of 1672 sq.km it occupies 1.29% of the total area of Tamil Nadu. It ranks first in literacy among the districts in Tamil Nadu. The Kanyakumari district comprises of 2 revenue divisions, 4 revenue taluks, 18 firka and 188 revenue villages

Rainfall, Climate and Geo-hydrology

The Kanyakumari district received the rain under the influence of both South West and North West Monsoons. The South West Monsoon chiefly contributes to the rainfall in the district. Most of the precipitation occurs in the form of cyclonic storms caused due to the depressions in Bay of Bengal. The normal annual rainfall over the district varies from about 826 to 1456 mm. It gradually increases towards

West, North and North West and attains a maximum around Thackalay. The highest humidity is generally recorded in May with the value of 95 percent whereas the minimum of 45 percent is recorded during February. The maximum wind speed of 17.74 km/hr is recorded during August and the minimum wind speed of 5.53 km/hr is recorded during December. Wind velocity is low from October to December. The sun shine hours per day are the maximum during March-April. The maximum of 12.74 hrs/day has been recorded during April and the minimum of 5.74 hrs/day is recorded during November. The temperature data indicate higher and lower temperatures prevailed during monsoon period. The average maximum temperature during May is 35.93^{o} C. The average minimum temperature recorded is 23.85^{o} C during January. The annual mean minimum and maximum temperatures are 23.78 and 33.95^{o} C, respectively. The predominant geological formation of Kanyakumari district is mainly on Recent Alluvium, Warkalai Sandstones, Peninsular Gneisses Charnockites, Khondalites, Granites and Pegmatites. The hydrogeology is mainly based on major water bearing formation *viz.,* Warkalai Sandstones, Coastal sand and weathered and fractured Charnockites, Khondalites and Granites gneisses. The pre-monsoon depth of ground water table is ranged from 2.66 to 20.06 m bgl (May, 2006) and post-monsoon depth of ground water table is ranged from 1.19 to 14.57 m bgl (January, 2007). The long term groundwater level trend was decreased from the year 1996 to 2007. The rate of minimum and maximum level of ground water level trend was falling on 0.0417 and 0.6789 m/year, respectively whereas

the rise on maximum and minimum of 0.1119 and: 0.5744 m/year (Balachandran, 2008).

Survey and characterization of ground water of Kanyakumari District for irrigation

To characterize the ground water quality of Kanyakumari District, 215 water samples (open and bore wells) were collected from different parts of Kanyakumari district based on GPS location. The water samples were analyzed for pH, EC, cations (Ca, Mg, Na and K) and anions (CO_3, HCO_3, Cl^- and SO_4). Quality parameters like SAR and RSC were calculated. Classification of water quality is done based on EC, SAR and RSC values as suggested by CSSRI, Karnal (Table.1). Kanyakumari District has 8 blocks *viz*., Thovalai block, Kuruthencode block, Munchirai block, Thiruvattar block, Kiliiiyur block, Thucklay (Kozhipulai) block, Agastheeswaram block and Rajakamangalam block. The ranges for pH, ground water (EC), Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) for these blocks are given in Table 2.

Table 2: Quality of ground waters in different blocks of Kanyakumari District

Name of the Block	pH			EC (dSm^{-1})			RSC (meq. l^{-1})			SAR		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Agasthee swaram	7.35	8.56	7.95	0.6	5.59	1.89	Nil	1.98	0.71	1.41	13.4	5.7

Rajakamangalam	7.52	8.24	8.02	0.2	5.91	1.25	Nil	1.12	0.15	0.12	11.0	4.04
Thucklay (Kozhipulai)	7.46	8.64	8.03	0.25	1.73	0.86	Nil	0.25	0.02	0.81	4.73	2.07
Killiyur	7.17	8.23	7.91	0.12	6.83	1.14	Nil	1.55	0.32	0.24	8.46	1.58
Thiruvattar	7.85	8.36	8.10	0.08	3.61	0.73	Nil	1.15	0.34	0.03	3.87	1.23
Munchirai	7.57	8.23	7.97	0.48	3.21	1.34	Nil	1.25	0.42	0.92	4.28	2.23
Kuruthencode	7.97	8.51	8.16	0.12	4.16	3.70	Nil	1.98	0.75	0.15	5.85	2.60
Thovalai	7.37	8.62	8.19	2.56	5.71	4.36	Nil	1.98	0.97	2.58	7.54	5.35

In general, the major distribution of cations followed in the order of Ca^{2+}> Mg^{2+}> Na^{+}> K^{+} in Thovalai, Kuruthencode, Thiruvattar, Kiliiiyur, and Agastheeswaram whereas in the

remaining blocks the distribution of cations followed as Na^{+}> Ca^{2+}> Mg^{2+}> K^{+} in Rajakamangalam and Munchirai and Ca^{2+}>Na^{+}>Mg^{2+}>K^{+} in Thucklay (Kozhipulai). With respect to the distribution of anions followed in the order of HCO_3^{-}> Cl^{-} > CO_3^{2-}> $SO_4^{2-}$the Thiruvattar, Kiliiiyur, Agastheeswaram, Rajakamangalam, Munchirai blocks whereas in the reaming blocks the distribution followed as CO_3^{2-}> HCO_3^{-}> Cl^{-}> SO_4^{2-} in Thucklay (Kozhipulai) and Kuruthencode and Cl^{-} > CO_3^{-} >HCO_3^{-}> SO_4^{2-} in Thovalai block (Table. 3).

Table 3: Cationic and Anionic distribution in ground water samples of Kanyakumari district

Blocks	Cationic order	Anionic order
Agastheeswaram	Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}
Rajakamangalam	Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}
Thucklay (Kozhipulai)	Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}	CO_3^{2-}> HCO_3^{-}> Cl^{-}> SO_4^{2-}
Killiyur	Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}
Thiruvattar	Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}
Munchirai	Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}
Kuruthencode	Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}	CO_3^{2-}> HCO_3^{-}> Cl^{-}> SO_4^{2-}
Thovalai	Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}	Cl^{-}> CO_3^{-}>HCO_3^{-}> SO_4^{2-}

Among the 8 blocks, the distribution of 100 % good quality ground water samples were observed in Thucklay block followed by Rajakkamangalm (89.7%), Agastheeswaram (80.0 %), Munchirai (81.25 %) and Thiruvattar blocks (80.95 %). The good quality water was absent in Thovalai block and almost 73.68 % of ground water samples were saline water. Marginally saline water is also seen in Thovalai block (26.32%), Thiruvarttar block (28.57 %), Munchirai (18.75 %)

and Killiyur block (16.66 %). High SAR saline water was found in Agastheeswaram (15%) and Rajakamangalam block only (10.3%). Alkali water was almost absent in all the blocks. Out of the total samples collected from Kanyalumari district, 73.02% is coming under good quality, 12.57% is marginally saline, 14.81% is saline water and 3.16 % is under high SAR saline categories

The distribution of water samples in different water quality classes (Table. 4) reveals that the samples of good quality underground irrigation water was found in almost all the blocks Thucklay (100 %), Rajakamangalam (89.7%) Munchirai (81.25%) Thiruvattar (80.95 %), Kuruthencode (73.7%) except Thovalai block. Thovalai block in Kanyakumari district is seen with saline water (73.68%) and marginally saline water (26.32%) (Fig.3). The spatial distribution of ground water quality categories is provided in Fig. 4.

Table 4: Water quality distribution (%) in Kanyakumari district

S. No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Agasthees waram	20	80.0	5.00	-	15.0	-	-	-
2.	Rajakama ngalam	39	89.7	-	-	10.3	-	-	-
3.	Thucklay (Kozhipulai)	39	100.0	-	-	-	-	-	-
4.	Killiyur	42	78.57	16.66	4.76	-	-	-	-
5.	Thiruvattar	21	80.95	28.57	19.05	-	-	-	-
6.	Munchirai	16	81.25	18.75	-	-	-	-	-
7.	Kuruthe	19	73.7	5.26	21.05	-	-	-	-

	ncode								
8.	Thovalai	19	-	26.32	73.68	-	-	-	
	Average	**215**	**73.02**	**12.57**	**14.81**	**3.16**	**-**	**-**	**-**

MS= Marginal Saline; HSS= High SAR Saline; MA= Marginal Alkali; HA= High Alkali

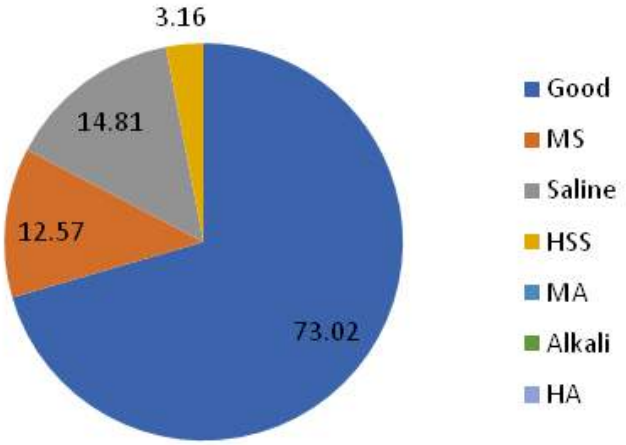

Fig. 3: Percent distribution of Ground water samples of Kanyakumari District

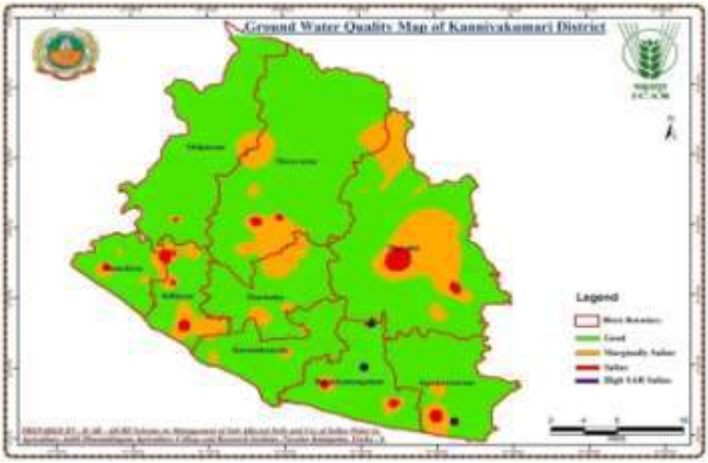

Fig. 4: Spatial distribution of ground water quality categories for Kanyakumari district

2.2 Tirunelvelli District

Tirunelveli is one of the coastal districts bounded on the North by Virudhunagar district, on the Southwest by the Kanniyakumari district, on the west by Western Ghats in Kerala state and on the East by Thoothukudi district. The district headquarters is located at Tirunelveli. Thamiraparani river, and Nambiar river are flowing in the district and they will be dry during the summer season. The total geographical area of the district is 6,810 sq.km. The district receives the rain under the influence of both southwest and northeast monsoons. The North East monsoon chiefly contributes to the rainfall in the district. Most of the precipitation occurs in the form of cyclonic storms caused due to the depressions in Bay of Bengal. The South West Monsoon rainfall is highly erratic and summer rains are negligible. Rainfall data from two stations over the period of 2019 were utilized and a perusal of the data shows that the normal annual rainfall over the district is 844.4 mm. The district enjoys a Tropical climate. The period from May to June is generally hot and dry. The weather is pleasant during the period from December to January. Usually mornings are more humid than afternoons. The relative humidity is on an average between 74 and 79%. The mean minimum temperature is 28°C and mean maximum daily temperature is 36°C, respectively.

Water quality distribution (%) in Tirunelveli district

In general, the distribution of cations followed the order of Na^{+}> Mg^{2+}> Ca^{2+}>$K^{+}$and anions followed the order of Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}, respectively (Table 5). Out of the total samples collected in Tirunelveli district, 57 per cent is

characterized under good quality, (18%) Marginally saline, (4%) Saline, (1%) High-SAR saline, (11%) Marginally alkali, (8%) Alkali and (1%) High alkali (Table.6). The distribution of water samples in different water quality classes reveals that the samples of good quality underground irrigation water was found in almost all the Kalakkadu and Pappakudi (100%), Ambasamudram (87.5%), Cheranmahadevi and Alangulam (80%) and Nanguneri (70%) (Table 6 and Fig. 5). The spatial distribution of ground water quality categories is provided in Fig. 6.

Table 5.Cationic and anionic pattern in different blocks of Tirunelveli district

S. No.	Block name	Cations (me /L)				Cationic order	Anions (me /L)				Anionic order
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	
1.	Palayamkottai	5.00	7.92	13.55	0.25	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	3.20	6.60	20.76	5.53	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
2.	Cheranmahadevi	2.96	6.52	6.76	1.56	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	3.60	6.00	8.52	1.184	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
3.	Nanguneri	1.94	3.46	6.01	0.20	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	3.20	5.00	4.94	1.59	HCO_3^{-}>Cl^{-}> CO_3^{2-}> SO_4^{2-}
4.	Radhapuram	3.23	15.10	24.66	0.72	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	2.58	3.54	44.11	3.89	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
5.	Valliyur	3.17	5.98	12.23	0.22	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	2.28	6.11	11.98	1.71	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
6.	Kalakkadu	2.63	3.83	4.70	0.41	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	2.00	3.83	5.17	1.10	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
7.	Ambasamudram	2.35	3.18	3.02	0.55	Mg^{2+}>Na^{+}> Ca^{2+}>K^{+}	2.55	4.50	3.53	0.91	HCO_3^{-}>Cl^{-}> CO_3^{2-}> SO_4^{2-}
8.	Tenkasi	2.48	6.84	7.13	0.91	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	4.00	5.80	8.72	1.48	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
9.	Shencottai	2.12	8.96	10.90	1.88	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	4.00	6.40	11.52	2.64	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
10	Kadayanallur	2.04	7.44	7.57	0.29	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	2.80	5.20	10.00	0.97	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
11.	Vasudevanallur	2.42	10.37	13.07	0.32	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	2.57	9.28	15.26	3.54	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
12.	Sankarankoil	2.66	7.50	8.84	1.40	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	3.33	6.66	11.33	1.60	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
13.	Keezhapavur	2.84	6.24	5.49	0.17	Mg^{2+}>Na^{+}> Ca^{2+}>K^{+}	2.40	8.40	9.16	0.79	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
14.	Kadayam	1.65	3.70	2.42	1.91	Mg^{2+}>Na^{+}> Ca^{2+}>K^{+}	2.00	6.25	3.30	0.77	HCO_3^{-}>Cl^{-}> CO_3^{2-}> SO_4^{2-}
15.	Pappakudi	2.15	6.05	3.92	0.05	Mg^{2+}>Na^{+}> Ca^{2+}>K^{+}	2.50	5.50	5.35	1.71	HCO_3^{-}>Cl^{-}> CO_3^{2-}> SO_4^{2-}
16.	Alangulam	2.32	6.16	4.89	0.46	Mg^{2+}>Na^{+}> Ca^{2+}>K^{+}	2.40	4.40	5.96	1.21	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
17.	Melaneelithanallur	2.88	10.28	5.65	0.50	Mg^{2+}>Na^{+}> Ca^{2+}>K^{+}	2.80	6.00	10.20	1.31	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
18.	Kuruvikulam	4.60	9.97	9.38	1.29	Mg^{2+}>Na^{+}> Ca^{2+}>K^{+}	2.66	8.00	12.30	5.19	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
19.	Manur	3.76	6.43	5.29	0.82	Mg^{2+}>Na^{+}> Ca^{2+}>K^{+}	3.00	7.50	9.30	1.36	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}

Table 6: Water quality distribution (%) in Tirunelveli district

S. No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Palayamkottai	5	20		20		20	40	
2.	Cheranmahadevi	5	80	20					
3.	Nanguneri	10	70				20	10	
4.	Radhapuram	24	49.9	16.6	8.3	4.1	20.8		
5.	Valliyur	9	55.5	22.2			11.1		11.1
6.	Kalakkadu	6	100						
7.	Ambasamudram	8	87.5					12.5	
8.	Tenkasi	5	60	20				20	
9	Shencottai	5	60	40					
10.	Kadayanallur	5		60			40		
11.	Vasudevanallur	7	42.84	42.84	14.28				
12.	Sankarankoil	6	66.64	16.66				16.66	
13.	Keezhapavur	5	20	20			20	40	
14.	Kadayam	4	50				25	25	
15.	Pappakudi	4	100						

16.	Alangulam	5	80	20					
17.	Melaneelithanallur	5	60	20			20		
18.	Kuruvikulam	6	33.32	16.66	16.66		16.66	16.66	
19.	Manur	6	49.98	33.32				16.66	
	Average	130	57	18	4	1	11	8	1

Marginal Saline (MS), High-SAR Saline (HSS), Marginally Alkali (MA), High Alkali (HA)

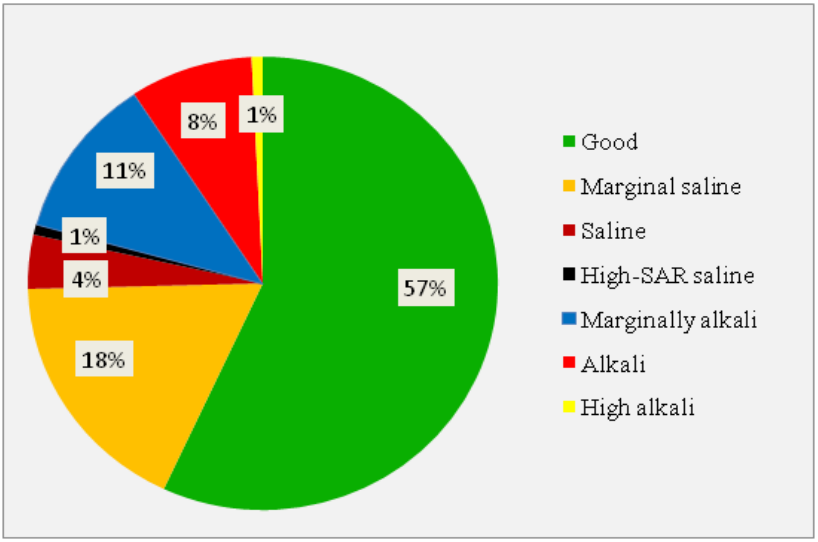

Fig. 5: Percentage distribution of ground water quality in Tirunelveli district

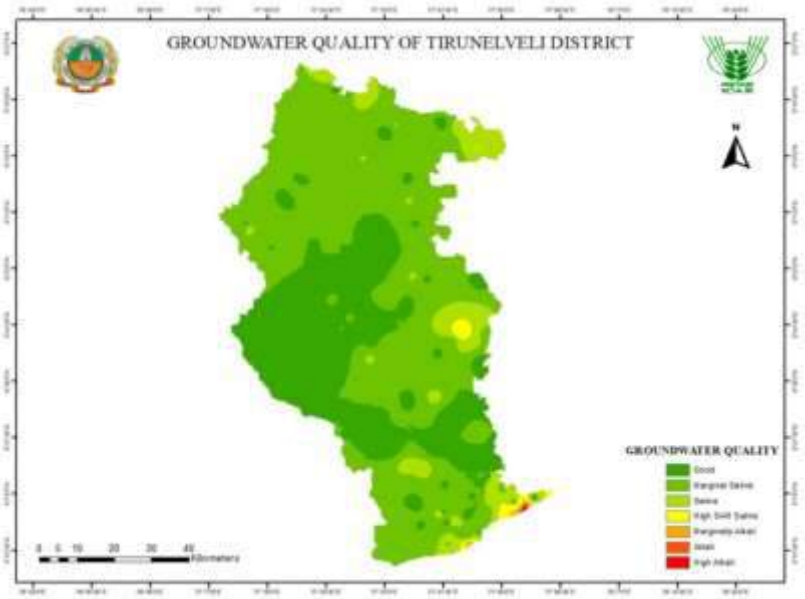

Fig. 6: Spatial distribution of ground water quality categories for Tirunelveli district

2.3 Thoothukudi District

Water Quality Distribution (%) in Thoothukudi District

In general, the distribution of cations followed the order of Na^{+}> Mg^{2+}> Ca^{2+}>K^{+} in all the blocks. With respect to the distribution of anions followed the order of Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2} in all blocks (Table 7). Out of the total samples collected in Thoothukudi district, 51 per cent is coming under Good quality, 21 per cent in Marginally saline, 13 per cent in Saline water, 3 percent in Marginally alkali, 2 percent in Alkali water, 7 per cent in High SAR saline and 3 per cent in Highly alkali categories. The distribution of water samples in different water quality classes reveals that the samples of good quality underground irrigation water was found in almost all the Ottapidaram block (92.3 %) followed by Karunkulam (81.8 %), Srivaikuntam (75 %), Alwarthirunagari (71.4 %), Vilathikulam (57.1 %), Thiruchendur (58.9 %), Kayathar (50 %), Udangudi (46.1 %), Kovilpatti (37.5 %), Thoothukudi (30 %), Sathankulam (18.8 %) (Table 8 and Fig. 7). The spatial distribution of ground water quality categories is provided in Fig. 8.

Table 7.Cationic and anionic pattern in different blocks of Thoothukudi District

S. No.	Block name	Cations(m.eq/l)				Cationic order	Anions(m.eq/l)				Anionic order
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	
1.	V.Pudur	3.12	5.24	12.16	0.19	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.80	3.80	17.80	0.80	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
2.	Vilathikulam	7.29	5.20	37.36	0.35	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.86	5.71	42.00	0.75	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
3.	Kovilpatti	5.35	7.05	11.99	0.54	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	1.58	5.19	19.75	0.61	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
4.	Kayathar	5.72	8.48	10.08	0.32	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.80	4.70	19.40	0.40	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
5.	Karunkulam	3.93	3.15	4.57	0.25	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.67	2.80	9.41	0.30	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
6.	Ottapidaram	2.92	2.94	2.81	0.60	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.46	2.83	8.00	0.36	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
7.	Thoothukudi	7.10	8.04	17.03	0.31	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	3.60	10.90	15.50	0.57	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
8.	Srivaikuntam	3.65	5.28	3.95	1.53	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.25	3.38	11.13	0.11	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
9.	Alwarthirunagari	3.13	3.63	8.64	0.42	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.29	4.14	12.79	0.19	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}

10	Thiruchendur	6.00	6.35	14.84	0.61	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.82	3.39	26.41	0.40	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
11.	Udangudi	7.02	7.85	16.88	2.30	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.31	4.54	26.69	0.24	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
12	Sathankulam	12.60	12.14	14.59	0.95	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	0.25	4.94	36.19	0.14	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}

Table 8.Water quality distribution (%) in Thoothukudi district

S.No.	Block	No.of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	V.Pudur	5	-	60	-	-	20	-	20
2	Vilathikulam	7	57.1	-	-	42.9	-	-	-
3	Kovilpatti	16	37.5	43.7	18.8	-	-	-	-
4	Kayathar	10	50	40	10	-	-	-	-
5	Karunkulam	22	81.8	18.2	-	-	-	-	-
6	Ottapidaram	13	92.3	7.7	-	-	-	-	-
7	Thoothukudi	10	30	10	30	-	-	20	10

8	Srivaikuntam	8	75	12.5	12.5	-	-	-	-
9	Alwarthirunagari	14	71.4	14.2	-	-	7.2	-	7.2
10	Thiruchendur	17	58.9	11.7	5.9	17.6	5.9	-	-
11	Udangudi	13	46.1	7.7	30.8	15.4	-	-	-
12	Sathankulam	16	18.8	31.2	43.8	6.2	-	-	-
	Average	151	51	21	13	7	3	2	3

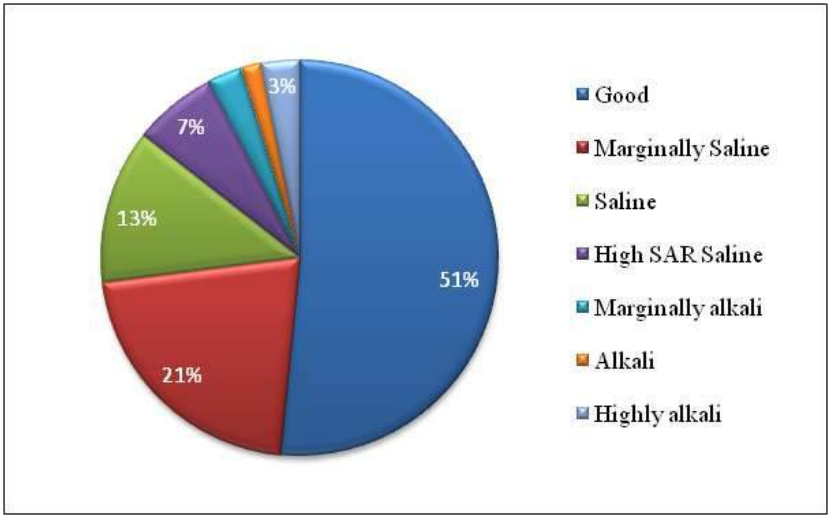

Fig. 7: Percentage distribution of ground water quality in Thoothukudi district

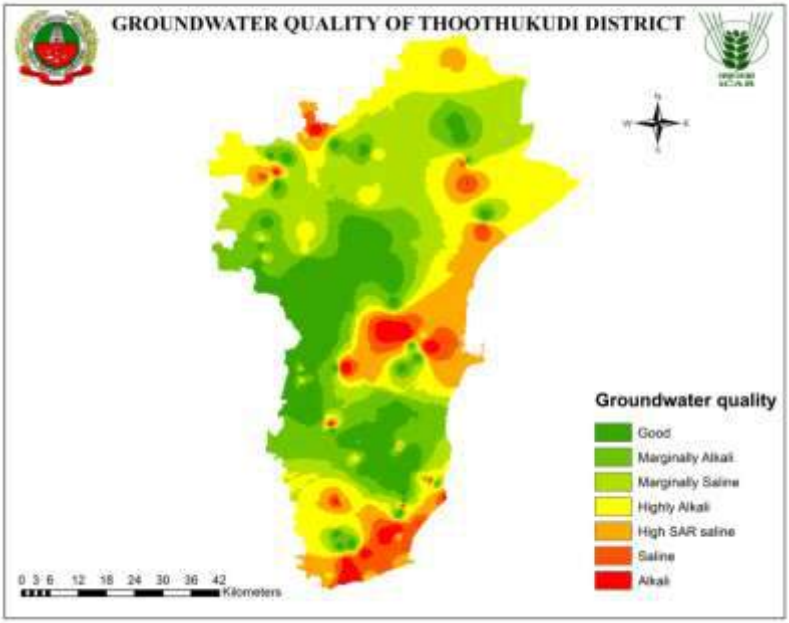

Fig. 8: Spatial distribution of ground water quality categories for Thoothukudi district

2.4 Ramanathapuram District

Ramanathapuram is one of the coastal districts bounded on the North by Sivagangai and Pudukottai districts, on the East and South by the Bay of Bengal, and on the West by Thoothukudi and Virudhunagar districts. The district headquarters is located at Ramanathapuram. The district lies between 9°05 and 9°5′ North Latitude and 78°1′ and 79°27′ East Longitude. The general geographical information of the district is simple and flat. Vaigai river and Gundar river are flowing in the district and they will be dry during the summer season. The total geographical area of the district is 4,175 sq.km.

Rainfall, Climate and Geo-hydrology

The district receives the rain under the influence of both South West and North East monsoons. The North East monsoon chiefly contributes to the rainfall in the district. Most of the precipitation occurs in the form of cyclonic storms caused due to the depressions in Bay of Bengal. The South West monsoon rainfall is highly erratic and summer rains are negligible. Rainfall data from two stations over the period from 1901 to 2000 were utilized and a perusal of the data shows that the normal annual rainfall over the district is 827mm with the maximum around Pamban and all along the coast and it decreases towards inland. The district enjoys a Tropical climate. The period from May to June is generally hot and dry. The weather is pleasant during the period from December to January. Usually mornings are more humid than afternoons. The relative humidity is on an average between 79 and 84 per cent. The mean minimum temperature is 25.7°C and mean maximum daily temperature is 30.6°C, respectively.

The predominant geological formation of Ramanathapuram district are mainly on recent Alluvium, Laterite Cuddalore sand stone and crystalline (Quartzite, Gnessiccomplex, Hornblendegranite) The hydrogeology is mainly based on major water bearing formation viz., Sandstones, Lime stone and Weathered and fractured Gnessic Rock. The pre-monsoon depth of ground water table is ranged from 0.95 to 8.80 m bgl (May, 2006) and post-monsoon depth of ground water table is ranged from 0.76 to 8.42 m bgl (January, 2007). The long term ground water level trend was decreased from the year 1996 to 2007. The rate of minimum and maximum level of ground water level trend was falling on 0.0133 and 1.2420 meter/year, respectively whereas the rise on maximum and minimum of 0.0102 and: 0.3331 meter/year, respectively (Balachandran, 2009).

Survey and characterization of ground water of Ramanathapuram District

To characterize the ground water quality of Ramanathapuram District 116 water samples were collected from different parts of Ramanathapuram district based on GPS location. The water samples were analyzed for pH, EC, cations (Ca, Mg, Na and K) and anions (CO_3, HCO_3, Cl and SO_4). Quality parameters like SAR and RSC were calculated.

Classification of water quality is done based on EC, SAR and RSC values as suggested by CSSRI, Karnal. Ramanathapuram District has 11 Blocks *viz.*,Tiruvadanai, R.S. Mangalam, Paramakkudi, Bogalur, Nainarkoil, Kamudi, Mudukulathur, Kadaladi, Ramanathapuram, Tiruppullani, Mandapam. The ranges for pH, ground water (EC), Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) for these blocks are given in Table 9.

Table 9: Quality of ground waters in different blocks of Ramanathapuram District

Name of the Block	pH			EC (dSm^{-1})			SAR			RSC ($meq.\ l^{-1}$)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Ramanathapuram	7.22	8.24	7.82	1.85	32	13.19	9.31	45.55	20.20	Nil	21.2	Nil
Paramakkudi	7.77	8.49	8.12	2.56	21.96	6.40	8.5	37.09	21.7	Nil	15.2	1.05
Kamuthi	7.46	8.31	7.97	0.51	30.28	5.4	1.15	25.12	8.92	Nil	10.6	Nil
Kadaladi	6.85	8.3	7.76	1.62	51.9	18.63	1.76	126.5	29.84	Nil	5.6	Nil
Tirupullani	7.18	8.01	7.64	1.01	47.2	14.96	1.39	49.1	21.24	Nil	0.6	Nil
Nainarkovil	7.32	8.22	7.73	0.87	9.89	5.35	2.28	25.52	11.15	Nil	0.6	Nil
Mandapam	7.27	8.57	7.92	0.72	80.1	11.13	0.89	144.4	18.61	Nil	22.8	Nil
Mudukalathur	7.36	8.3	7.86	0.17	10.82	4.95	0.54	24.05	11.46	Nil	Nil	Nil
Bogalur	7.63	8.34	7.94	1.22	18.27	8.22	6.23	62.66	27.82	Nil	11	2.15
Tiruvadanai	7.17	8.17	7.71	0.29	80	16.53	0.51	44.51	19.79	Nil	10.2	Nil
R.S Mangalam	7.3	8.08	7.61	1.91	49.4	16.79	6.76	40.44	18.16	Nil	9.2	Nil

In general, the distribution of cations followed the order of Na^{+}> Mg^{2+}> Ca^{2+}>K^{+} in all the blocks. With respect to the distribution of anions followed the order of Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2} in all blocks (Table.10)

Table 10: Cationic and anionic pattern in different blocks of Ramanathapuram district

Blocks	Cationic order	Anionic order
Ramanathapuram	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
Paramakkudi	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
Kamuthi	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
Kadaladi	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
Tirupullani	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
Nainarkovil	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
Mandapam	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
Mudukalathur	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
Bogalur	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
Tiruvadanai	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}
R.S Mangalam	Na^{+}> Mg^{2+}> Ca^{2+}>K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2}

Out of the total samples collected in Ramanthapuram district, 10% is characterized under good quality, 10% is marginally saline, 4 % is saline, 1 % is marginally alkaline, 10% is alkaline, 46% high SAR saline and 19% high alkaline. The distribution of water samples in different water quality classes reveals that the samples of good quality underground irrigation water was found in almost all the Mudukalathurblocks (25%), Mandapam (20%), Nainarkovil (20 %), Kamuthi (20%), Tirupullani (10%), Tiruvadanai (7.6%) and Kadaladi (7.1%), respectively (Table 11 and Fig. 9). The spatial distribution of ground water quality categories is provided in Fig. 10.

Table 11.Water quality distribution (%) in Ramanathapuram district

S.No.	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Ramanathapuram	12		16.6		33.3			50
2.	Paramakkudi	10		10		10		10	70
3.	Kamuthi	10	20	30		20		20	10
4.	Kadaladi	14	7.1			71.4	7.1		14.2
5.	Tirupullani	10	10	20		70			
6.	Nainarkovil	10	20	20	10	50			
7.	Mandapam	15	20			33.3		33.3	13.3
8.	Mudukalathur	8	25	12.5	12.5	50			
9	Bogalur	8				62.5		12.5	25
10.	Tiruvadanai	13	7.6	7.6	7.6	46.1		15.3	15.3
11.	R.S Mangalam	6			16.6	50		16.6	16.6
	Average	116	10	10	4	46	1	10	19

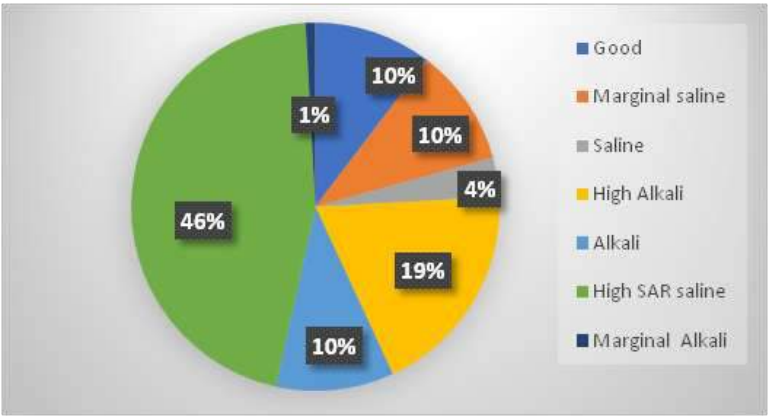

Fig. 9. Percentage distribution of ground water quality in Ramanathapuram district

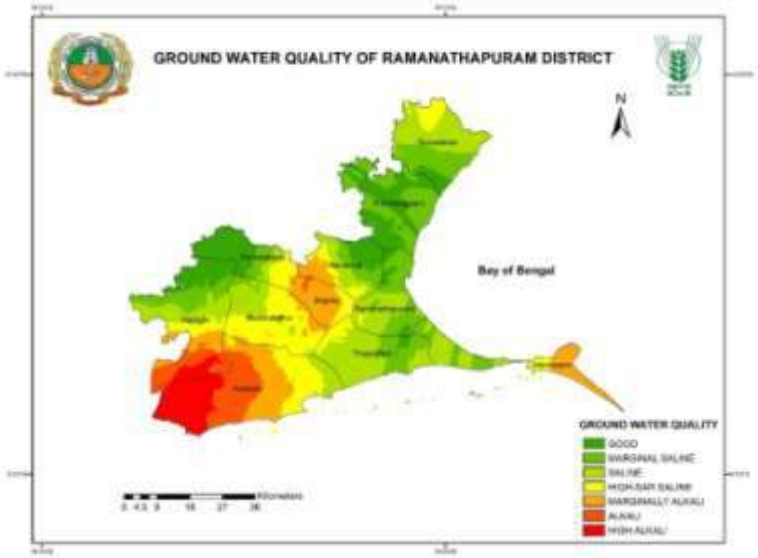

Fig. 10: Spatial distribution of ground water quality categories for Ramanathapuramdistrict

2.5. Pudukottai District

Survey and characterization of ground water quality of Pudhukottai District for irrigation

A study was undertaken to assess the ground water quality in Pudukkottai district bycollecting 149 ground water samples using GPS and analyzed for pH, EC, cations *viz.*, Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} and anions *viz.*, CO_3^{2-} , HCO_3^{-}, Cl^{-} and SO_4^{2-} by adopting standard procedures and thematic maps were prepared using Arc GIS software 10.1. The investigation revealed that ground water samples (Table 12) with respect to pH and EC ranged from 7.28 to 8.62 and 0.06 to 78.25 dS m^{-1}. Residual Sodium Carbonate (RSC) varied from nil to 13.67 meq L^{-1} and Sodium Adsorption Ratio (SAR) ranged from 0.19 to 44.61. According to CSSRI, Karnal water quality classification, 45 per cent of ground water found under good quality, (12%) Marginally saline,(1%)Saline,(4%) High-SAR saline (14%) marginallyalkali, (14%) Alkali and (10%) High alkali. The cationic and anionic order of different blocks in Pudukkottai district are followed as the $Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$ and $Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}$, respectively. Among the different blocks investigated, the highest percentage of samples with good quality was found in Thiruvarankulam (75%),Viralimalai (62.5%), Gandarvakottai(55%), Arantangi (55%), Arimalam (55%), Annavasal (50%) and Thirumayam (50%). Similarly, the poor-quality water recorded *viz.*, Marginal saline from Manamelkudi (36%) and Ponnamaravathi (35%), Saline from Avadaiyurkovil block (6.7%), high SAR saline from Avadaiyurkovil (33%). Marginally alkali from Karambakudi (40%) and

Gandarvakottai(36.4%), Alkali from Thiruvarankulam and Thirumayam (25%), High alkali from Pudukkottai (50%) and Manamelkudi (35%). Among the different blocks of Pudukkottai district, Avadaiyurkovil (40%) and Manamelkudi (35%) recorded the high level of possible sea water intrusion which were near to the sea coast.

Table 12: Quality of Ground Waters in Different Blocks of Pudukkottai District

Name of the blocks	Range/Mean	pH	EC (ds/m)	SAR	RSC($meqL^{-1}$)
Viralimalai	Min	7.61	0.58	0.187	-15.49
	Max	8.43	4.33	11.658	6.82
	Mean	7.82	1.51	4.255	-0.443
Annavasal	Min	7.6	0.59	0.846	-6.82
	Max	8.37	2.47	11.54	8.64
	Mean	7.85	1.364	5.308	0.474
Ponnamaravathi	Min	7.54	0.61	1.627	-11.3
	Max	8.53	2.8	12.68	7.86
	Mean	8.02	1.91	5.43	-0.87
Avadaiyurkovil	Min	7.7	0.54	4.463	-129
	Max	8.59	78.25	44.61	7.08
	Mean	8.23	7.92	24.38	-6.73
Manamelkudi	Min	7.89	1.55	5.051	-14.9
	Max	8.62	5.18	28.51	13.67
	Mean	8.2	2.77	14.04	0.587
Arantangi	Min	7.4	0.44	2.58	-11.1
	Max	8.42	3.55	12.8	3.39
	Mean	7.8	1.56	8.27	-0.86

Thirumayam	MinMaxMean	7.47	0.69	2.23	-5.32
		8.29	3.29	10.3	6.72
		7.88	1.69	5.39	0.331
Arimalam	MinMaxMean	7.52	0.46	1.855	0.72
		8.18	2.99	7.239	9.03
		7.71	1.08	3.426	2.82
Thiruvarankulam	MinMaxMean	7.28	0.06	1.95	-2.1
		7.92	1.94	4.97	6.20
		7.63	0.996	3.58	1.81
Pudukkottai	MinMaxMean	7.53	0.65	4.089	1.66
		8.26	2.53	27.39	12.9
		7.86	1.52	12.91	5.85
Kunnandarkovil	MinMaxMean	7.45	0.21	1.896	-0.8
		7.93	1.91	5.828	6.7
		7.68	0.99	3.501	3.39
Gandarvakottai	MinMaxMean	7.45	0.25	0.49	-1.8
		7.9	1.5	7.44	4.8
		7.61	0.733	2.56	1.62
Karambakudi	MinMaxMean	7.49	0.37	1.99	-9.5
		7.95	1.98	3.56	4.1
		7.645	0.84	2.72	1.06

Water Quality Distribution (%) in Pudukkottai District

In general, the distribution of cations followed the order of $Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$and anions followed the order of $Cl^{-}_{4}>$ $HCO_3^{-}>$ $CO_3^{2-}>$ SO_4^{2-} , respectively (Table 13). Out ofthe total samples collected in Pudukkottai district 45 per cent of ground water were found asgood quality and its remaining samples were found in different categories of water

quality*viz.*, Marginally saline (12%), Saline (1%), High-SAR saline (4%), Marginally alkali (14%),Alkali (14%) and High alkali (10%). Among the different blocks investigated, the highestpercentage of samples with good quality was found in Thiruvarankulam (75%), Viralimalai(62.5%), Gandarvakottai (55%), Arantangi (55%), Arimalam (55%), Annavasal (50%) and Thirumayam (50%) (Table 14 and Fig. 11). The spatial distribution of ground water qualitycategories o fPudukkottai districtis provided in Fig. 12

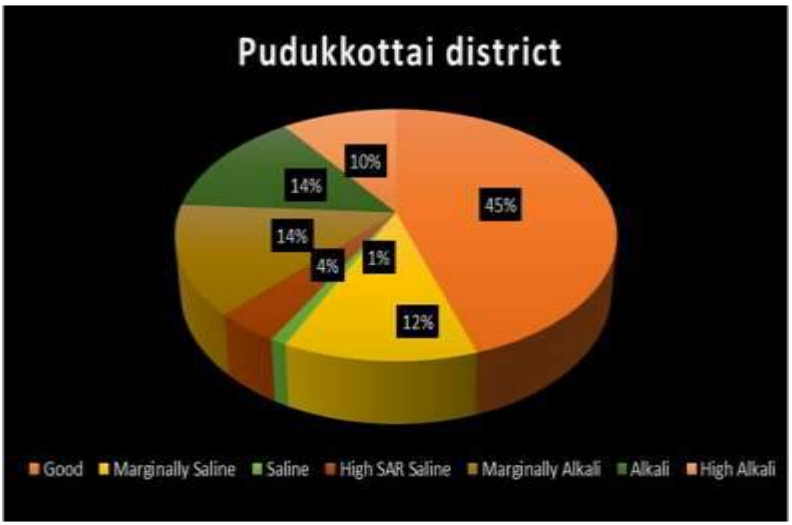

Fig. 11. Percentage distribution of ground water quality in Pudukkottaidistrict

Table 13: Cationic and anionic pattern in different blocks of Pudukkottai district

S. No.	Blockname	Cations(meq/L)				Cationicorder	Anions(meq/L)				Anionicorder
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	
1.	Viralimalai	4.54	5.43	9.44	0.58	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	3.28	6.25	9.10	0.61	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO_4^{2-}$
2.	Annavasal	4.20	4.99	10.79	0.41	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	3.32	6.35	8.71	0.33	$Cl^{-}>HCO_3^{-}>CO_3^{2-}> SO_4^{2}$
3.	Ponnamaravathi	4.73	6.82	12.60	1.84	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	3.90	6.78	12.2	0.61	$Cl^{-}>HCO_3^{-}>CO_3^{2-}> SO_4^{2}$
4.	Avadaiyurkovil	4.84	10.30	53.88	3.35	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	2.69	5.72	57.76	1.32	$Cl^{-}>HCO_3^{-}>CO_3^{2-}> SO_4^{2}$
5.	Manamelkudi	4.61	5.83	28.04	1.11	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	3.89	7.13	22.80	1.19	$Cl^{-}>HCO_3^{-}>CO_3^{2-}> SO_4^{2}$
6.	Arantangi	4.49	3.35	16.60	0.45	$Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$	2.39	4.59	13.85	0.33	$Cl^{-}>HCO_3^{-}>CO_3^{2-}> SO_4^{2}$

7.	Thirumayam	3.39	7.01	12.46	0.36	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	2.78	7.95	13.10	0.44	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO_4^{2}$
8.	Arimalam	2.54	4.07	6.37	0.25	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	3.14	6.28	5.56	0.51	$HCO_3^{-}>Cl^{-}>CO_3^{2-}>SO_4^{2}$
9.	Thiruvarankulam	3.35	3.25	6.64	0.96	$Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$	2.76	5.65	5.75	0.34	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO_4^{2}$
10.	Pudukkottai	1.83	4.06	20.04	0.27	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	3.79	7.95	9.70	0.76	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO_4^{2}$
11.	Kunnandarkovil	2.09	3.15	5.63	0.21	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	3.09	5.55	4.69	0.24	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO_4^{2}$
12.	Gandarvakottai	2.15	2.68	4.01	0.19	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	2.00	4.45	4.44	0.19	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO_4^{2}$
13.	Karambakudi	2.68	3.16	4.46	0.37	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	2.20	4.70	4.80	0.19	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO_4^{2}$

Table 14: Water quality distribution(%) in Pudukkottai district

S.No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Viralimalai	16	62.50	19.00	-	-	12.50	6.25	-
2.	Annavasal	14	50.00	14.00	-	-	7.00	22.00	7.00
3.	Ponnamaravathi	14	28.60	35.00	-	-	21.50	7.00	7.00
4.	Avadaiyurkovil	15	13.00		6.70	33.0	7.00	7.00	33.00
5.	Manamelkudi	14	21.50	36.00	-	7.0	-	-	35.00
6.	Arantangi	11	55.00	10.00	-	18.2	18.00	-	-
7.	Thirumayam	8	50.00	25.00	-	-	-	25.00	-
8.	Arimalam	9	55.00	11.00	-	-	22.00	11.11	-
9.	Thiruvarankulam	8	75.00	-	-	-		25.00	-
10.	Pudukkottai	8	25.00	-	-	-	12.50	12.50	50
11.	Kunnandarkovil	11	45.00	-	-	-	10.00	45.45	-
12.	Gandarvakottai	11	55.00	-	-	-	36.40	10.00	-
13.	Karambakudi	10	50.00	-	-	-	40.00	10.00	-
	Average	149	45	12	1	4	14	14	10

Marginal Saline(MS), High-SAR Saline (HSS), Marginally Alkali(MA), High Alkali (HA)

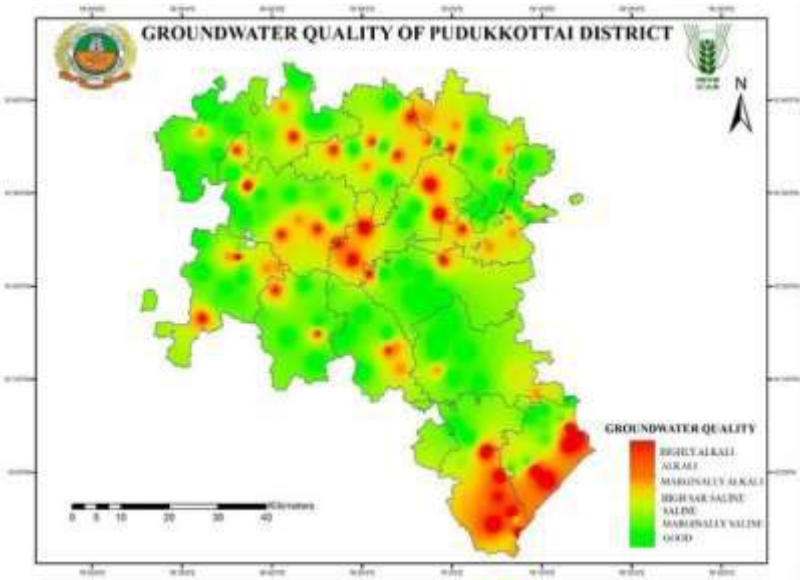

Fig. 12: Spatialdistributionof different categoriesofground waterqualityin Pudhukottai district

2.6 Thanjavur District

Thanjavur district lies between 9° 50′ and 11° 25′ North latitude and 78° 45′ and 79° 25′ East longitude. It is bounded on the North by Tiruchirappalli and Cuddalore districts, on the East by Tiruvarur and Nagapattinam districts, on the South by Palk Strait and Pudukottai district and on the west by Pudukkottai district and Tiruchirapalli districts. Total geographical area of the district is 3,602.86 sq.km. This constitutes just 2.77 % of the area of the State.Administrative profile of the district are taluks 8 and revenue villages (906).

Rainfall, Climate and Geo-hydrology

Within the Thanjavur district the rainfall is uneven. The annual normal (1988 – 1996) varies partially from 1179 mm

(Lower Anaicut) to 763 mm (Budalur). The rainfall is high on the Eastern part of the district compared to the Western part. The district receives major portion of its annual rainfall during North East monsoon (Oct-Dec). A moderate amount of rainfall is received during the South West monsoon period (Jan-Sept). Since the North East monsoon rainfall is dominating, its effect is felt on the Eastern part of the district (Kumbakonam-698 mm, Aduthurai-611 mm, Lower Anicut-706 mm). The intensity decreases gradually towards West and the Western most part of the district (Thiruvaiyaru-387 mm, Budalur-377 mm). The rainfall in the coastal area is heavy because of cyclonic storms and depressions formed in the Bay of Bengal.

The climate of the Thanjavur district is humid and tropical. The mean maximum temperature of the district (Aduthurai) shows variation between 36.5° C in June and 27.8° C in May. The mean minimum temperature shows variation from 22.1° C to 27.1°C in December. The relative humidity varies between 70 and 85 percent, the highest occurs during the months of Dec-January and the lowest during the month of June.

The predominant geological formation of Thanjavur district are mainly on Recent alluvium, Padakkudi, Orthanadu formations and Eastern Ghats weathered and fractured gneissic rocks. The hydrogeology is mainly based on major water bearing formation *viz.,* Recent alluvium, Cuddalore sandstone and Weathered and fractured gneissic rocks. The pre- monsoon depth of ground water table is ranged from 1.55 to 18.32 m bgl (May 2006) and post- monsoon depth of ground water table is ranged from 0.22 to 19.20 m bgl(January, 2007). The long term ground water level trend was decreased from

the year 1996 to 2007. The rate of minimum and maximum level of ground water level trend was fall on 0. 0097 and 0.7347 meter/year, respectively whereas the rise on maximum and minimum of 0.0027 and: 0.3276 meter/year, respectively (Dhinagaran, 2009).

Survey and Characterization of Ground Water of Thanjavur District for Irrigation

In the processes of characterizing the ground water quality of Thanjavur district was surveyed during the report period. About 412 water samples were collected based on GPS location from Thanjavur district covering all the blocks. The water samples were analyzed for pH, EC, cations (Ca, Mg, Na and K) and anions (CO_3, HCO_3, Cl and SO_4). Quality parameters like SAR and RSC were calculated. Classification of water quality is done based on EC, SAR and RSC values as suggested by CSSRI, Karnal.

Thanjavur District has 14 Blocks *viz.,* Ammapettai, Budalur, Kumpakonam, Mathukur, Orathanadu, Papanasam, Peravurani, Pattukottai, Sethubavasathiram, Thanjavur, Thiruppanadal, Thiruvaiyaru, Thiruvidaimarudur and Thiruvonam. The ranges for pH, ground water (EC), Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) for these blocks are given in Table 15.

In general, the distribution of majority of cations followed in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ in Ammapettai, Budalur, Kumpakonam, Mathukur, Orathanadu, Papanasam, Pattukottai, Thanjavur, Thiruvaiyaru, and Thiruvonam whereas in the remaining blocks viz., Peravurani, Sethubavasathiram, Thiruppanadal, and Thiruvidaimarudur

distributions followed as Ca^{2+}>Na^{+}>Mg^{2+}> K^{+}. With respect to the distribution of anions followed in the order of HCO_3^{-}> Cl^{-} > CO_3^{2-}>SO_4^{2} in Ammapettai, Kumpakonam, Peravurani, Pattukottai, Thanjavur, Thiruvaiyaru, and Thiruvidaimarudur whereas in the remaining blocks the distribution followed in the order of Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2} (Table 16).

Table 15: Quality of ground waters in different blocks of Thanjavur District

Name of the Block	pH			EC (dSm^{-1})			RSC (meq. l^{-1})			SAR		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Ammapettai	8.04	8.74	8.34	0.27	4.01	0.81	Nil	4.0	1.32	1.93	8.33	3.35
Budalur	7.79	8.74	8.34	0.54	8.31	1.57	Nil	6.5	1.28	2.14	13.1	5.20
Kumpakonam	7.57	8.79	8.26	0.24	3.3	0.86	Nil	7.0	0.54	1.10	6.07	3.19
Mathukur	7.83	12.7	8.41	0.42	2.44	0.89	Nil	3.4	0.66	0.73	6.38	3.58
Orathanadu	7.96	8.81	8.24	0.32	1.3	0.65	Nil	4.1	0.29	1.11	5.09	2.95
Papanasam	7.96	8.56	8.28	0.41	0.96	0.60	Nil	3.1	0.40	1.94	5.09	3.04
Peravurani	7.15	8.16	7.91	0.69	1.56	1.03	Nil	3.4	-1.33	0.58	5.32	2.43
Pattukottai	8.01	8.82	8.31	0.68	2.45	1.42	Nil	7.2	1.08	2.45	7.02	4.65
Sethubavasathiram	7.15	8.49	8.10	0.60	2.94	1.26	Nil	2.6	-0.98	1.01	6.73	3.36
Thanjavur	7.42	8.42	8.16	0.2	1.84	0.84	Nil	4.5	0.81	1.18	6.82	3.13
Thiruppanadal	7.43	8.21	7.93	0.34	1.32	0.65	Nil	0.6	-1.99	0.08	4.56	1.62
Thiruvaiyaru	7.69	9.46	8.28	0.52	3.51	1.00	Nil	4.5	1.24	0.97	6.11	3.81
Thiruvidaimarudur	7.05	8.82	7.87	0.4	2.45	0.80	Nil	7.4	-0.47	0.59	6.63	2.06
Thiruvonam	7.65	8.35	8.09	0.45	1.56	0.80	Nil	2.4	-0.32	0.37	4.98	2.82

Table 16: Cationic and Anionic distribution in ground water samples of Thanjavur district

Blocks	Cationic order	Anionic order
Ammapettai	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$HCO_3^- > Cl^- > CO_3^{2-} > SO_4^{2}$
Budalur	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2-}$
Kumpakonam	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$HCO_3^- > Cl^- > CO_3^{2-} > SO_4^{2}$
Mathukur	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2}$
Orathanadu	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2}$
Papanasam	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2}$
Peravurani	$Ca^{2+} > Na^+ > Mg^{2+} > K^+$	$HCO_3^- > Cl^- > CO_3^{2-} > SO_4^{2}$
Pattukottai	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$HCO_3^- > Cl^- > CO_3^{2-} > SO_4^{2}$
Sethubavasathiram	$Ca^{2+} > Na^+ > Mg^{2+} > K^+$	$Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2}$
Thanjavur	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$HCO_3^- > Cl^- > CO_3^{2-} > SO_4^{2}$
Thiruppanadal	$Ca^{2+} > Na^+ > Mg^{2+} > K^+$	$Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2}$
Thiruvaiyaru	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$HCO_3^- > Cl^- > CO_3^{2-} > SO_4^{2}$
Thiruvidaimarudur	$Ca^{2+} > Na^+ > Mg^{2+} > K^+$	$HCO_3^- > Cl^- > CO_3^{2-} > SO_4^{2}$
Thiruvonam	$Na^+ > Ca^{2+} > Mg^{2+} > K^+$	$Cl^- > HCO_3^- > CO_3^{2-} > SO_4^{2}$

Out of the total samples collected in Thanjavur district, 84.2 % is coming under good quality, 2.19 % is marginally saline, 9.3 % is marginally alkaline, 3.6 % is alkaline, 0.46 % is saline and 0.25 % high SAR saline. 100 % good quality water was observed in Thiruppanadal and Thiruvonam blocks. More than 90 % water samples collected from Mathukur, Orathanadu, Papanasam, Peravurani, and Thiruvidaimarudur blocks coming under the category of good quality. Marginally saline water was observed in Ammapettai (10 %), Pattukottai (6.66 %), Sethubavasathiram (15.4 %) and Thanjavur (4.54 %) blocks. Saline water was observed in Ammapettai (93.3 %) block only. High SAR saline water was present in Budalur

block only. Marginally alkali water was found in some blocks (3.7 to 28.0 %) except Ammapettai, Orathanadu, Sethubasathiram, Thirupananthal, Thiruvidaimarudur and Thiruvonam blocks. Alkali water was found in Ammapettai (3.33%), Budalur (3%), Kumpakonam (5.71), Orathanadu (8.51), Pattukottai (6.66 %), Sethubavasathiram (2.56 %), Thiruvaiyaru (12 %) and Thiruvidaimarudur (8.51 %) Blocks. Highly alkali water was not found in any part of the district. (Table 17 and Fig. 13). The spatial distribution of ground water quality categories is provided in Fig. 14.

Table 17. Water quality distribution (%) in Thanjavur district

S. No.	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	Ammapettai	30	83.3	-	3.33	-	10	3.33	-
2	Budalur	20	60	-	-	5	20	15	-
3	Kumpakonam	35	77.14	-	-	-	17.14	5.71	-
4	Mathukur	24	91.6	-	-	-	8.33	-	-
5	Orathanadu	33	97.0	-	-	-	-	3.0	-
6	Papanasam	27	96.29	-	-	-	3.70	-	-
7	Peravurani	32	93.7	-	-	-	6.3	-	--
8	Pattukottai	15	73.33	6.66	-	-	13.3	6.66	-
9	Sethubavasathiram	39	82.05	15.38	-	-		2.56	-
10	Thanjavur	22	81.8	4.54	-	-	13.63	-	-
11	Thiruppanadal	36	100		-	-	-	-	-
12	Thiruvaiyaru	25	56	4	-	-	28	12	-
13	Thiruvidaimarudur	47	91.48	-	-.	-	-	8.51	-
14	Thiruvonam	27	100	-	-	-	-	-	-
	Total /average	412	84.2	2.19	0.46	0.25	9.3	3.6	-

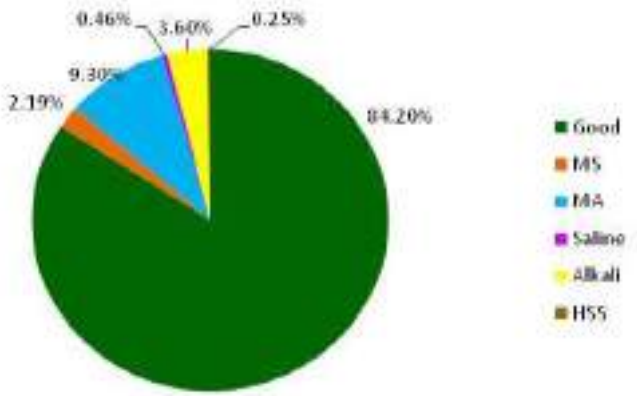

Fig. 13: Percentage distribution of ground water quality of Thanjavur district

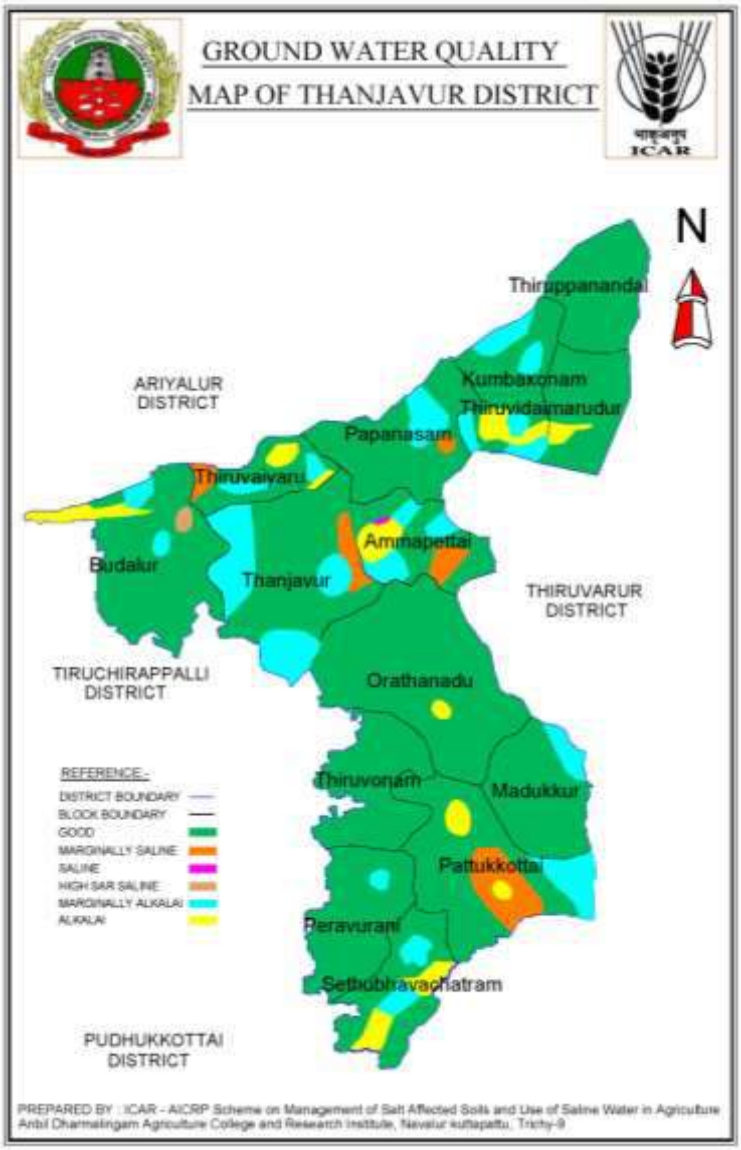

Fig. 14: Spatial distribution of ground water quality categories for Thanjavur district

2.7 Nagapattinam District

Nagapattinam is a coastal district of Tamil Nadu situated on the Eastern side of Nagapattinam the district headquarters lie 326 km, south of the State capital, Chennai, 145 km from Trichy, this district lies South of Cuddalore district and another part of the Nagapattinam district lies to the South of Karaikkal and Tiruvarur districts. Nagapattinam lies between Northern Latitude 10.7906 degrees and 79.8428 degrees Eastern longitude. The district spreads over an area of 2,715.83 sq.km. This district envelops 11 Panchayat unions, 4 municipalities, 8 town Panchayats on its development side 2 revenue divisions and 523 revenue villages.

Rainfall, Climate and Geo-hydrology

The district receives rainfall under the influence of both South West and North East monsoon. A good part of the rainfall occurs as very intensive storms resulting mainly from cyclones generated in the Bay of Bengal especially during North East monsoon. The district receives rainfall almost throughout the year. Rainfall data analyzed (period 1901- 70) shows the normal annual rainfall of the district is 1230 mm. The rainfall pattern in the district shows interesting features. Annual rainfall, which is 1500 mm at Vedaranyam, the southeast corner of the district, rapidly decreases to about 1100 mm towards West of the district. The district enjoys humid and tropical climate with hot summers, significant to mild winters and moderate to heavy rainfall. The temperatures various from 40.6 to 19.3° C with sharp fall in night temperatures during monsoon period. The relative

humidity ranges from 70 to 77% and it is high during the period of October to November.

The predominant geological formations of Nagapattinam district are mainly on Pliocene to recent. The hydrogeology is mainly based on major water bearing formation *viz.,* Lower Miocene deeper aquifers and Pliocene quaternary shallow aquifers. The pre-monsoon depth of ground water table is ranged from 2.0 to 9.45 m bgl (May, 2006) and post-monsoon depth of ground water table is ranged from ground level to 2.641 m bgl (January, 2007). The long term ground water level trend was decreased from the year 1996 to 2007. The rate of minimum and maximum level of ground water level trend was fall on 0.022 and 0.29 meter/year, respectively whereas the rise on maximum up 0.31 m/year , respectively (Dhinagaran, 2008).

Survey and Characterization of Ground Water of Nagapattinam District for Irrigation

To characterize the ground water quality of Nagapattinam District 215 water samples were collected from different parts of Nagapattinam district based on GPS location. The water samples were analyzed for pH, EC, cations (Ca, Mg, Na and K) and anions (CO_3, HCO_3, Cl and SO_4). Quality parameters like SAR and RSC were calculated. Classification of water quality is done based on EC, SAR and RSC values as suggested by CSSRI, Karnal.

Nagapattinam District has 11 Blocks viz., Keelaiyur, Kilvelur, Kollidam, Kuttalam, Mayiladuthurai, Nagapattinam, Sembanar Koil, Sirkazhi, Thirumarugal, Talanayar and Vedaranniyam. The ranges for pH, ground water (EC), Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) for these blocks (Table 18).

Table 18. Quality of ground waters in different blocks of Nagapattinam District

Name of the Block	pH			EC (dSm^{-1})			RSC (meq. l^{-1})			SAR		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maxim um	Mean
Keelaiyur	7.02	7.99	7.51	0.43	4.82	2.63	Nil	Nil	-	1.15	2.86	2.05
Kilvelur	7.07	8.65	7.86	0.49	6.48	3.49	Nil	9.2	-	1.34	13.9	7.62
Kollidam	7.09	8.52	7.81	0.44	2.84	1.64	Nil	2.9	-	1.36	4.05	2.70
Kuttalam	7.05	8.4	7.73	0.31	1.36	0.84	Nil	8	-	0.82	4.62	2.72
Mayiladuthurai	7.05	8.35	7.70	0.3	1.99	1.15	Nil	2.7	-	0.63	5.37	3.00
Nagapattinam	7.25	8.55	7.90	0.51	26.8	13.6	Nil	5.2	-	2.03	5.80	3.91
Sembanar Koil	7.17	8.37	7.77	0.42	4.2	2.31	Nil	2.6	-	1.12	4.10	2.61
Sirkazhi	7.1	8.67	7.66	0.37	6.24	3.31	Nil	5.6	-	0.81	5.71	3.26
Talanayar	7.09	7.62	7.36	0.48	4.1	2.29	Nil	Nil	-	0.86	3.65	2.25
Thirumarugal	7.5	8.65	8.08	0.1	4.55	2.33	Nil	4.4	-	1.16	4.62	2.89
Vedaranniyam	7.02	8.92	7.97	0.46	13.3	6.88	Nil	4.1	-	1.14	4.51	2.82

In general, the major distribution of cations followed in the order of Ca^{2+}> Mg^{2+}> Na^{+}> K^{+} in Keelaiyur, Nagapattinam, SembanarKoil, Thirumarugal,Vedaranniyam and in the remaining blocks followed the different orders *viz*., Ca^{2+}> Na^{+}>Mg^{2+}> K^{+} (Talanayar, Sirkazhi, Mayiladuthurai, Kuttalam) and Na^{+}> Ca^{2+}> Mg^{2+}> K^{+} (Kilvelur, Kollidam). With respect to the distribution of majority of anions followed in the order of Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-} in Keelaiyur, Kollidam, Kuttalam, Mayiladuthurai, Sirkazhi, Talanayar followed by Cl^{-}> HCO_3^{-}>SO_4^{2-}> CO_3^{2-} in Thirumarugal, Vedaranniyam whereas in the remaining two blocks (Kilvelur, Sembanar Koil) the distribution of anions as HCO_3^{-}> Cl^{-}> SO_4^{2-} > CO_3^{2-}(Table 19).

Table 19: Cationic and Anionic Pattern in Different Blocks of Nagapattinam District

Block name	Cationic order	Anionic order
Keelaiyur	Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
Kilvelur	Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}	HCO_3^{-}> Cl^{-}> SO_4^{2-}> CO_3^{2-}
Kollidam	Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
Kuttalam	Ca^{2+}> Na^{+}> Mg^{2+}> K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
Mayiladuthurai	Ca^{2+}> Na^{+}> Mg^{2+}> K^{+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
Nagapattinam	Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}	Cl^{-}> HCO_3^{-}> SO_4^{2-}> CO_3^{2-}
Sembanar Koil	Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}	HCO_3^{-}> Cl^{-}> SO_4^{2-}> CO_3^{2-}

Sirkazhi	$Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$	$Cl^{-} > HCO_3^{-} > CO_3^{2-} > SO_4^{2}$
Talanayar	$Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$	$Cl^{-} > HCO_3^{-} > CO_3^{2-} > SO_4^{2}$
Thirumarugal	$Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$	$Cl^{-} > HCO_3^{-} > SO_4^{2-} > CO_3^{2-}$
Vedaranniyam	$Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$	$Cl^{-} > HCO_3^{-} > SO_4^{2-} > CO_3^{2-}$

Out of the total samples collected in Nagapattinam district, 72.6 % is characterized under good quality, 12.7 % is marginally saline, 7.8 % is saline, 2.9 % is marginally alkaline, 2.9 % is alkaline, and 0.4 % high SAR saline. More than 90 % water samples collected from Kuttalam and Mayiladuthurai blocks were good quality waters. Nagapattinam and Vedaranniyam blocks have less than 50 per cent good quality waters. Marginally saline water was observed in almost all the blocks except Kuttalam and Mayiladuthurai. The distribution of marginally saline water was 9.09 % in Sembanarkoil, 9.0 % in Sirkazhi, 16.7 % in Kollidam, 18.2 % in Thirumarumarugal, 18.5 % in Kilvelur, 25 % in Keelaiyur, 38.5 % in Thalanayar and 17.6 % in Vedaranniyam Blocks. The distribution of saline water was 4.54 % in Sembanar Koil, 9% in Sirkazhi, 0.09 % in Thirumarugal, 44.4 % in Nagapattinam, 6.25 % in Keelaiyur, 7.69 in Talanayar and 7.8 % in Vedaranniyam Block. Small quantity of marginally alkali and alkali water was distributed in almost all the blocks. High SAR Saline water was present only in Kilvelur Block (Tables 20 and Fig 15). The spatial distribution of ground water quality categories is provided in Fig. 16.

Table 20: Water Quality Distribution (%) Nagapattinam District

S. No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Keelaiyur	16	68.7	25	6.25	-	-	-	-
2.	Kilvelur	27	66.66	18.51	-	3.70	3.70	7.40	-
3.	Kollidam	18	77.8	16.66	-	-	5.55	-	-
4.	Kuttalam	36	97.22	-	-	-	2.77	-	-
5.	Mayiladuthurai	14	92.85	-	4.54	-	7.14	-	-
6.	Nagapattinam	9	33.3	-	44.4	-	11.1	11.1	-
7.	Semmanar kovil	22	81.8	9.09	4.54	-	4.54	-	-
8.	Sirkazhi	22	77.2	9.0	9.0	-	-	4.54	-
9.	Talanayar	13	53.8	38.5	7.69	-	-	-	-
10.	Thirumarugal	11	63.63	18.18	9.09	-	-	9.09	-
11	Vedaranniyam	17	41.1	17.6	35.2	-	-	5.88	-
	Average	205	72.6	12.7	7.8	0.4	2.9	2.9	-

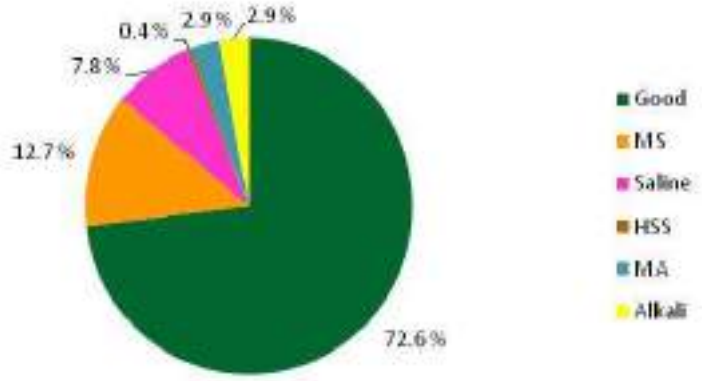

Fig 15: Percentage distribution of ground water quality of Nagapattinam District

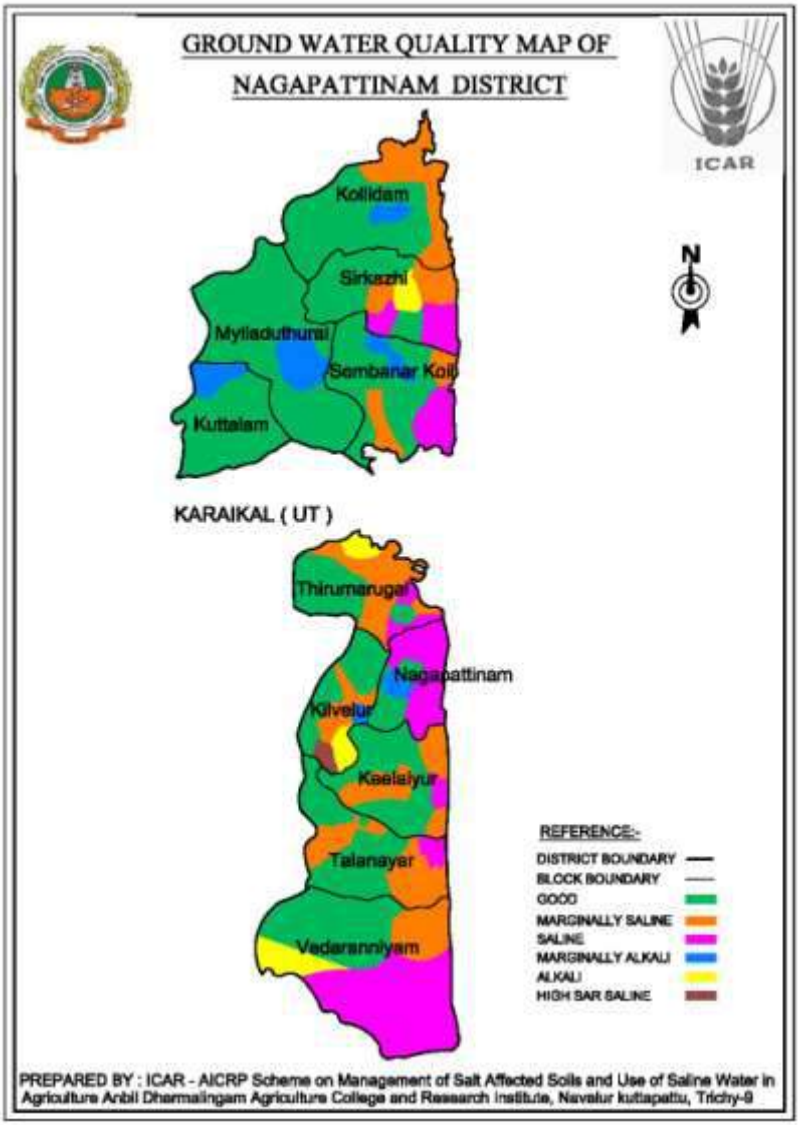

Fig. 16: Spatial distribution of ground water quality categories for Nagapattinam district

2.8 Thiruvarur District

Thiruvarur district was formed by integrating Valangaiman Taluk from Thanjavur District and Thiruvarur, Nannilam, Kudavasal, Needamangalam, Mannargudi, Thirutturaippoondi Taluks from Nagappatinam District on 01.01.1997. The geographical area of the district is 2,377 sq.km and it lies between 10°20′ and 11°07′ North latitude and 79°15′ and 79°45′ East longitude. There are 2 revenue divisions, 7 taluks, 10 community development blocks, 3 municipalities, 7 town panchayats and 573 villages in Thiruvarur district.

Rainfall, Climate and Geo-hydrology

The district receives rainfall from both South East and North East monsoons. The normal annual rainfall in the district ranges from 1100 to 1260 mm. It gradually increases towards East and South and attains a maximum around Thiruvarur in the Eastern part. It is observed that the chances of receiving normal annual rainfall vary from 40 percentages at Needamangalam to 51 per cent at Thiruthuraipoondi. These changes are the highest (50-55 per cent) in a small area around Thiruthuraipoondi in the eastern part. In the rest of the district these chances are in the range 40-50 per cent. The district has a hot tropical climate the summer season, which is very oppressive, is from March to about the end of May. The humidity is generally high in the coastal region throughout the year and exceeds 70 percentages during period from August to May. It is much drier towards the interior of the district.

The predominant geological formation of Thiruvarur district are mainly Recent and Tertiary formations. The

hydrogeology is mainly based on major water bearing formation *viz.,* Alluvium, sand stone, sand. The pre-monsoon depth of ground water table is ranged from 3.07 to 7.01 m bgl (May, 2006) and post-monsoon depth of ground water table is ranged from 0.37 to 4.71 m bgl (January, 2007). The long term ground water level trend was decreased from the year 1998 to 2007. The rate of minimum and maximum level of ground water level trend was fall on 0.0368 and 0.4262 m /year, respectively (Dhinagaran, 2008).

Survey and characterization of ground water of Thiruvarur District for irrigation

To characterize the ground water quality of Thiruvarur District 161 water samples were collected from different parts of Thiruvarur district based on GPS location. The water samples were analyzed for pH, EC, cations (Ca^{++}, Mg^{++}, Na^{+} and K^{+}) and anions (CO_3^{--}, HCO_3^{-}, Cl^{-} and SO_4^{-}), Quality parameters like SAR and RSC were calculated. Classification of water quality is done based on EC, SAR and RSC values as suggested by CSSRI, Karnal. Thiruvarur District has 10 Blocks *viz.,* Koradacheri, Kottur, Kudavasal, Mannarkudi, Muttupt, Nidamangalam, Nannilam, Thiruthuraipundi, Thiruvarur and Valangaiman. The ranges for pH, ground water (EC), Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) for these blocks are given in Table 21.

Table 21: Quality of Ground Waters in Different Blocks of Thiruvarur District

Name of the Block	pH			EC (dSm^{-1})			RSC (meq. l^{-1})			SAR		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Koradacheri	6.65	9.80	7.03	0.77	2.85	1.52	Nil	7.3	-	0.45	8.59	0.53
Kottur	6.66	8.01	7.30	0.38	2.88	1.08	Nil	0.3	-	0.13	3.59	1.54
Kodavasal	7.30	9.05	8.01	0.40	1.10	1.03	Nil	8.2	-	0.77	10.40	3.77
Mannarkudi	6.70	7.71	7.22	0.46	2.67	1.14	Nil	0.60	-	0.65	4.78	2.88
Muttupt	6.79	8.10	7.45	0.56	1.64	1.18	Nil	0.9	-	0.78	5.74	1.45
Nannilam	6.99	8.70	7.05	0.53	2.59	0.93	Nil	4.2	-	3.31	5.60	2.00
Nidamangalam	7.17	7.50	8.01	0.39	2.32	1.10	Nil	Nil	-	1.19	4.64	4.24
Thiruthuraipundi	7.17	8.20	7.68	0.24	1.78	1.13	Nil	2.1	-	0.68	6.94	1.48
Thiruvarur	6.91	8.10	7.59	1.33	1.97	1.91	Nil	0.8	-	0.96	5.24	3.06
Valangaiman	6.68	8.40	7.21	0.33	8.03	1.67	Nil	3.7	-	0.40	13.35	12.7

In general, the distribution of cations followed the order of Ca, >Na >Mg > K in Koradacheri, Kottur, Muttupt, Nidamangalam, andThiruthuraipundi whereas the distribution of cations followed the order of Na > Ca >Mg> K. Kudavasal, Mannarkudi, Nannilam, Thiruvarur and Valangaiman.With respect to the distribution of anions followed the order of HCO_3> Cl > CO_3 > SO_4 in Koradacheri whereas in the remaining blocks the distribution of anions followed the order of Cl > HCO_3> CO_3 > SO_4 (Table 22).

Table 22: Cationic and Anionic distribution in ground water samples of Thiruvarur district

Blocks	Cationic order	Anionic order
Koradacheri	$Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}$	$HCO_3^{-}> Cl^{-}> CO_3^{2-} > SO_4^{2}$
Kottur	$Ca^{2+}> Na^{+}>Mg^{2+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2-}$
Kodavasal	$Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2}$
Mannarkudi	$Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2}$
Muttupt	$Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2}$
Nannilam	$Na^{+}> Ca^{2+}>Mg^{2+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2}$
Nidamangalam	$Ca^{2+}> Na^{+}>Mg^{2+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2}$
Thiruthuraipundi	$Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2}$
Thiruvarur	$Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2}$
Valangaiman	$Na^{+}> Ca^{2+}> Mg^{2+}> K^{+}$	$Cl^{-}> HCO_3^{-}> CO_3^{2-} > SO_4^{2}$

Out of the total samples collected in Thiruvarur district, 83.2 % is coming under good quality, 9.93 % is marginally saline, 3.72 % is marginally alkaline, 1.24 % is alkaline, 0.62 % high SAR saline and 1.24 % highly alkaline. Among the 10 blocks, the distribution of good quality samples was the highest in Thiruthuraipundi (100%) and the lowest in

Nannilam (53.3%) Block. The occurrence of marginally saline water (5.6 to 19.0%) was prevalent in all the Blocks, marginally alkali water is prevalent in Kudavasal (10%), Nannilam (26.7%) and Valangaiman (4.8%). Alkali water was prevalent in Nannilam (13.3%) and highly alkali was found in Koradacheri (5.5%) and Kudavasal (10%) block. High SAR saline water was found in Valangaiman block only (4.8%) (Table.23 and Fig.17).The spatial distribution of ground water quality categories is provided in Fig. 18.

Table 23: Water Quality Distribution (%) in Thiruvarur District

S.No.	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	Koratacheri	18	77.8	16.7					5.5
2	Kottur	22	90.9	9.1					
3	Kudavasal	10	80				10		10
4	Mannarkudi	16	81.2	18.8					
5	Muttupet	18	94.4	5.6					
6	Nannilam	15	53.3	6.7			26.7	13.3	
7	Nidamangalam	11	90.9	9.1					
8	Thiruthuraipundi	21	100						
9	Thiruvarur	9	88.9	11.1					
10	Valangaiman	21	71.4	19.0		4.8	4.8		
	Total	161	83.2	9.93		0.62	3.72	1.24	1.24

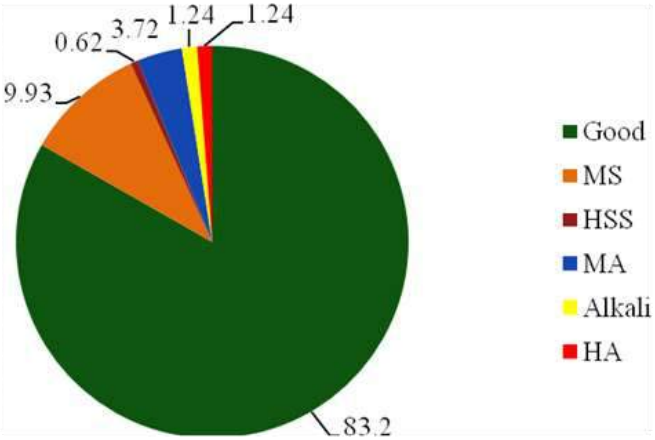

Fig. 17. Percentage distribution of ground water quality in Thiruvarur district

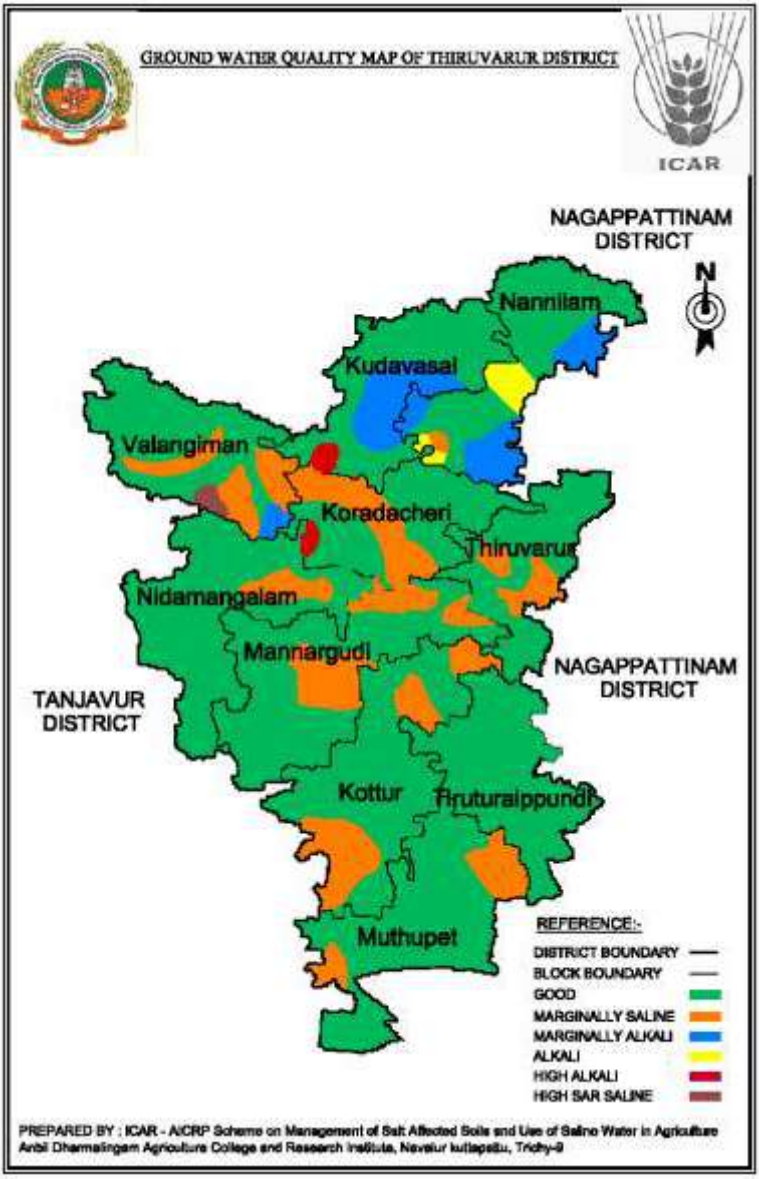

Fig. 18: Spatial distribution of ground water quality categories for Thiruvarur district

2.9 Cuddalore District

The district of Cuddalore lies on the East coast. It is bounded on the north by Villupuram district, on the south by Nagapattinam district, on the west by Perambalur and Villupuram districts and on the east by Bay of Bengal. Headquarter of this district is Cuddalore. The Southern boundary follows for the greater part of the length of two rivers - the Vellar and the Coloroon. The district lies between 78° 38′ and 80° East latitude and 11° 11′ and 12° 35′ North longitude. The total geographical area of the district is about 3,678 sq.km. The Cuddalore district comprises of 3 revenue divisions, 7 revenue taluks, 32 firka and 896 revenue villages.

Rainfall, Climate and Geo-hydrology

The district has a hot tropical climate. The summer season, which is very oppressive, is from March to May. The South West monsoon, which follows, lasts till September. October to December constitutes North East monsoon season. January to February is the comparatively cooler period. The annual normal rainfall for the period (1901-2000) ranges from 1050-1400 mm. The normal annual rainfall over the district varies from about 1050 mm to about 1400 mm. It is the minimum around Vriddhachalam (1051.3 mm). It gradually increases and reaches a maximum around Chidambaram (1402.6 mm) and Portonovo (1347.1). The contributions of individual seasons are as follows: NE-57%, SW-31%, Summer 7% and winter 5%.

The predominant geological formations of Cuddalore district are mainly on Charnockite, Sandstone, Laterite and Alluvium. The hydrogeology is mainly based on major water

bearing formation *viz.*, Weathered and fractured Charnockite, sandstone, Limestone and Alluvium. The pre-monsoon depth of ground water table is ranged from 1.5 to 17.54 m bgl (May, 2006) and post-monsoon depth of ground water table is ranged from 0.04 to 7.46 m bgl (January, 2007). The long term ground water level trend was decreased from the year 1996 to 2007. The rate of minimum and maximum level of ground water level trend was fall on 1.2953 and 1.275 m/year, respectively whereas the rise on maximum and minimum of 0.02147 and 0.0424 m/year, respectively (Dhinagaran, 2009).

Survey and Characterization of Ground Water Quality of Cuddalore District for Irrigation

To characterize the ground water quality of Cuddalore district 161 bore well sample locations were chosen based on GPS location to collect ground water samples in 13 blocks of Cuddalore district during May, 2018. Classification of water quality is done based on EC, SAR and RSC values as suggested by CSSRI, Karnal.Cuddalore District has 13 Blocks *viz.*, Panruti, Cuddalore, Annagaramam, Kurinjipadi, Bhuvanagiri, Keerapalayam, Kattumannarkoil, Kammapuram, Virudhachalam, Nallur, Mangaloore Kumaratchi and Parangipettai. The ranges for pH, ground water (EC), Residual Sodium Carbonate (RSC) and Sodium Adsorption Ratio (SAR) for these blocks (Table24).

Table 24: Quality of ground waters in different blocks of CuddaloreDistrict

Name of the Block	pH			EC (dSm^{-1})			RSC (meq. l^{-1})			SAR		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Panruti	7.21	8.47	7.89	0.14	2.64	1.10	0.82	1.81	1.37	2.46	5.37	4.32
Cuddalore	6.43	8.58	8.09	0.35	2.07	1.04	0.36	2.86	1.65	1.94	5.21	3.55
Annagramam	7.73	8.34	8.05	0.74	1.49	1.08	0.17	2.36	1.39	2.02	5.23	3.26
Parangipettai	7.16	8.12	7.78	2.14	11.53	4.39	1.76	3.48	2.47	1.87	39.9	8.83
Kurinchipadi	6.52	8.58	7.65	1.98-	3.06	2.43	0.71	2.48	1.88	1.77	4.51	3.38
Bhuvanagiri	7.71	8.32	7.99	1.34	5.62	2.60	0.43	2.46	1.64	2.23	5.72	3.84
Keerapalayam	7.83	8.35	8.08	0.63	3.77	1.38	1.36	2.47	2.03	1.77	4.71	2.99
Kattumannarkoil	7.36	8.53	7.93	0.62	1.42	0.96	0.14	2.28	1.42	1.98	5.10	3.41
Kumarachi block	7.02	8.46	7.74	4.02	17.62	7.42	1.63	5.77	2.96	2.87	5.22	15.03
Kammapuram	6.96	8.64	7.77	0.46	1.43	0.90	0.10	2.17	1.20	2.08	4.66	3.19
Virudhachalam	6.54	7.96	7.18	0.38	1.28	0.75	0.46	2.34	1.63	1.99	5.02	3.12
Nallur	7.63	10.83	8.42	0.46	3.02	1.42	0.12	2.26	1.28	1.99	4.88	3.14
Mangaloor	6.87	9.03	8.09	0.96	3.15	1.45	0.26	2.17	0.86	1.91	5.55	3.70

The various ionic constituents like cations viz., Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and anions *viz.*, CO_3^{2-}, $HCO_3^{-}Cl^{-}$, $SO4^{2-}$ were analyzed and cationic and anionic distribution pattern for varies blocks (Table 25). The total cations and anions dominantly present in Kumaratchi block while comparing with other blocks in cuddalore district. The cationic order $Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$ was found in Panruti, Cuddalore, Annagaramam, Kurinjipadi, Bhuvanagiri, Keerapalayam, Kattumannarkoil, Kammapuram, Virudhachalam, Nallur, Mangaloore blocks and also another cationic order ($Na^{+} > Mg^{2+} > K^{+} > Ca^{2+}$) was found in Kumaratchi and Parangipettai block of cuddalore district. The anionic order $HCO_3^{-} > Cl^{-} > CO_3^{2-} > SO_4^{2-}$ was found in Cuddalore, Annagaramam, Kurinjipadi, Bhuvanagiri, Keerapalayam, Kattumannarkoil, Kammapuram, Virudhachalam, Nallur, Mangaloore blocks except Kumaratchi and Parangipettai and Panruti has $Cl^{-} > HCO3^{-} > CO_3^{2-} > SO_4^{2-}$.

Table 25: Cationic and Anionic distribution in ground water samples of Cuddalore district

Blocks	Cationic order	Anionic order
Panruti block	$Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$	$Cl^{-} > HCO_3^{-} > CO_3^{2-} > SO_4^{2-}$
Cuddalore block	$Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$	$HCO_3^{-} > Cl^{-} > CO_3^{2-} > SO_4^{2-}$
Annagramam block	$Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$	$HCO_3^{-} > Cl^{-} > CO_3^{2-} > SO_4^{2-}$
Parangipettai block	$Na^{+} > Mg^{2+} > K^{+} > Ca^{2+}$	$Cl^{-} > HCO_3^{-} > CO_3^{2-} > SO_4^{2-}$
Kurinchipadi block	$Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$	$HCO_3^{-} > Cl^{-} > CO_3^{2-} > SO_4^{2-}$
Bhuvanagiri block	$Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$	$HCO_3^{-} > Cl^{-} > CO_3^{2-} > SO_4^{2-}$
Keerapalayam block	$Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$	$HCO_3^{-} > Cl^{-} > CO_3^{2-} > SO_4^{2-}$
Kattumannarkoil block	$Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$	$HCO_3^{-} > Cl^{-} > CO_3^{2-} > SO_4^{2-}$

Kumarachi block	Na^{+}> Mg^{2+}> K^{+}> Ca^{2+}	Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}
Kammapuram block	Mg^{2+}> Na^{+}> Ca^{2+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}
Virudhachalam block	Mg^{2+}> Na^{+}> Ca^{2+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}
Nallur block	Mg^{2+}> Na^{+}> Ca^{2+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}
Mangaloor block	Mg^{2+}> Na^{+}> Ca^{2+}> K^{+}	HCO_3^{-}> Cl^{-}> CO_3^{2-}> SO_4^{2-}

Out of the total ground water samples collected from Cuddalore district, 69.9 per cent is coming under good quality, 16.27 per cent is marginally saline, 9 per cent is saline water, 0.8 per cent is marginally alkali and 3.4 per cent is under high alkali categories. Hence, around 70 percent of the ground water resources can only be made available for irrigation purpose, the remaining are under threat (Table 26 and Fig 19). The spatial distribution of ground water quality categories is provided in Fig. 20.

Table 26: Water quality distribution (%) in Cuddalore district

S.No.	Blocks	No. of samples collected	Good	Marginally saline	Saline	High SAR saline	Marginally alkali	Alkali	High alkali
1.	Panruti	11	90.9	9.1	-	-	-	-	-
2.	Cuddalore	25	92	4	-	-	4	-	-
3.	Annagramam	12	100	-	-	-	--	-	-
4.	Parangipettai	13	-	39	38.5	-	7	-	15.4
5.	Kurinchipadi	16	6.3	93.7	-	-	-	-	-
6.	Bhuvanagiri	14	50	35.7	14.3	-	-	-	-
7.	Keerapalayam	10	90	10	-	-	-	-	-
8.	Kattumannarkoil	10	100	-	-	-	-	-	-
9.	Kumarachi	10	-	-	70	-	-	-	30
10.	Kammapuram	10	100	-	-	-	-	-	-
11.	Virudhachalam	10	100	-	-	-	-	-	-
12.	Nallur	10	90	10	-	-	-	-	-
13.	Mangaloor	10	90	10	-	-	-	-	-
	Average	161	69.9%	16.27%	9%	-	-	-	3.4%

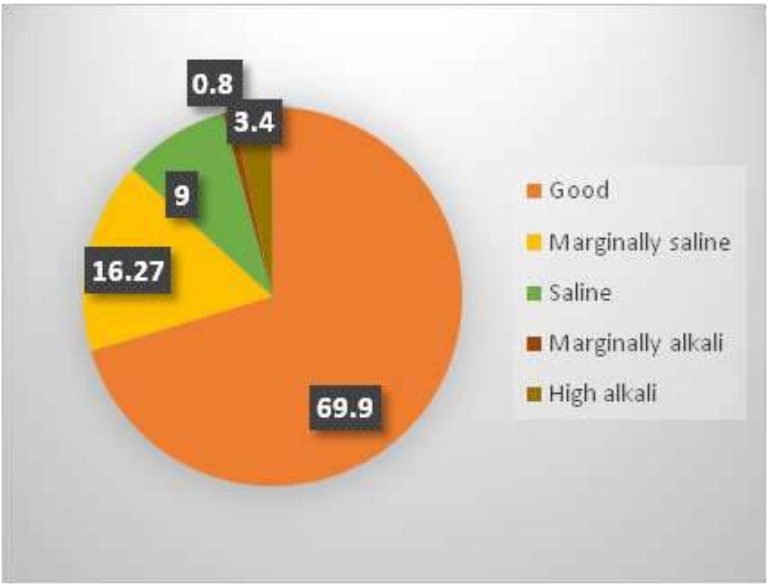

Fig.19: Percentage distribution of quality of ground water samples of Cuddalore district

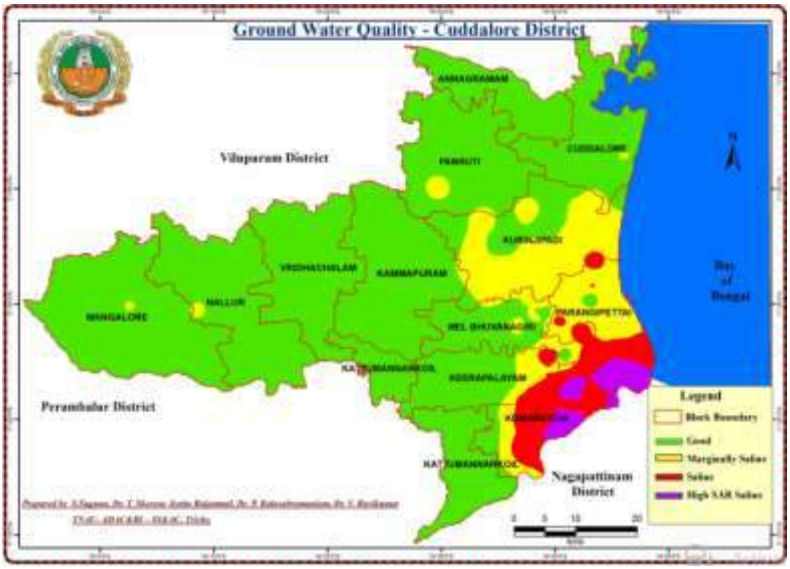

Fig. 20: Spatial distribution of ground water quality categories for Cuddalore district

2.10 Villupuram District

A study was undertaken to assess the ground water quality in Villupuram district by collecting 143 ground water samples using GPS and analyzed for pH, EC, anions *viz*., HCO_3^-, CO_3^-, Cl^-, SO_4^{2-} and cations *viz*., Ca^{2+}, Mg^{2+}, Na^+ and K^+ by adopting standard procedures and thematic maps were prepared using Arc GIS software 10.1. The investigation revealed that ground water samples with respect to pH ranged from 7.0 to 8.4 with mean of 7.7 and EC ranged from 0.27 to 4.35 dSm^{-1} with mean of 1.14 dSm^{-1}, respectively. Residual Sodium Carbonate (RSC) varied from nil to 11.10 meq L^{-1} and Sodium Absorption Ratio (SAR) ranged from 0.26 to 20.31 with a mean SAR of 0.93. In the coastal blocks surveyed, the frequency of good quality water was more in Marakkanam block based on the CSSRI, Karnal water quality classification. The Vanur blocks have the highest alkalinity (75%) and the lowest alkalinity was found in Marakkanam block (63.63%). Based on the results of this investigation, only 9.09 per cent of samples were of good quality, Viluppuram district of the coastal blocks. Alkali accounted for 69.3% among all samples, with 12.87 per cent (marginal Alkali), 8.71 per cent (marginal saline) and 4.54 per cent (marginal saline) following closely behind (high SAR saline). The largest percentage of alkali water samples were found in Vanur. In the Marakkanam blocks, there was an equal percentage of good water, marginal saline, high SAR saline and marginal alkali. 95.45 per cent of samples in Viluppuram district's coastline blocks had varying salinity levels, which could be related to the district's wide coastal line and the district's prolonged drought.

Water quality distribution (%) in Villupuram district

In general, the distribution of cations followed the order of Na^{+}> Mg^{2+}> Ca^{2+}>K^{+} and anions followed the order of Cl^{-}> HCO_3^{-}> CO_3^{2-}> SO_4^{2-}, respectively (Table 27). The distribution of water samples in different water quality classes reveals that the samples of Alkaline quality ground water was found in all the blocks and recorded highest in Koliyanur andKandamangalam blocks (100%), Vikkravandi (92.3%), Thiruvennainallur (87.5%), Olakkur and Melmalayanur blocks (80%), Mugaiyur (76.9%), Vanur (75%), Gingee (64.3%), Marakkanam (63.6%), Vallam (62.5%), Kanai(46.2%), Mailam (33.3%). The Marginal Alkali water was found highest in Kanai Block (46.2%), followed by Mailam (41.7%), Melmalayanur and Olakkur blocks (20%), Vallam (18.8%), Marakkanam (18.2%), Vanur (16.7%), Mugaiyur (15.4%), Thiruvennainallur (12.5%), Vikkravandi (7.7%). The samples of good quality ground water were found in Mailam (25%), Vallam (18.8%), Kanai (7.7%), and Gingee (7.1%). The samples of Marginal saline quality ground water were found in Marakkanam (9.1%), Vanur (8.3%), and Mugaiyur (7.7%). The High-SAR saline water was only found in Marakkanam (9.1%). Ground water samples of saline and high alkali quality were not observed in any of the Villupuram district blocks (Table 28and Fig.21).The spatial distribution of ground water quality categoriesis provided in Fig.22.

Table 27.Cationic and anionic pattern in different blocks of Villupuram district

S.No.	Block Name	Cations($meqL^{-1}$)				Cationicorder	Anions($meqL^{-1}$)				Anionicorder
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		CO_3^{2-}	$HCO3^{-}$	Cl^{-}	SO_4^{2-}	
1	Mailam	1.55	1.8	0.80	0.02	Mg^{2+}> Ca^{2+}>Na^{+}>K^{+}	2.0	6.0	6.5	0.29	Cl^{-}>HCO_3^{-} > CO_3^{2-}>$SO4^{2-}$
2	Vallam	2.10	2.0	1.33	0.05	Mg^{2+}> Ca^{2+}>Na^{+}>K^{+}	4.0	5.5	8.5	0.40	Cl^{-}>HCO_3^{-} > CO_3^{2-}>$SO4^{2-}$
3	Melmalayanur	2.05	1.4	1.10	0.04	Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}	4.0	6.5	8.0	0.36	Cl^{-}>HCO_3^{-} > CO_3^{2-}>$SO4^{2-}$
4	Gingee	1.75	1.5	1.54	0.03	Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}	4.0	7.0	9.0	0.69	Cl^{-}>HCO_3^{-} > CO_3^{2-}>$SO4^{2-}$
5	Vikkravandi	2.30	1.9	1.60	0.04	Ca^{2+}>Mg^{2+}>Na^{+}> K^{+}	4.0	6.0	12.0	0.33	Cl^{-}>HCO_3^{-} > CO_3^{2-}>$SO4^{2-}$
4	Kanai	2.40	2.4	2.08	0.07	Ca^{2+}=Mg^{2+}>Na^{+}> K^{+}	4.0	5.0	18.0	0.50	Cl^{-}>HCO_3^{-} > CO_3^{2-}>$SO4^{2-}$

7	Mugaiyur	1.50	2.2	1.52	0.07	$Mg^{2+}>Na^{+}>Ca^{2+}>K^{+}$	4.0	5.0	12.0	0.50	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO4^{2-}$
8	Thiruvennainallur	1.85	1.6	1.15	0.05	$Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$	6.0	4.5	8.0	0.42	$Cl^{-}>CO3^{-}>HCO_3^{2-}>SO4^{2-}$
9	Marakkanam	1.60	4.0	1.16	0.02	$Mg^{2+}>Ca^{2+}>Na^{+}>K^{+}$	4.0	5.0	8.0	0.44	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO4^{2-}$
10	Vanur	1.60	2.4	0.88	0.05	$Mg^{2+}>Ca^{2+}>Na^{+}>K^{+}$	4.0	6.0	6.5	0.42	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO4^{2-}$
11	Olakkur	1.45	2.5	1.79	0.30	$Mg^{2+}>Na^{+}>Ca^{2+}>K^{+}$	4.0	6.0	8.0	0.39	$Cl^{-}>HCO_3^{-}>CO_3^{2-}>SO4^{2-}$
12	Koliyannur	0.90	1.2	2.48	1.03	$Na^{+}>Mg^{2+}>K^{+}>Ca^{2+}$	6.0	2.0	10.0	0.48	$Cl^{-}>CO3^{2-}>HCO_3^{-}>SO4^{2-}$
13	Kandamangalam	1.65	1.85	2.27	1.03	$Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$	7.0	5.5	12.0	0.64	$Cl^{-}>CO3^{2-}>HCO_3^{-}>SO4^{2-}$

Table 28: Water quality distribution (%) in Villupuram district

S. No.	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Mailam	12	25.0	-	-	-	41.7	33.3	-
2.	Vallam	16	18.8	-	-	-	18.8	62.5	-
3.	Melmalayanur	10	-	-	-	-	20.0	80.0	-
4.	Gingee	14	7.1	-	-	-	-	64.3	-
5.	Vikkravandi	13	-	-	-	-	7.7	92.3	-
6.	Kanai	13	7.7	-	-	-	46.2	46.2	-
7.	Mugaiyur	13	-	7.7		-	15.4	76.9	-
8.	Thiruvennainallur	08	-	-	-	-	12.5	87.5	-
9	Marakkanam	11	-	9.1	-	9.1	18.2	63.6	-
10.	Vanur	12	-	8.3	-	-	16.7	75.0	-
11.	Olakkur	10	-	-	-	-	20.0	80.0	-
12.	Koliyanur	05	-	-	-	-	-	100.0	-
13.	Kandamangalam	06	-	-	-	-	-	100.0	-
	Average	**143**	**6**	**2**	**-**	**1**	**18**	**73**	-

Marginal Saline (MS), High-SARSaline(HSS), Marginally Alkali(MA), High Alkali (HA)

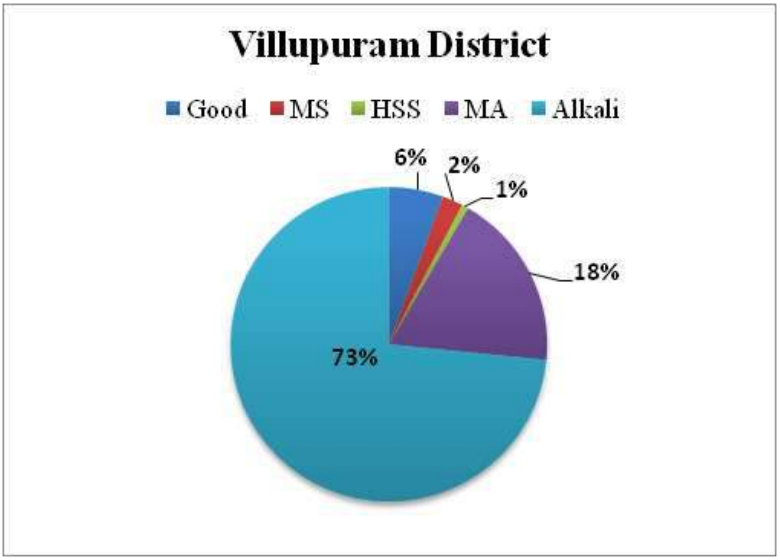

Fig 21. Percentage distribution of ground water quality in Villupuram district

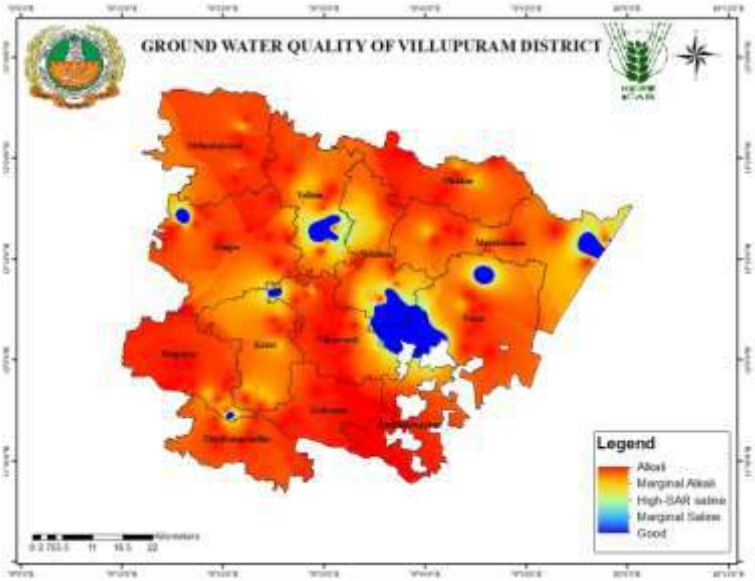

Fig. 22. Spatial distribution of different categories of ground water quality in Villupuram district

2.11 Chengalpattu District

According to the inquiry, alkali made up 45% of the district of Chengalpattu, while marginal alkali made up 31%. 16% of samples fall into the good quality category, whereas 4% fall into the marginal saline and highly alkali categories. These results were compared to Vishnupriya*et al.,* (2021) who found that 73.42% of samples come under alkali followed by marginal alkali (18.18%). The risk of sodium (Alkali) substituting for calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the soil through the cation exchange process damages the soil structure, namely permeability, which eventually affects the physical qualities of the soil and lowers crop output (Islam and Shamsad,2009).

The distribution of water samples in different water quality classes in Chengalpattu district reveals that most of the samples come under the alkaline category. In this St. Thomas Mount account for 80% followed by Madhuranthagam (53%), Thiruporur (46%), Thirukalukundram (42%), Chithamur and Acharambakkam (41%), Lathur(40%) and Kattankolathur (38%). Marginally alkali water found highest in Lathur (46%), Thirukalukundram and Thiruporur (36%), Chithamur (33%), Madhuranthagam (28%), Kattankolathur (22%), Acharambakkam (18%) and St.ThomasMount (13%). The highly alkali present in Acharambakkam (18%), Kattankolathur (9%), Chithamur(7%), Thirukalukundram and Madhuranthagm block have 3% of highly alkali water. The marginal saline water highly present in Chithamur (7%) followed by Thirukalukundram and Kattankolathur (6%), Acharambakkam (5%), Thiruporur and Lathur (3%). The

highest amount of good quality present in Kattankolathur (25%) followed by Acharambakkam (18%),Chithamur (17%), Madhuranthgam (16%), Thiruporur (15%), Thirukalukundram (13%), Lathur (11%) and St.Thomas mount (7%) (Fig.23). Ground water samples of saline and high SAR saline not found in Chengalpattu district.Kumar *et al.* (2019) finds similar reports. There is just a little amount of good quality water in the Ramanathapuram area since only 10% of water samples are considered to be of good quality.

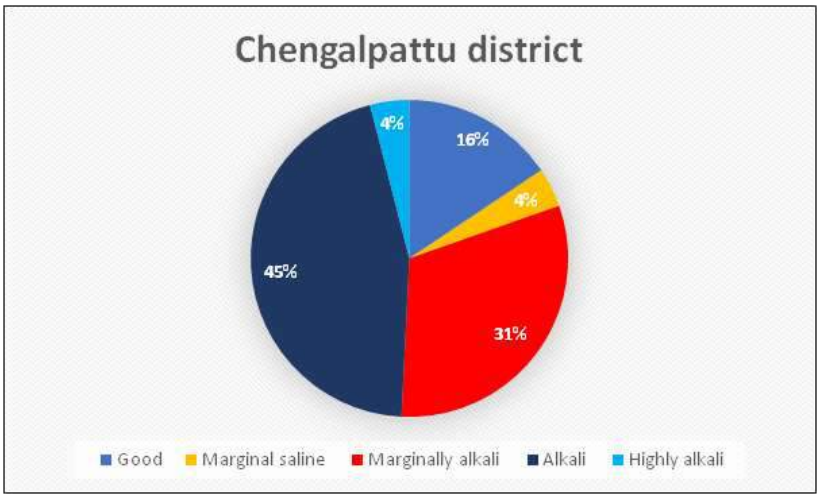

Fig.23: Percentage distribution of ground water quality in Chengalpattu district

Mapping of Water Quality Parameters

The CSSRI water quality classification was used to categorise ground water samples based on EC, SAR, and RSC. The Arc GIS Software 10.1 was used to create thematic maps of several water quality criteria in Chengalpattu district. The spatial distribution of the Chengalpattu district ground water quality map is presented in figure 18.The thematic map of

Chengalpattu district represents that most of the samples comes under alkali categories followed by marginally alkali. These results were corroborated with Monisha, (2021) and Vishnupriya*et al*. (2021).

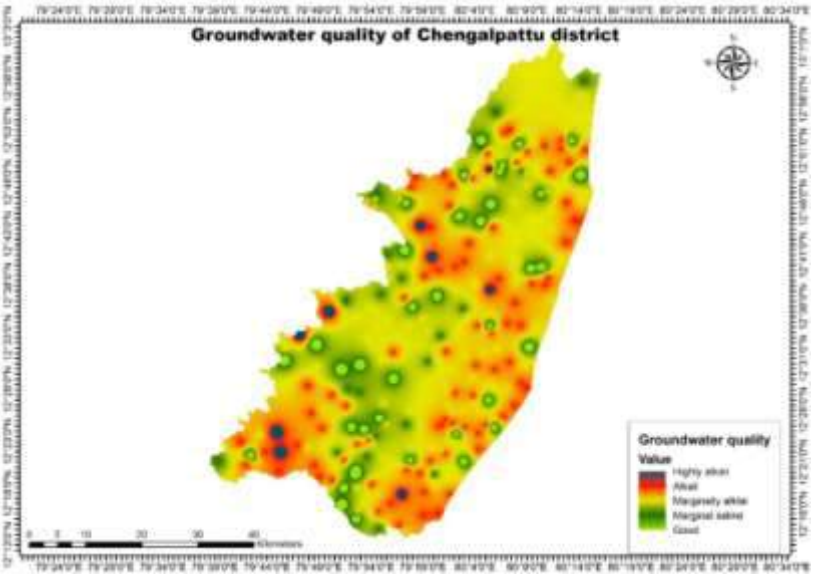

Fig.24: Spatial distribution of different categories of ground water quality in Chengalpattu district

2.12 Thiruvallur District

Out of the total 166 samples collected in Tiruvallur district, 34 per cent is characterized under good quality, 2 percent characterized as marginally saline, 41 per cent characterized as marginally alkali, 23 per cent characterized as Alkali (Fig.25). Spatial distribution of different quality parameters of ground water of Tiruvallur district is shown in Fig.26. The samples with good quality were found in the following blocks: Minjur (32 per cent), Puzhal (29per cent), Ambathur (30per cent), Poondi (30 per cent),Tiruvelangadu (60 per cent), Tiruthani (20 per cent), R.K.Pet (20 per cent), Pallipet (30 per

cent), Thiruvallur (33per cent), Sholavaram (55 per cent), Gummidipoondi (39 per cent), Ellapuram (30 per cent), Kadambathur (20 per cent), Poonamallee (13 per cent).The marginal saline was recorded in Tiruvelangadu(20 per cent) and Poonamallee (11 per cent) (Table.29). The samples with Marginally alkali water was found in the following blocks:Minjur (44 per cent), Puzhal (57per cent), Ambathur (10 per cent), Poondi (50 per cent), Tiruthani (60 per cent), R.K.Pet (50 per cent), Pallipet (40 per cent), Thiruvallur (40per cent), Sholavaram (27 per cent),Gummidipoondi(50 per cent), Ellapuram (40 per cent), Kadambathur (60 per cent), and Poonamallee (63 per cent).The samples with alkali water were found in the following blocks: Minjur (24 per cent), Puzhal (14per cent), Ambathur (60per cent), Poondi (20 per cent), Tiruvelangadu (20 per cent), Tiruthani (20 per cent), R.K.Pet (30 per cent), Pallipet (30 per cent), Thiruvallur (27per cent), Sholavaram (18 per cent),Gummidipoondi(11 per cent), Ellapuram (30 per cent), Kadambathur (20 per cent) and Poonamallee (13 per cent).

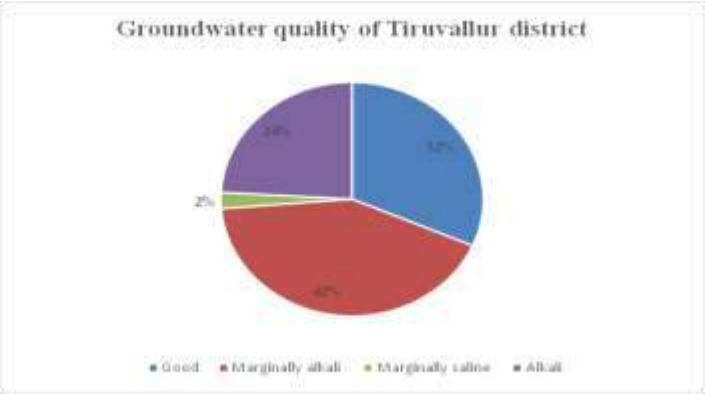

Fig.25: Percentage distribution of ground water quality in Tiruvallur district

Table 29: Water quality distribution in Tiruvallur district

S.No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	Minjur	25	32	-	-	-	44	24	-
2	Puzhal	7	29	-	-	-	57	14	-
3	Villivakkam	10	30	-	-	-	10	60	-
4	Poondi	10	30		-	-	50	20	-
5	Tiruvelangadu	10	60	20	-	-		20	-
6	Tiruthani	11	20	-	-	-	60	20	-
7	R.K.Pet	11	20	-	-	-	50	30	-
8	Pallipet	10	30	-	-	-	40	30	-
9	Tiruvallur	15	33	-	-	-	40	27	-
10	Sholavaram	11	55	-	-	-	27	18	-
11	Gummidipoondi	18	39	-	-	-	50	11	-
12	Ellapuram	10	30	-	-	-	40	30	-
13	Kadambathur	10	20	-	-	-	60	20	-
14	Poonamallee	8	13	11	-	-	63	13	-

MS-Marginally saline; MA-Marginally alkali; HA-Highly alkali; HSS-High SAR saline

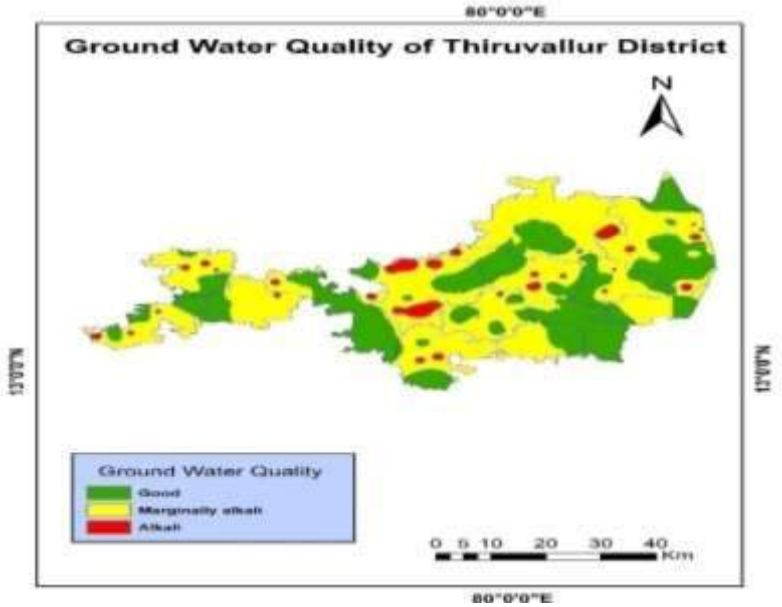

Fig.26: Spatial distribution of different quality parameters of ground water at Tiruvallur district

3. MANAGEMENT OPTIONS FOR POOR QUALITY WATER USE IN AGRICULTURE

Appropriate selection of crops, improvement in water management and maintenance of soil structure/permeability are necessary for sustaining irrigation with these poor quality water (Minhas *et al.*,1998; Kaledhonkar et al. 2019). A committee of consultants recommended the guidelines for utilising poor quality water in 1990 for their wider applicability in different agro-ecological zones of India (Table30).

Table 30: Guidelines for using poor quality ground waters for irrigation in India

a. Saline water (RSC < 2.5 me/L)

Soil texture (% clay)	Crop Tolerance	ECw (dS/m) limit for rainfall region		
		< 350	350-550	> 550 mm
Fine (>30)	Sensitive Semi-tolerant Tolerant	1.0 1.5 2.0	1.0 2.0 3.0	1.5 3.0 4.5
Moderately fine (20-30)	Sensitive Semi-tolerant Tolerant	1.5 2.0 4.0	2.0 3.0 6.0	2.5 4.5 8.0
Moderately coarse (10-20)	Sensitive Semi-tolerant Tolerant	2.0 4.0 6.0	2.5 6.0 8.0	3.0 8.0 10.0

Coarse (<10)	Sensitive Semi-tolerant Tolerant	-- 6.0 8.0	3.0 7.5 10.0	3.0 9.0 12.5

b. Alkali waters (RSC > 2.5 me/L, EC_{iw}< 4.0 dS/m)

Soil texture (%clay)	**SAR (mmol/l) ½**	**Upper limit of RSC (me/L)**	**Remarks**
Fine (> 30)	10	2.5 - 3.5	Limits pertain to *kharif* fallow/*Rabi* crop rotation when annual rainfall is 350-550 mm. When the water have Na < 75% (Ca+Mg > 25%) or rainfall is 550 mm, the upper limit of the RSC range becomes safe, RSC neutralization with gypsum is essential based on quantity of water used during the *rabi* season. Grow low water requiring crops during *kharif*.
Moderately fine	10	3.5 - 5.0	
Moderately coarse	15	5.0 - 7.5	
Coarse (> 10)	20	7.5 - 10	

3.1 Management of Saline Water

Plant growth is affected adversely with saline irrigation primarily through the impacts of excessive salts on osmotic pressures of the soil solution. Under the field situations, the first reaction of plants to the use of saline water is reduction in the germination but the most conspicuous effect is the growth retardation of crops. A general conclusion can be that the detrimental effects of salinity include reduced initial growth resulting in smaller plants. These smaller plants with lesser leaf area in turn are able to produce lesser assimilates for their conversion to seeds.

3.1.1 The management options for successful use of saline water are as follows

For successful utilisation of saline water, crops those are semi-tolerant to tolerant (mustards, wheat, cotton), as well as those with low water requirement are recommended while crops like rice, sugarcane and berseem, those require liberal water use, should be avoided. In low rainfall areas (< 40cm), mono-cropping is recommended for maintaining salt balances.

The accumulation of salts vis-à-vis tolerance limits to the use of saline waters gets modified with soil texture, annual rainfall and ionic constituents of salinity. As a 'thumb rule' accumulation of salts is nearly one half that of irrigation water in coarse textured soils (loamy sand and sand). It is equal to that of irrigation water in medium textured sandy loam to loam soils and more than two times in fine textured soils (clay and clay loam). In other terms, irrigation with water of salinity 8 dSm^{-1} would result in soil salinity of about 4, 8 and 16 dSm^{-1}

in loamy sand, sandy loam and clay loam soils, respectively. Thus, waters of as high salt concentration as having an EC of 12 dSm^{-1} can be used for growing tolerant and semi-tolerant crops in coarse textured soils, provided the annual rainfall is not less than 400 mm. But in fine textured soils, waters with EC more than 2 dSm^{-1} would often create salinity problems.

One of the fortunate situations with continental monsoon climate of India is the concentration of rains in a short span of 2-3 months. In Tamil Nadu during North East monsoon (October-December) majority of rainfall is received. Thus, if the water penetrating into soils during this period exceeds the evapo-transpiration demands of crops, it induces leaching of salts added through saline irrigation to summer or *Kharif* winter crops or in low rainfall regions. The amount and frequency of rains basically govern the salt leaching occurring during monsoon season but soil texture has also been shown to influence leaching.Predictions show that removal of 80% of the salts accumulated during the period preceding monsoons would require 1.85, 0.95 and 0.76 cm of rainwater per cm soil depth in fine, medium and coarse textured soils. Thus, in areas with annual rainfall less than 250 mm, saline waters of EC about 4 dSm^{-1} will cause salt toxicity in most of the crops. But in areas where annual rainfall exceeds 500 mm, waters up to an EC of 16 dSm^{-1} could be gainfully utilised for saline tolerant crops in coarse textured soils. Such waters, however, should not be used for raising *kharif* or summer season crops. Chlorides, being more toxic tend to reduce the tolerance limits of crops to the use of saline water by 1.2-1.5 times as compared with sulphate rich waters). Similarly, more salts tend to accumulate in soils when irrigated with waters of high

SAR and thus these also tend to reduce the limits of saline water use. All crops do not tolerate salinity equally well at different stages of their growth *e.g.* germination and early seedling establishment being the most critical stage followed by the phase changes from vegetative to reproductive *i.e.* heading and flowering to fruit setting. Therefore, the use of saline waters should be avoided during initial stages of crop growth (Table 31).In addition to intergenic variations, crop cultivars also vary in their tolerance to salinity. Such cultivars have been identified on their rating for high yield potential, salt tolerance and stability under saline environments.

Table 31: Salt tolerance of crops

Category	Crops
Sensitive	
Field crops	Field bean, green gram, lentil
Fodders (Forage)	Red clover, white clover, guar (cluster bean)
Vegetables	Celery, radish, green bean
Fruits	Peach, apricot, pear, apple, plum, strawberry, blackberry
Semi salt tolerant	
Field crops	Oats, rice, sorghum, maize, pearl millet, wheat (improved var.), pigeon pea, gram, castor, flax, soybean, rye
Fodders (forage)	Senji (Melilotus sp.), sorghum, maize, berseem,cowpea, ryegrass, sudan grass, oat

Vegetables	Tomato, cabbage, cauliflower, lettuce, potato, radish, carrot, onion, ladies finger, pea, cucumber, pumpkin, sweet potato
Fruits	Grape, olive, fig, guava, mango, banana, pomegranate, orange, lemon, almond, pineapple
Salt tolerant	
Field crops	Barley, dhaincha (*Sesbania sp*.) sugar beet, tobacco, cotton, wheat (some local var.), sugarcane, rapeseed, dub grass (*Cyanodon sp*.),
Fodders (Forage)	Rhodes grass, Bermuda grass
Vegetables	Beetroot, asparagus, spinach, kale, turnip
Fruits	Date palm, coconut, falsa (*Grewia sp*)

3.2 Management of Alkali Waters

These waters are characterised by low total salt concentration (EC < 4 dSm^{-1}) while the proportion of Ca and Mg salts is much smaller as compared with Na that often constitutes >70 per cent of the total cations. Such waters usually have sodium bicarbonate as the predominant salt such that their RSC > 2.5 me L^{-1}. In certain cases, the calcium salts may be nearly absent. Irrigation with alkali waters leads to increase in alkalinity and sodium saturation in soils. The increase in exchangeable sodium percentage (ESP) adversely affects soil physical properties including water infiltration and soil aeration. On drying soils become very hard and on wetting the soil particles get dispersed and clog the soil pores, which affect root respiration and development. The waters with low Ca^{2+} (<2 me L^{-1}) and high amounts of carbonates

result in specific toxicity symptoms on plants. These include scorching and leaf burning at the early seedling development stage of crops.

3.2.1 Crop selection

As is the case with salinity, considerable variations also exist in the tolerance of crops to sodicity in soils and the crops may be accordingly selected as per the expected sodicity build up from the use of particular alkali water (Table 32).

Table 32 Relative Tolerance of Crops to Alkalinity/Sodicity in Soils

ESP Range	Crops
10-15	Safflower, peas, pigeon-pea, black gram, green gram
16-20	Bengal gram, soybeans
20-25	Ground nut, cowpea, onion, pearl-millet
25-30	Garlic, guar
30-50	Sunflower
50-60	Sesbania
60-70	Rice

Cultivation of high water requiring crops like sugarcane and rice should be avoided with alkali waters as these aggravate the sodicity problems. In low rainfall areas (average annual rainfall < 400 mm) if the good quality canal water is not available, it is advisable to keep the fields fallow during *kharif* season. During *rabi*, only tolerant and semi-tolerant crops should be grown.For areas having rainfall > 400 mm/annum, it is ensured that sowing, particularly of *kharif* crops is done with rain water or good quality canal water.

Besides, not more than 2 to 3 irrigations should be applied with alkali waters in the *kharif*.Alkali waters should not be used for growing summer crops in the month of April to June.

3.2.2 Amendment needs

Adverse effect of alkali waters on physical properties of the soil can be mitigated, provided calcium-bearing amendments like gypsum is used. It is considered as the cheapest source of calcium and is available in large quantity in the country. Acids or the acid forming substances such as sulphuric acid or pyrites can also be used which on reaction with soil $CaCO_3$ release Ca^{2+}. However, by virtue of low cost and ease in handling, gypsum is by far the most suitable amendment for creating favourable sodium to calcium ratio and the crop growth is highly improved.

Quantity of gypsum: Application of gypsum has earlier been recommended when RSC of irrigation water exceeds 2.5 me/L (Plate 1). However later on it has been shown that factors such as the level of the existing deterioration of the soil, cropping intensity and the water requirements of the crops to be raised will ultimately decide the amount of gypsum required. Field observations are that gypsum helps in maintaining the yields of the crops irrigated with alkali waters (RSC > 5 me/L) especially when paddy is grown in rotation and rainfall of the area being is < 50 cm. In wheat-fallow rotation, no response to gypsum has been reported on light textured (sandy loam) soils when irrigated with waters having RSC upto 10 me/L. Once the role of amendments is established for raising crops with alkali waters, questions

regarding its mode, amount and time of application have to be answered.

Plate 1: Gypsum application

Gypsum requirement to neutralise residual alkalinity of water: The quantity of agricultural grade gypsum (70% purity) for neutralization of each me/L of RSC is 90 kg/ha per irrigation of 7.5cm depth. The quantity of gypsum is thus determined by the quality of water (RSC to be neutralised) and the quantity of water required for irrigation during a growing season or on yearly basis.

Gypsum requirement of soil: Since knowing the gypsum requirement of irrigation water alone is not sufficient in case the soils which are previously deteriorated soils either due to irrigation with alkali water or for some other reason is alkali in nature, gypsum requirement of the soil should be determined separately. Hence during the first year, gypsum

should be added both based on soil as well as irrigation water. Subsequently, application of gypsum is needed on the basis of irrigation water only. Since the same water is to be used year after year, application of gypsum has also to be repeated.

Time of application: The best time for application of gypsum is after the harvest of crops, preferably in the month of May or June if some rain has occurred. Otherwise, if no rain is received during these months, its application should be postponed till the first good monsoon showers are received. Gypsum could be applied even in the standing water, as it will hasten leaching of salts and the reclamation process. The soil should be subsequently ploughed, upon attaining proper soil moisture condition.

Method of application: Gypsum is preferably added to the soil, being easier to accomplish, than treating the water itself. The ISI grade gypsum may be applied through broadcast in requisite quantity on a previously graded field and mixed in a shallow depth of soil with a cultivator or disc. Proper levelling of the fields is another important pre-requisite. Fields should be provided with 35 to 40 cm high strong bunds for retaining the entire rainwater. Bunds also prevent the entry of water from outside.

Use of gypsum beds: Itrequires some mechanism for dissolution of gypsum in the irrigation water itself. Such a practice will also eliminate the costs involved in powdering, bagging and proper storage before its actual use. In view of the costs involved, the dissolution of gypsum directly in water through the use of gypsum beds or its application to the irrigation channels, appears an economical preposition. Dissolution of gypsum is affected by factors such as size

distribution of gypsum fragments, flow velocity, salt content and chemical composition of water. For flowing water to pick up Ca through dissolution of gypsum, special gypsum bed has been designed. Nevertheless, it is pointed here that gypsum bed water quality improvement technique may not dissolve > 8 me/l of Ca^{2+} (Plate 2).

Plate 2: Gypsum bed treatment for alkali water

At Tiruchirapalli, a new model of gypsum bed was designed using RCC rings of 0.9 m diameter and 0.3 m height to treat alkali water using phospho-gypsum. Totally four RCC rings were used to achieve the structural dimension of 1.2 m height and 0.9 m diameter which is closed at the bottom with inlet (50mm size) in the bottom ring and other in the upper most ring, so as to enable the water coming from the PVC conveyance pipes in the farmers holdings to pass through the gypsum beds. The phospho–gypsum was placed in cloth bags over the iron mesh provided in between the third and fourth ring. The cost of one such structure is estimated at Rs.4,000/- and therefore it should it should be possible for the farmer to construct the same at their fields.

3.2.3 Fertilizer application

Since alkali waters cause a rise in soil pH that leads to greater nitrogen losses through volatilisation and denitrification, extra nitrogen may have to be added to meet the requirement of the crops. Similarly, the availability of zinc and iron is also low due to their precipitation as hydroxides and carbonates.

- Application of 25% extra nitrogen is needed as compared to the normal conditions.
- Zinc sulphate @ 25 kg/ha should be added, particularly to the *rabi*crops.
- Phosphorus, potassium and other limiting nutrients may also be applied on the basis of soil test values.
- Some alkali waters may be rich in nutrients like nitrogen, potassium and sulphur. Such waters should be analysed and the fertiliser dose of concerned nutrient reduced accordingly.

Water quality researches over past few decades have enabled development of technological options to cope up with the problems of sodic water use. The adverse effect of residual sodium carbonate (RSC) in irrigation water can be reduced by soil application of gypsum or passing of RSC waters through gypsum bed. Possibilities have now emerged to safely use the water otherwise designated unfit. These options are as below:

- Appropriate irrigation scheduling and conjunctive use options with canal water; rain water management and leaching strategies to maintain a high level of soil moisture and low level of salts and exchangeable sodium in the rhizosphere.

- Use of land management practices to increase the uniformity of water distribution, infiltration and salt leaching besides the optimal use of chemical amendments like agricultural grade gypsum and acidic pyrite at proper time and mode of their application with judicious use of organic materials and chemical fertilizers. The gypsum can be directly applied before rice crop in soil top layer or can be used in gypsum bed for passing sodic groundwater.
- In case of irrigation by sodic waters, the conjunctive use strategy should either minimize the precipitation of calcium or maximize the dissolution of precipitated calcium. This is particularly relevant to the areas, where canal water supplies are either un-assured or less than required, and farmers often pump sodic groundwater for crop production. For the efficient use of waters of different qualities, good quality waters can be used for sensitive crops and sodic waters for tolerant crops. The most appropriate practice, however, can be the conjunctive use of these waters by:

1. blending in supply network, making appropriate water quality available for each crop irrespective of soil conditions;
2. alternate use of sodic and canal water according to availability and crop needs; and switching these water sources during the growing season according to critical stages of crop growth. The blending of sodic water and canal water is done in such proportion so that final RSC is maintained below the threshold limit

of the crop to be grown. The alternate use is preferable and has operational advantages.

3. Selection of crops, cropping patterns and crop varieties that produce satisfactory yields under the existing or predicted conditions of sodicity.
4. The other guidelines pertinent to selecting crops suitable for sodic waters are:
5. Fields should be kept fallow during *kharif* in low rainfall areas (< 400 mm) where good quality water is not available. However, only tolerant and semi-tolerant crops like barley, wheat and mustard should be grown during rabi.
6. Jower-wheat, guar-wheat, pearl millet-wheat and cotton-wheat rotations can be successfully grown in areas having rainfall > 400 mm/annum provided that sowing of kharif crops is done with rain or good quality water and only 2 to 3 sodic water irrigations can be applied to kharif crops. In rice-wheat belt of alluvial plains having rainfall ≥600 mm, rice-wheat, rice-mustard, sorghum mustard, and *dhainacha* (GM)-wheat rotations can be successfully practiced with gypsum application.
7. Sodic water should not be used for summer crops in the months of April to June.

4. IRRIGATION MANAGEMENT UNDER CHANGING CLIMATIC SCENARIOS

Field experiment was conducted during 2016 at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli for assessing the effect of drip, sprinkler and furrow irrigation methods on vegetable crops under sodic soil. The investigations revealed that an increase of vegetable yield under drip irrigation over furrow irrigation was 43% in cluster bean, 34% in bhendi, 71% in vegetable cowpea and 49% in onion, respectively. Therefore, it is recommended that the drip irrigation method for vegetable crops under sodic soil environment for sustainable use of water resources with improved efficiency. AICRP on SAS&USW, Indore Madhya Pradesh used drip for vegetables on sodic Vertisols and similar results were obtained. Further, experiment was also conducted to study the efficacy of irrigation with ameliorated alkali water using gypsum bed and distillery spentwash through drip system on cotton BG II hybrid RCH – 20 under sodic soil. Based on the results, drip irrigation with gypsum bed treated alkali water will be a better option for enhancing cotton productivity in sodic soil with a sustainable use of alkali water. Hence, it is suggested that wherever possible the pressurized irrigation system will be a better option for enhancing crop productivity in sodic soil(Annual Report, 2016-17). The PC Unit and AICRP on SAS&USW, Bapatla used poly houses to grow vegetable crops (Capsicum, Chilly and Tomato) with saline water. It was observed that plants experienced less water and salinity stress and yields were

higher than open field cultivation. Such innovative practices can useful to handle challenges arising from climate change.

Mulching with Organic/ Crop Residues

Organic mulching is one of the best options for salt affected soils. Continuous application of organic / crop residues for mulch reduces salt load in soils by reducing soil evaporation. As rhizosphere region of the soil remains at optimum moisture condition, leaching salts is easier in case of drip irrigation. Further, application of organic mulch leads to release of organic acids on its decomposition. Results from AICRP on SAS&USW, Ganagavathi showed that use of rice straw for mulch, in case of cotton crop, improved yield significantly on waterlogged saline Vertisols.

Use of Harvested Rain Water in Conjunction with Saline/Alkali Water

In some sodic ground water areas, annual rainfall is more than 1000 mm. If surface runoff is harvested and stored in lined pond and used with saline/ sodic ground water through drip system, it would be possible for farmers to grow vegetable crops and other cash crops during winter season. In general irrigation water shortage is experienced after monsoon season and conjunctive use of harvested rainwater and saline/ sodic water will be able overcome the problem. There is need to have demonstrations on farmers' fields for assessing the potential of the concept.

5. SUMMARY

In Tamil Nadu out of 13M ha of total geographical area, about 5.46 M ha is net area sown and 2.9 M ha is under irrigation. Of this, about 51.2 per cent is irrigated by surface water *viz.,* canals and tank, while 48.8 per cent is irrigated by wells including tube wells. Presently there are about 18 lakh wells in Tamil Nadu of which 16.3 lakh are open wells and 1.7 lakh are bore wells. Against the total water requirement of 6.5 M ha m, the total water potential of Tamil Nadu is 5.6 M ha m, of which 2.5 M ha m is from surface water and 3.1 M ha m from ground water. This gap between demand and potential has led to over exploitation of ground water resulting in increase in depth of water table, deterioration of water quality and way to increase sea water intrusion. In this connection we made attempt to survey and characterization of ground water samples to assess suitability for irrigation. The ground water samples were collected and assessed in twelve coastal districts *viz.,Kanyakumari, Tirunelvelli, Thoothukudi, Pudhukottai,* Cuddalore, Nagapattinam, Thanjavur, Thiruvarur, Ramanathapuram, Chengalpattu, Thiruvallur and Villupuram for assessing ground water quality suitable for irrigation. The results revealed that the highest percentage of good quality water were found in Thanjavur district (84.2%) due to Cauvery Delta Zone and followed by the Kanyakumari (73.02%), Nagapattinam (72.6%) and Cuddalore (69.90 %) whichmay be due to higher rainfall and Ramanathapuram district recorded lowest percentage (10%) may be due to low rainfall and more coastal length. Among the above twelve districts studied, highest percentage of high saline water found in Ramanathapuram District (46%) followed by the Thiruvarur (0.62%), Nagapattinam (0.4%) and Thanjavur (0.25%). The high area in high saline ground water in

Ramanathapuram might be due to long coastal line as well as prolonged drought prevails when compared to other districts. The high Alkali water is also found in the majority areas of Thiruvarur (19%) and Ramanathapuram district (19%) and also the alkali water is also recorded highest in Ramanathapuram district (10%). Among the coastal districts surveyed, Ramanathapuram district comes under highest saline and lowest good quality of ground water.

The strategies to be followed based on the efforts made in different centers of AICRP on "Management of salt affected soils and use of saline water in agriculture" and TNAU are growing tolerant crops and variety, conjunctive use of saline water with canal water in dilution/ cyclic mode, passing saline water through gypsum bed before irrigation and irrigation through pressurized systems (Drip/ sprinkler).

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