Coastal Region Groundwater Quality Integration Mapping through Geospatial Technology in Parts of Tuticorin Coast, Tamilnadu, India

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ABSTRACT

In the present study, the chemical characteristics of the groundwater in the various locations in parts of Tuticorin Coastal area have been studied for pre-monsoon and post-monsoon season to evaluate the suitability of groundwater for drinking and irrigation uses. 20 groundwater samples were collected and analysed for EC, pH, TDS, Calcium, Magnesium, Sodium, Potassium, Carbonate, Bicarbonate, Chloride, Sulphate etc., in the laboratory. The analyzed values were evaluated in detail and compared with WHO water quality standards. It is observed that, for most of the groundwater quality parameters, the values are not potable for drinking use. To understand the spatial distribution of unsuitable zones, ArcGIS was employed. Attributes were linked and spatial interpolation mapping was done. Inverse distance weighted Interpolation technique was followed for raster and vector mapping. Finally the overlay analyses were also carried out to locate the worst quality zone. The cause behind the quality using geospatial technology is derived.

Key words: *Groundwater Quality; Spatial Distribution Map; Overlay Analysis;*

INTRODUCTION

During the last 50 years urban and industrial development has led to a sharp increase in the demand for water resources in India, which in turn, has led to an increase in the exploitation of groundwater located in alluvial aquifers. The uncontrolled exploitation of groundwater along the coastal aquifers has seriously degraded the water quality due to repeated episodes of saline intrusion.

The Tuticorin coast is a narrow coastal region extending southeast along the Bay of Bengal. Groundwater is the only source for regular water supply. Running water is limited and rain is irregular, falling mainly during winter (January – February). The area is subject a subtropical, hot humid climate. Annual precipitation ranges from 200 mm east to 600 mm in the west. Geochemical processes in groundwater involve the interaction of country rocks with water, leading to the development of secondary mineral phases. The principles governing the chemical characteristics of groundwater were well documented in many parts of the world (Garrels and Christ, 1965; Stumm and Morgan, 1970; Swaine and Schneider, 1971; frappe et al., 1984; Herczeg, et al., 1991; Som and Bhattacharya, 1992; Pawar, 1993; Wicks and Herman, 1994; Kimblin, 1995; Raju, 1998). This paper investigates the possible chemical processes of groundwater rock interaction in hard rock terrain.

GIS has emerged as a powerful technology for instruction, for research, and for building the stature of programs (Openshaw 1991; Longley 2000; Sui and Morrill 2004; Baker and Case 2000). Saraf et al., (1994) have conducted GIS based study and interpretation of groundwater quality data. Durbude et al., (2002) mapped the ground water quality parameters in GIS environment.

In the present study, groundwater samples have been collected and analyzed for various parameters such as, EC, pH, TDS, Ca, Mg, HCO_3, Cl, Na and K etc., the analysed results were taken in to GIS environment. In GIS, spatial distribution maps were prepared for the above parameters. And multiple thematic maps overlay analyses were carried out to find the bat suitable zone with respect to all elements and the hydrochemical facies of groundwater and their relationships with the local hydro – environmental factors such as rainfall, lithology and seawater intrusion.

STUDY AREA

Thoothukudi is in South India about 540 km south west of Madras (Chennai) and is geographically located in the Gulf of Mannar. The district of Mannar (Bay of Bengal) lies south and southwest of the district of Tirunelveli, west and northwest of the district of Virudhunagar and north of the district of Ramanathapuram. The total study area covers 385.99 km². The Tuticorin coast extends between East longitude of 78° 4’ 6” to 78° 7’ 33” and North latitude of 8° 37’ 27” to 8° 55’ 36” (Fig.1). It covers an area of about 385.99 Km^2.

Methodology

The study area was demarcated in parts of Tuticorin coast. The Study area was buffered on one side (land) from the coast line to 12 Km on the land through GIS. Again the study area was divided into two parts as from the coast line to 6 Km designated as eastern part of the study area the rest of the 6 Km as designated as western part of the study area. The daily rainfall data collected from Statistical department is converted into average annual rainfall. Detailed investigation of the chemical quality of ground water from the study area has been attempted to generate the spatial distribution map. Then, these maps were integrated, one over the other, to find out the best combinations for groundwater quality. The detailed GIS overlay analysis methodology is given below in Fig.2. and another work to determine their hydrochemical facies. During the present investigation, 20 water samples were collected in both pre and post monsoon 2009 season from different wells which are almost uniformly distributed over the study area. After half an hour discharge of the water from the tube well, the samples were collected and air tight with the stoppers and subjected to chemical analysis to see variation in quality parameters. The locations of groundwater sampling stations are shown in the Fig. 1. pH and electrical conductance were measured within a few hours of collection by using Elico pH meter and conductivity meter. Ca and Mg were determined titrimetrically using standard EDTA, and chloride was determined by silver nitrate titration (Volgel, 1968). Carbonate and bicarbonate were estimated with standard sulphuric acid and sulphate was determined gravimetrically by precipitating $BaSO_4$ from $BaCl_2$. Na and K by Elico flame photometer (APHA, 1996).

RESULTS AND DISCUSSION

Hydrochemistry and hydrochemical facies

The diagonostic chemical properties of water are presented by various methods, the most common of which are the hydrochemcial facies, e.g., the Piper (1944) trilinear diagram. This diagram is useful in screening and sorting large numbers of chemical data, which makes interpretation easier. Furthermore, a Piper diagram can define the patterns of spatial change in the water chemistry among geological units, along a line of section or along a path line. In the present study, the results of the chemical analysis of the total wells, as well as those of each of the define geographical zones, are plotted on Piper diagram (Fig 3).

An examination Fig 3 demonstrates that two major hydrogeochemcial facies are dominant in the area these are ($Ca + Mg – CO_3 + HCO_3$) facies (Alkaline water - Type I) and ($Na + K + Cl + SO_4$) facies (Saline water – Type II).

Type - I ($Ca + Mg – CO_3 + HCO_3$)

This facies represents 72.5 % of the wells (Fig 3. Table1). This may indicate that the hydrochemcial properties as well as the factors affecting the hydrochemistry of this location are similar. In the study area, the western areas classified as having the best water quality for domestic and agricultural uses.

Type - II ($Na + K – Cl + SO_4$)

This facies represents 63 % of the samples (Fig 3). Its source could be from saline water intrusion or sea water intrusion from the east coast. The occurrence of the saline water facies in near coast that is within the 6 Km of the coast is attributed to the effects of brackish groundwater. Salinization of this brackish water is due to hydraulic contact of the coastal aquifer at its eastern margin with underlying Calcareous sandstone and siliceous limestone of quaternary age. In the eastern part of the study area, groundwater has relatively high TDS concentration.

There is a clear trend shown in the Piper diagrams that the western side of the study area is concentrated in the calcium carbonate facies and low chloride content. Similarly, the western wells show a trend to be concentrated in the saline water in the sodium chloride faceis. Basically, such a distinction between the western and eastern waters attributed to lithological and or climatic factors in addition to the regional flow it is now very observable that the regional flow mainly recharges the aquifer with saline water. This source of water contributes to improving the water quality, however, it worsen the quality as discussed above.

Geology

The study area is mainly underlined by Quarternary Marine Deposit and Quarternary Fluvio-Marine Formation. Quarternary Marine Deposit is the dominant group of rocks covering major parts of the study area, followed by the Hornblende-Biotite-Gneissic rocks. The type of formation and their spatial distribution are given in the Table 2 and Fig.4.

Water Quality Analysis for Drinking Purpose

The hydro-chemical analysis data of groundwater samples for the pre and post-monsoon season are presented in Table 1. The pre and post-monsoon pH values are in the range of 7.8 to 8.3 and 6.5 to 7.8. As per the WHO standards, all the samples of both the seasons fall within the recommended limits (6.5 to 9.2) for human consumption. The conductivity value of the samples varies from 260 to 45000 μScm^{-1} and 205 to 66425 μScm^{-1}. The TDS value varies from 154.7 to 33692 mg/l and 138 to 33692 during the pre and post-monsoon season. EC and

TDS (3,12,13,14,15,18 samples) falling not permissible limits (WHO, 1984). The alkalinity values varies from 40 to 615 mg/l during the pre-monsoon season 2009. The presence of carbonates, bicarbonates and hydroxides are the most common source of alkalinity in natural water. Bicarbonates represent the major form since they are formed in considerable amounts from the action of carbonates upon the basic materials in the soil.

The sodium concentration in the groundwater from study area varies between 6 to 10,000 mg/l. Calcium, magnesium and potassium in the groundwater are inter-related. Most of the samples showed normal values of calcium, magnesium and potassium well within permissible limits (WHO, 1996) and thus the groundwater is not much hard. The chloride contents range from 53.2 to 19273 mg/I and 42.6 to 19272.5 mg/I. 55% of samples falls within the permissible limit for drinking purpose (WHO, 1984).

Groundwater Quality Spatial Analysis for Drinking Use

It is an analytical technique associated with the study of location specific geographic phenomena together with their spatial dimensions and their associated attributes (like table analysis, classification, polygon classification and weight classification).

The pre and post-monsoon calcium, magnesium, sodium, potassium, chloride and sulphate thematic maps as described above have been converted into raster form considering 30m as cell size to get considerable accuracy. These were then reclassified and assigned suitable weightages for the spatial distribution map preparation.

Data and Maps Analysis for Drinking

Each thematic map such as calcium, magnesium, sodium, potassium, chloride, sulphate provides certain clues on for the quality of groundwater. In order to get all these informations unified, it is essential to integrate these data with appropriate factor. Therefore, numerically these informations are integrated through the application of GIS. Various thematic maps are reclassified on the basis of weightage assigned, and brought into the "Raster Calculator" function of Spatial Analysist tool for integration. A simple arithmetical model has been adopted to integrate various thematic maps. The pre and post-monsoon final out put (Domestic quality) maps used in spatial filtering analysis. Pre and post-monsoon spatial filtering maps (Fig. 5 and 6) reveals that there are 3 combinations results are given in Table 3.

Water Quality Analysis for Irrigation Purpose:

Groundwater always contains measurable quantities of dissolved substances, which are called salts. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. The total concentration of soluble salts in irrigation water can thus be expressed for the purpose of classification of irrigation water (Table 4) as follows:

The updated attribute table in Arc GIS package with EC and SAR data was used for the zonation of various salinity zones in the study area. The pre and post-monsoon salinity representation maps were prepared and very high salinity zone determined.

The pre and post-monsoon separately analyzed, EC irrigation quality map was superposed over SAR irrigation quality map, the output map is designated as irrigational quality maps (Fig. 7 and 8) and its results are given in the Table 5. The results show that four combinations are observed, High Salinity – No Problem combinations cover small areas (183.75 Sq km (Pre-Monsoon) and 166.21 Sq km (Post-

Monsoon)), are highly suitable for irrigational purpose.

Conclusions

Groundwater in the Tuticorin Coastal area, the western areas classified as having the best water quality for domestic and agricultural uses bassed on piper (1984) trilinear diagram. The groundwater quality parameters in the study area with reference to the WHO 1984 and 1996 standards, were used to prepare the pre and post-monsoon spatial distribution map. The final integrated map (Drinking quality) reveals that more number of combinations is present. Therefore spatial filtering for the potable and not potable combinations like all elements is within potable limiting. Ca-Acceptable, Mg-Acceptable, Na, K, Cl, EC, TDS-Potable and Ca-Acceptable, Mg-Allowable, and Na, K, Cl, EC, TDS-Potable combinations cover small areas (4.38 Sq km, 1.82 Sq km and 12.93 Sq km, 6.89 Sq km). Ca, Mg, Na, K, Cl, SO_4 - Not Potable combination is not suitable for the drinking use and covers an area of 22.85 Sq km and 13.53 Sq km. The saline area is demarcated and mapped using the EC and SAR water quality data. The integration map of EC and SAR quality zones (High Salinity (EC) – No Problem (SAR)) for suitability in terms of irrigation purposes covers an area of 183.75 Sq km (Pre-Monsoon) and 166.21 Sq km (Post-Monsoon)).

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Table 1. Chemic al Composition of Groundwater
(Ionic concentrations are expressed in mg/L and EC in μScm^{-1})

Station	Ca		Mg		Na		K		HCO_3		CO_3		SO_4		Cl		pH		EC*		TDS		SAR	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Arasadipanyur	68	64.1	24.3	21.9	26	26	3	3	207	195	0	0	0	0	89	82	7	6.5	450	620	312	292	0.65	4.1
Nayinapuram	52	48.1	48.6	47.4	144	143	45	43	391	384	0	0	70	67	177	170	8	6.8	1200	1360	728	707	1.38	1.3
Pandiyapuram	36	30.1	87.5	83.9	393	386	100	99	561	537	0	0	199	192	479	461	8	6.9	2400	2772	1569	1515	1.38	0.5
Kumaragiri	64	60.1	36.4	32.8	74	69	4	4	366	354	0	0	3	3	124	121	8	6.7	990	880	485	463	1.02	2.4
Kakkur	40	34.1	24.3	21.9	29	27	3	3	159	146	12	12	13	13	89	82	8	6.8	500	474	288	264	0.79	2.2
Milavittan	40	36.1	26.75	24.3	26	26	3	3	146	153	0	0	6	6	89	92	8	7.6	460	500	263	262	0.74	2.3
Matattuppatti	88	80.2	14.5	13.4	89	85	9	8	293	268	0	0	10	10	142	131	8	6.8	890	900	495	459	1.18	2.9
Tuticorin	52	48.1	48.6	46.2	152	150	9	9	354	354	0	0	78	73	177	220	8	6.8	1300	1293	690	719	1.42	1.3
Periyanayakapuram	196	190.4	124.0	119.9	117	115	16	16	183	171	12	12	26	26	638	613	8	6.5	2400	2474	1220	1176	0.71	5.8
Mahaligapuram	24	24.0	2.4	2.4	200	193	2	2	330	330	0	0	58	58	532	532	8	7.2	800	986	980	974	3.53	0.6
Terku Shukkanpatti	44	40.1	14.5	13.4	36	34	4	4	159	159	0	0	3	3	355	426	8	6.9	500	467	534	597	0.68	2.3

Pudukottai	497	497.0	2405.2	2405.2	10000	10000	268	268	146	146	0	0	1178	1178	19273	19273	7	7.4	45000	66425	33692	33692	1.98	1.7
Attnoor patti	112	108.2	124.0	119.2	255	252	87	86	391	391	12	12	311	311	585	550	8	6.8	3500	2835	1678	1629	1.18	2.1
Kovankadu	56	52.1	131.3	127.7	322	321	33	33	647	543	12	12	230	230	496	496	8	7.3	2800	2790	1598	1538	2.06	1.0
Peykulam	124	118.2	148.3	142.3	247	245	11	11	207	207	12	12	447	408	496	496	8	7.4	2900	2853	1588	1535	1.08	2.5
Palayakayal	7335	71.1	55.9	53.5	180	177	6	6	207	207	0	0	303	303	213	213	8	7.5	1700	1581	932	925	1.38	1.8
Dalavaipuram	36	32.1	24.3	23.1	53	51	4	4	183	156	0	0	10	10	89	85	8	7.1	400	580	305	281	1.1	1.5
Serndamangalam	88	80.2	99.7	91.2	380	379	21	21	256	256	12	12	236	236	869	833	8	7.1	3100	2851	1831	1778	1.62	1.4
Korkal	52	64.1	9.7	7.3	53	32	5	4	183	183	0	0	10	10	71	71	8	7.8	570	530	290	278	1.16	3.7
Mattanvilai	32	26.1	5	4.9	6	5.500	4	4	73	73	0	0	19	19	53	43	8	7.2	260	205	155	138	1	3.1

Table 2. Geological formation in the study area

S.No.	Type of Formation	Area in Km_2	Geographical Position
1	Calcgranulite and Limestone	9.09	Eastern Side
2	Hornblende biotite gneiss	102.89	Western Side
3	Quarternary Fluvial Formation	51.73	Western Side
4	Quarternary Fluvio-Marine Formation	75.20	Eastern Side
5	Quarternary Marine Deposit	136.21	Eastern Side
6	Quartzite	0.79	Western Side
7	Sandstone gneiss and claystone	10.09	Western Side

Table 3. GIS Result of Drinking quality

Sl.No.	Class	Pre-Monsoon Area in Sq km	Post-Monsoon Area in Sq km
1	Ca,Mg – Acceptable, Na,K,Cl,SO_4 - Potable	4.38 km^2	12.93 km^2
2	Ca – Acceptable,Mg – Allowable, Na,K,Cl,SO_4 - Potable	1.82 km^2	6.89 km^2
3	Ca,Mg Na,K,Cl,SO_4 – Not Potable	22.85 km^2	13.53 km^2

Table 4. Groundwater Classification for Irrigational Purpose

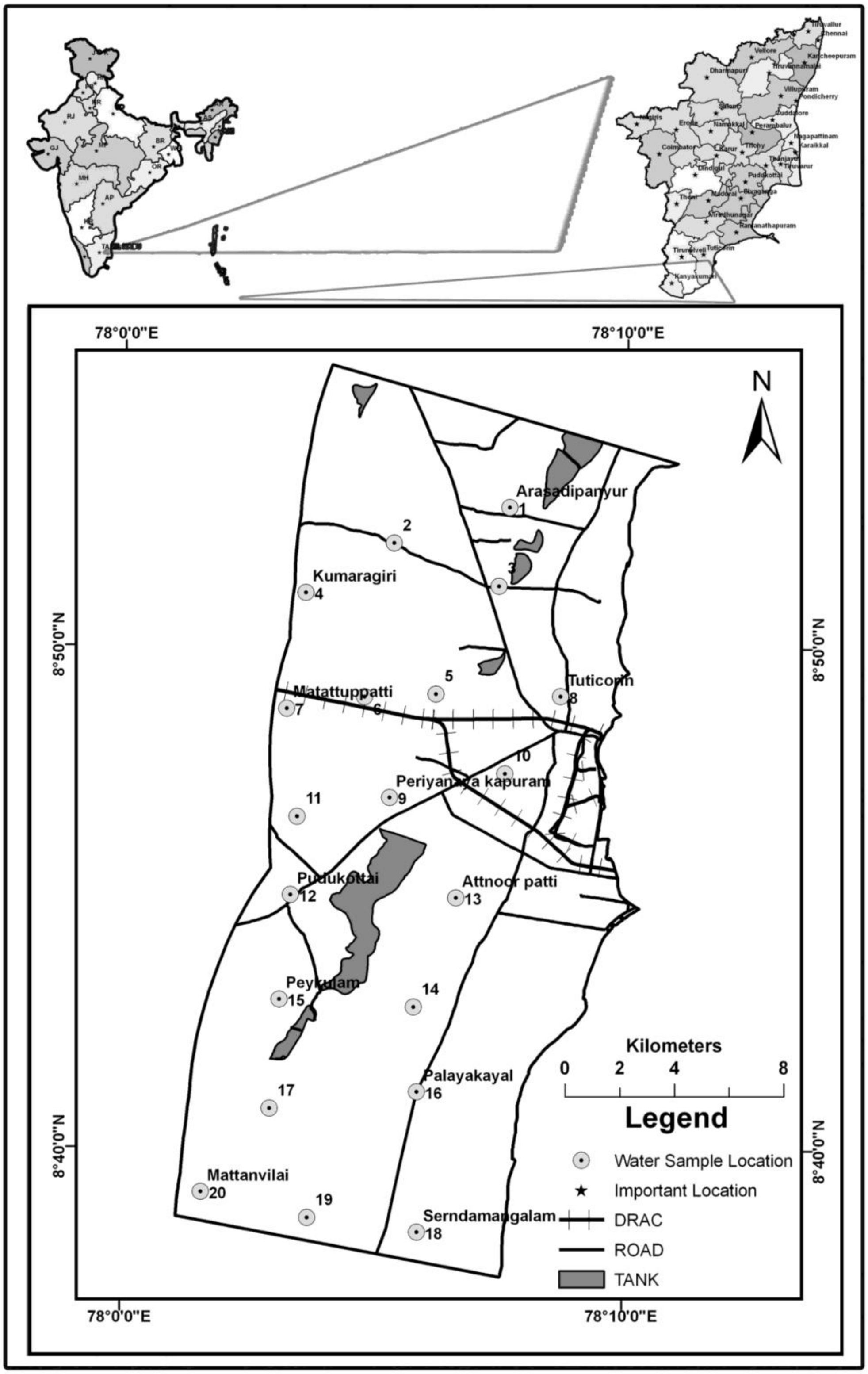
Sl.No.	EC (μScm^{-1}) Limiting Value	EC Classification	SAR Limiting Value	SAR Classification
1	< 250	Low Salinity Zone	0 – 6	No Problem
2	250-750	Medium Salinity Zone	6 – 9	Increasing Problem
3	750-2250	High Salinity Zone	> 9	Severe Problem
4	2250-5000	Very High Salinity Zone	-	-

(Durbude et al., 2007)

Table 5. EC-TDS GIS Integration Results

Sl.No.	Class	Pre-Monsoon Area in Sq km	Post-Monsoon Area in Sq km
1	Low Salinity – No Problem	-	0.18
2	Medium Salinity – No Problem	15.56	10.41
3	High Salinity – No Problem	183.75	166.21

4	Very High Salinity – No Problem	186.68	209.19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N
Arasadipanyur
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2
Kumaragiri
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3
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5
Matattuppatti
7
6
Tuticorin
8
10
Periyanaya kapuram
9
11
Pudukottai
12
Attnoor patti
13
Peykulam
15
14
Kilometers
0 2 4 8
Palayakayal
16
17
Legend
8°40'0"N
Water Sample Location
Important Location
Mattanvilai
20
19
Serndamangalam
18
DRAC
ROAD
TANK

Fig. 1. Study Area and Water Sample Location Map

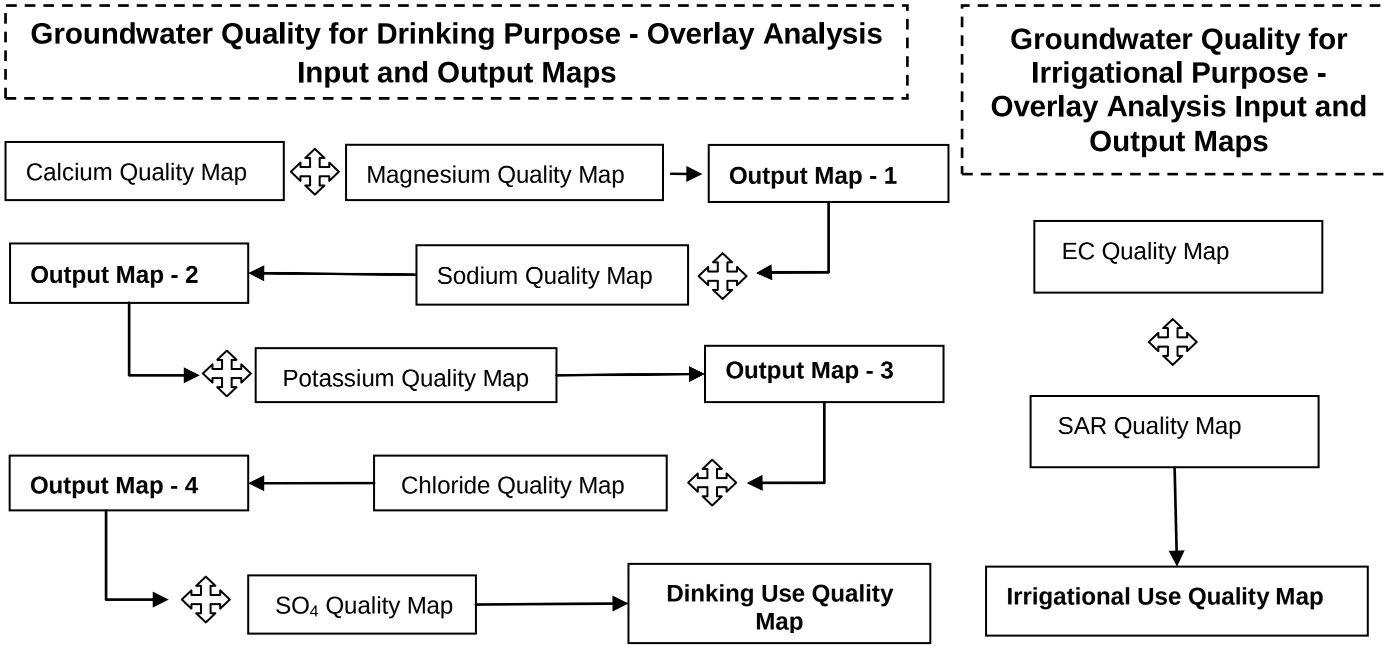


Fig.2. Methodology - Flow Chart

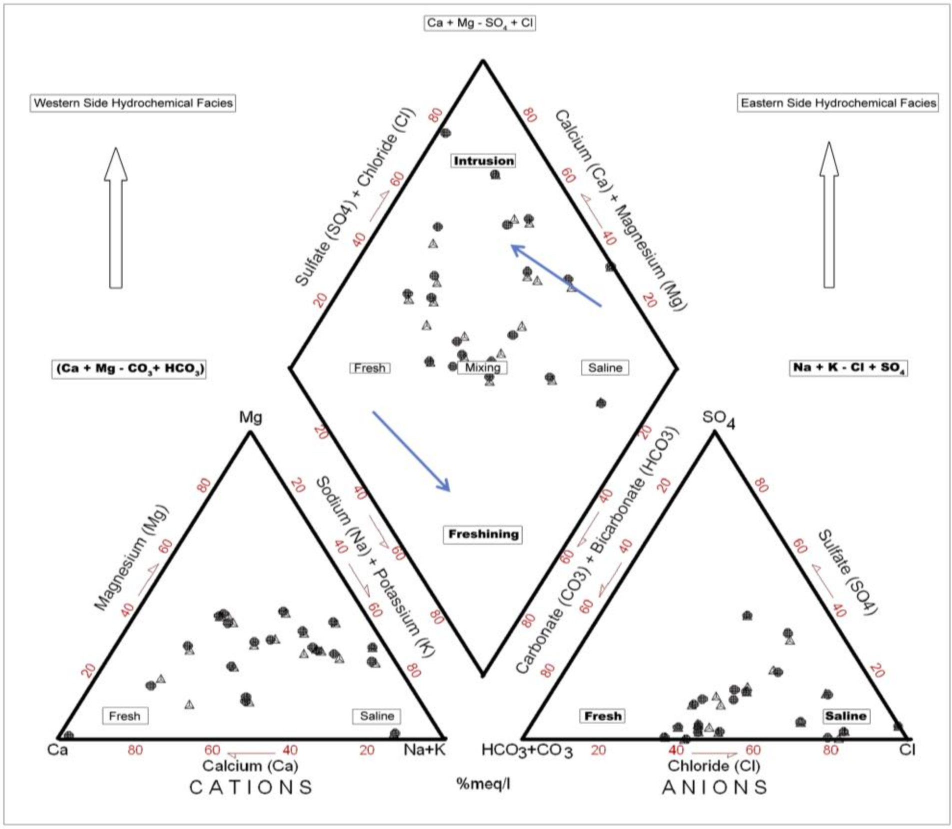
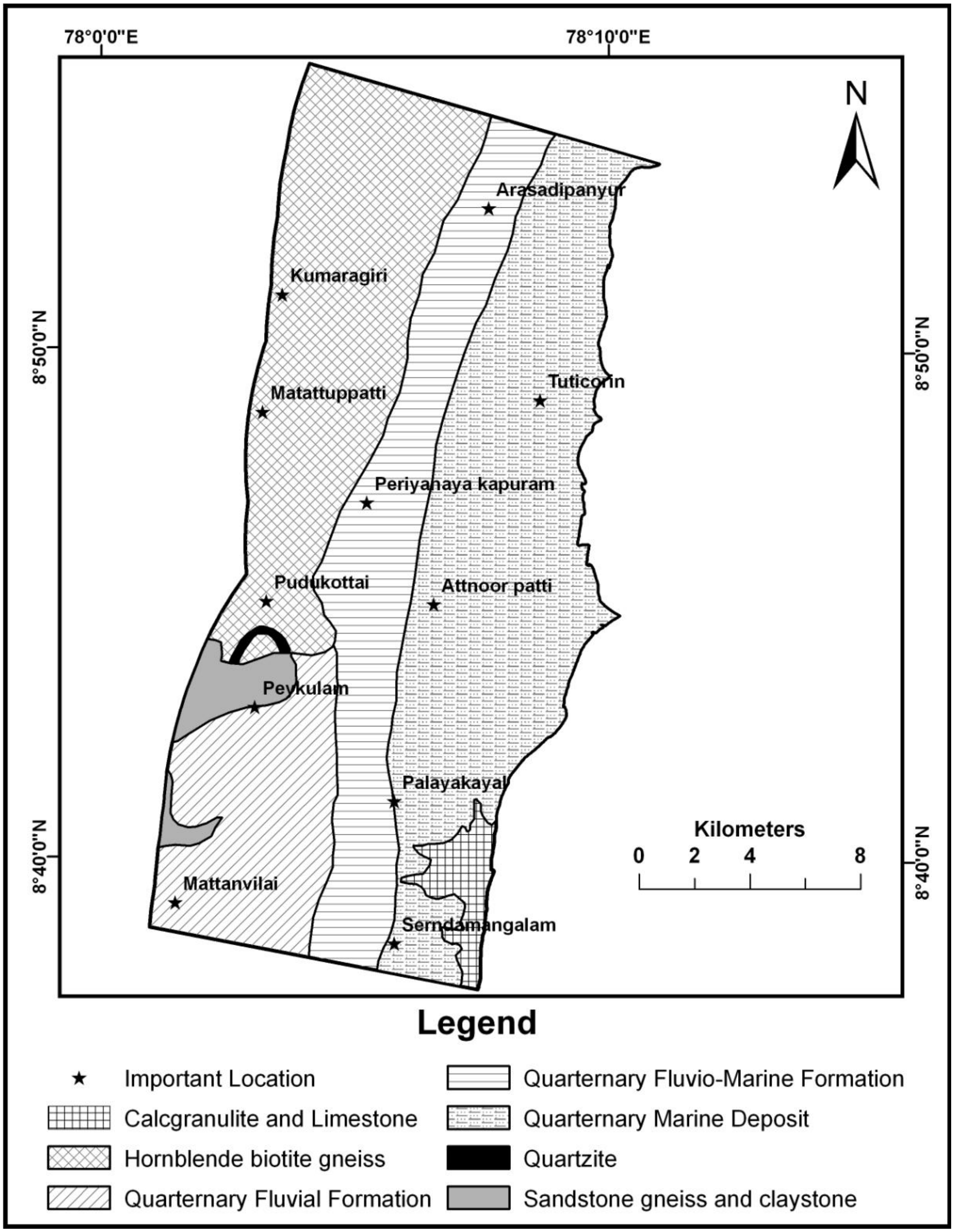


Fig.3.Piper Trilinear Diagram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Arasadipanyur
Kumaragiri
Matattuppatti
Tuticorin
Periyanaya kapuram
Pudukottai
Attnoor patti
Peykulam
Palayakayal
Kilometers
0 2 4 8
Mattanvilai
Serndamangalam
Legend
Important Location
Calcgranulite and Limestone
Hornblende biotite gneiss
Quarternary Fluvial Formation
Quarternary Fluvio-Marine Formation
Quarternary Marine Deposit
Quartzite
Sandstone gneiss and claystone

Fig.4. Geology Map

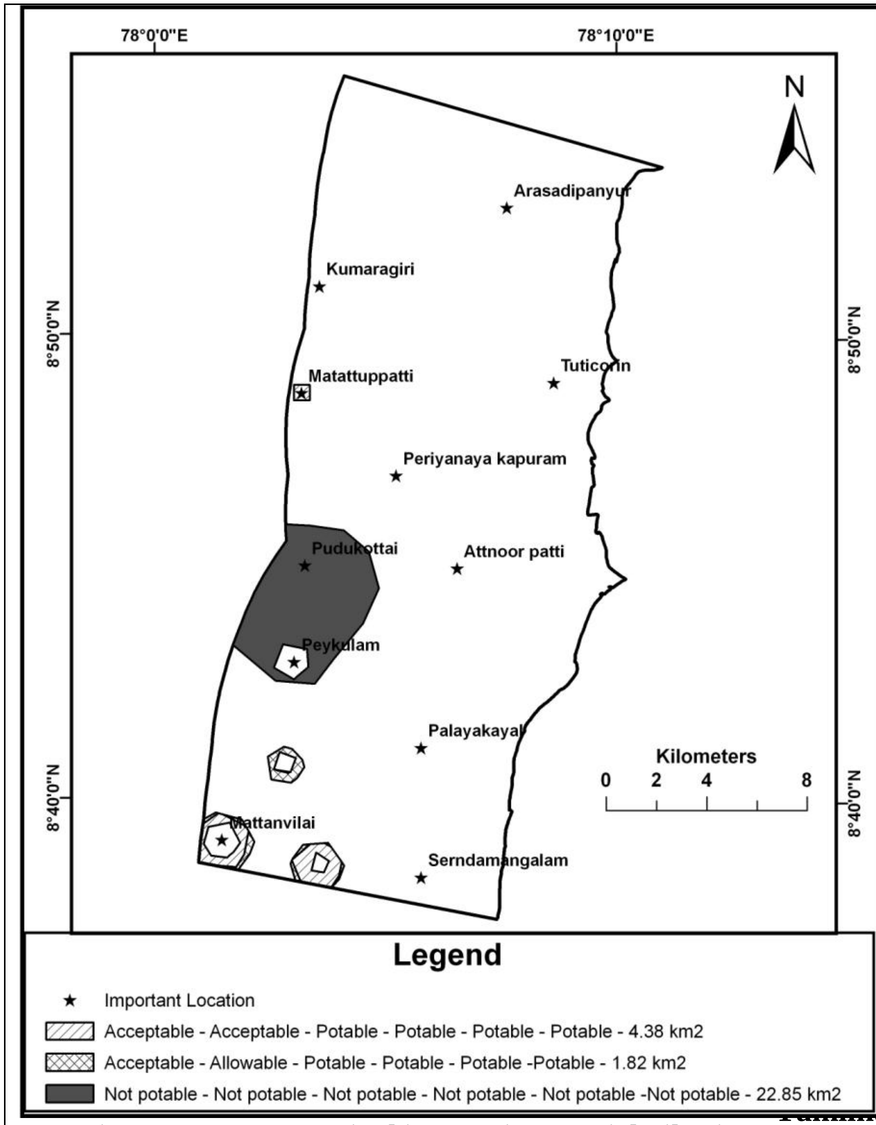

Fig.5. Pre-monsoon Final integration Spatial Filtering Map

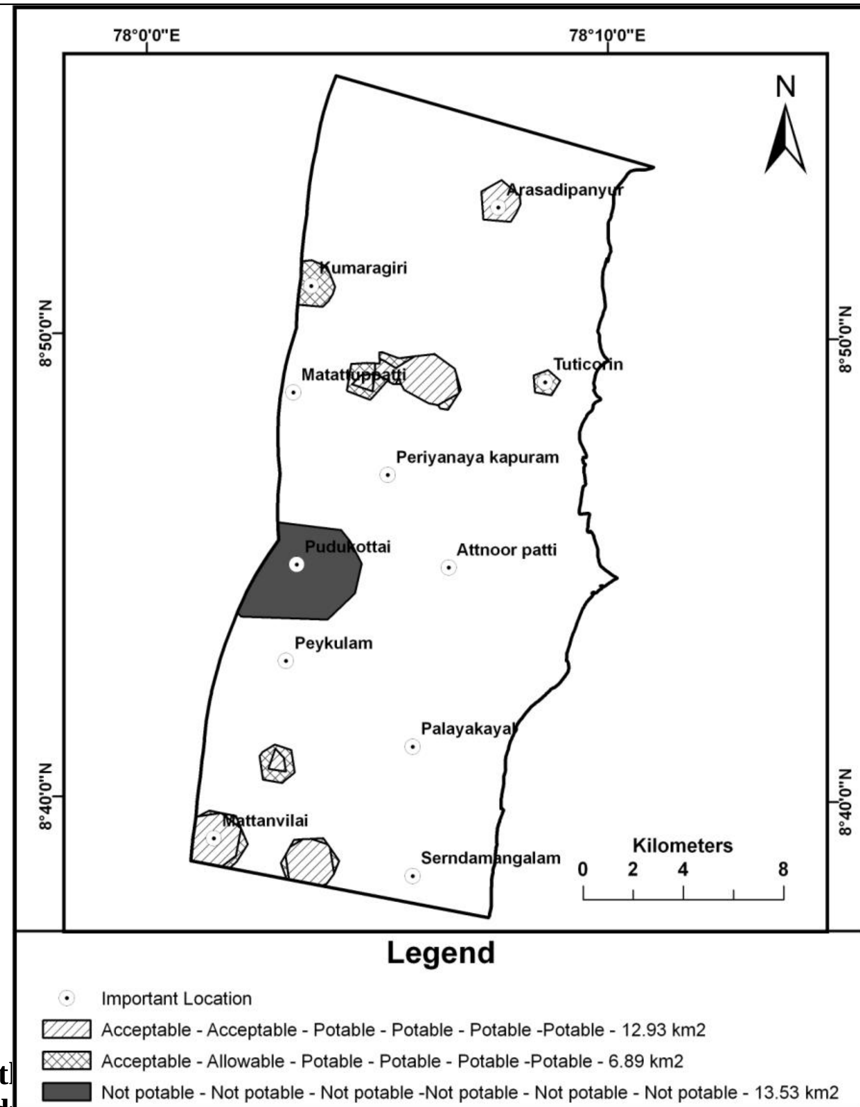

Fig.6. Post-monsoon Final integration Spatial Filtering Map

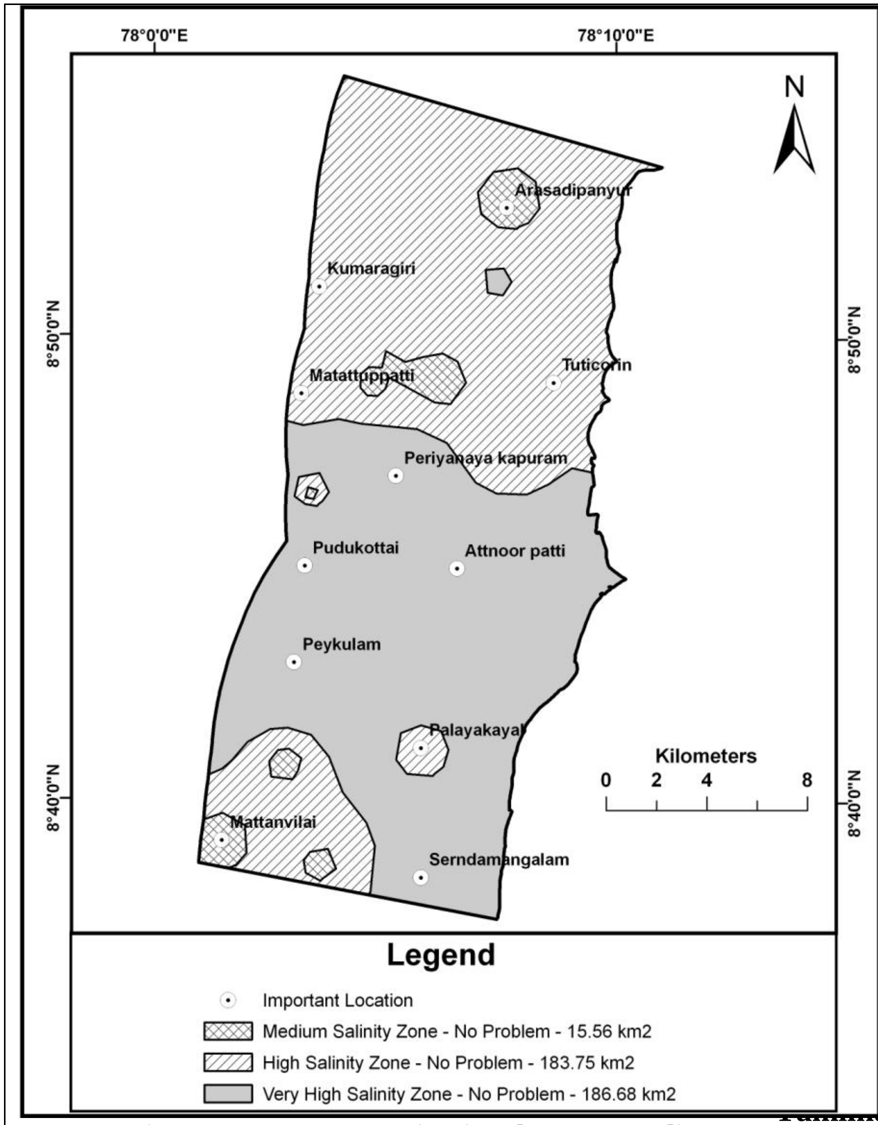

Fig.7. Pre-monsoon Irrigational Water quality Map

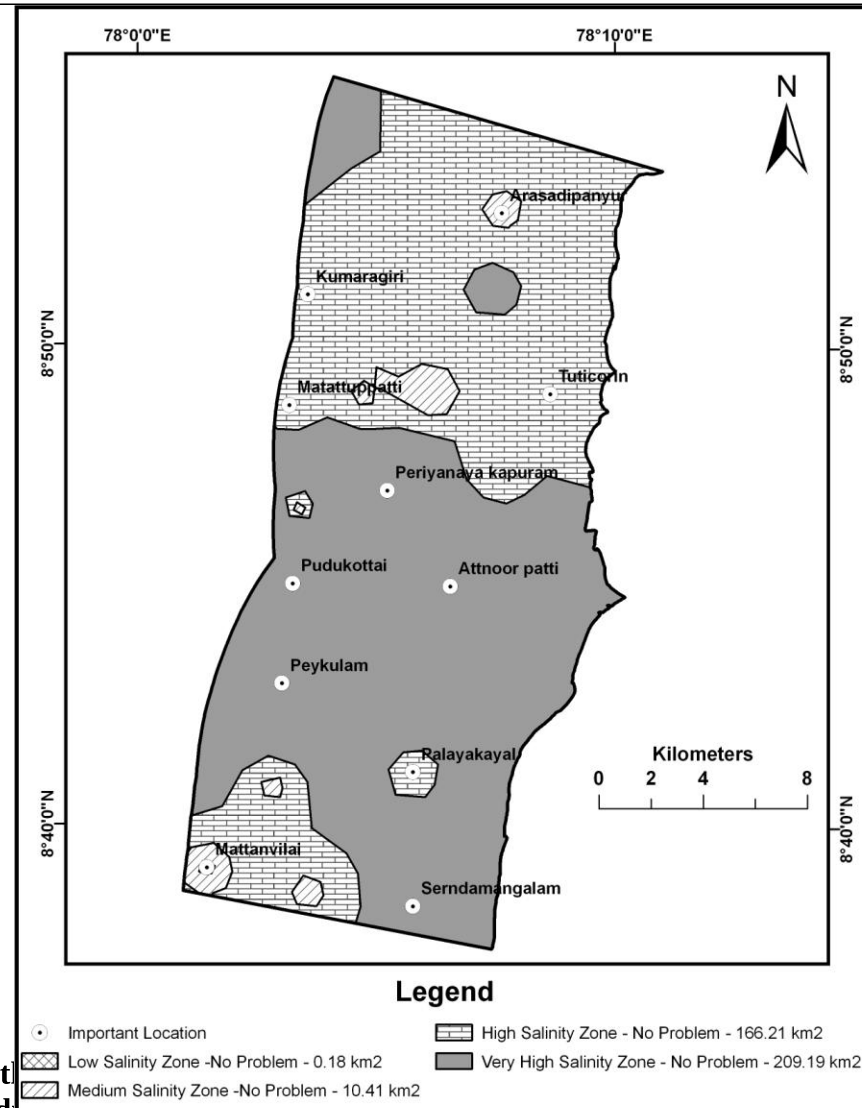

Fig.8. Post-monsoon Irrigational Water quality Map