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Geology

IMPACT ASSESSMENT OF SALINE WATER INTRUSION IN THE COASTAL AQUIFER OF RAMANATHAPURAM DISTRICT USING GEOSPATIAL TECHNIQUES.

S.Venkateswaran	Department of Geology, Periyar University, Salem-11, Tamil Nadu, India - Corresponding Author
G.Panneer Selvam	Department of Geology, Periyar University, Salem-11, Tamil Nadu,India
M.Vijay Prabhu	Department of Geology, Periyar University, Salem-11, Tamil Nadu,India
G.Prithiviraj	Department of Geology, Periyar University, Salem-11, Tamil Nadu,India

ABSTRACT Groundwater is the only replenishable natural resource available to man. Use of groundwater has been growing steadily over the years for domestic, agricultural and industrial purposes. Ramanathapuram district is one of the coastal areas is high tourism, salt pan and aqua cultural activities in sea water intrusion in the past three decades. Proper management of this vital resource needs special attention through continuous monitoring and identification of the problem area as well as delineation of safe zone. Groundwater quality is monitored spatially through GIS techniques. In the present study detailed investigation of water chemistry the 39 water sample collected from open well and bore well has been designed to assess the Groundwater status and to prepare the spatial distribution map for water quality parameters such as pH, EC, TDS, calcium, magnesium, sodium, potassium and chloride through Arc GIS environment. The data were used in the attribute table for preparing spatial distribution maps through IDW (Inverse Distance Weighting) interpolation techniques. Spatial distribution maps of each parameter were overlaid thematic maps and to find out the sea water intrusion affected areas. Also study has suggested suitable management planning strategies to improve the quality of groundwater.

KEYWORDS : Groundwater Quality, Geographical Information System Inverse Distance Weighting and Spatial Distribution

Introduction

Characterization of groundwater in terms of geochemical types is an essential component of scientific management of groundwater resources in order to monitor the quality of groundwater in an aquifer, and also for identification of recharge areas (Schoeller, 1967). Moreover, geochemistry of groundwater is also related to the nature of host rock as well as the overlying rock types. An understanding of chemical quality of water is essential in determining its usefulness for domestic, industrial and agricultural purposes (WHO, 1996).

The total dissolved salts in the water are a direct measure of the quality of water. Many authors viz., Fetter (1990), Freeze and Cherry (1979) and Davis and DeWiest (1966) studied the water quality and reported that high values of TDS is unsuitable for drinking and irrigation purposes. Also, the groundwater chemistry depends upon various rock-water interactions such as weathering, dissolution and ion exchange reactions as well as from the anthropogenic activities discussed above. In order to identify and evaluate the factors and processes that are responsible for the groundwater chemistry, detailed geochemical studies have to be carried out. The hydrogeochemical study of groundwater allows us to obtain important information on chemical weathering of rock/soil, chemical compositions of the aquifers and also on the impact of the anthropogenic activities.

Groundwater quality comprises the physical, chemical, and biological qualities of groundwater. Temperature, turbidity, colour, taste, and odour make up the list of physical water quality parameters. Since most Groundwater is colourless, odourless, and without specific taste, concern is typically with regard to its chemical and biological qualities. Natural groundwater contains various ions. These ions slowly dissolve from soil particles and rocks as the water travels along mineral surfaces in the pores or fractures of the unsaturated zone and the aquifer. They are referred to as dissolved solids. Some dissolved solids may have originated in the precipitation or from seepage from the river water.

Groundwater and surface water are intimately related. During dry periods, the groundwater contribution may be the total discharge of the stream, whereas during wet periods, the groundwater contribution may be insignificant. However, in places where the water table has been lowered, the reverse is true, that is, water leaks from the streams into the ground, particularly in some undermined areas. Hence, the geologic framework between groundwater and surface water the occurrence of water and its movement through the rock are important.

Todd et al., (1984) demonstrated local permeability impairment as a function of injected particles size and rock properties. They pointed out that initial permeability or pore size is not simple criteria for explaining the degree of damage to the cores. As gravity is the dominant driving force in groundwater movement, water flows from places of higher head to lower head. Under natural conditions, groundwater flows generally from topographically high places to low places (Cedergren, 1977).While non availability of water is one side of the problem, the deteriorating quality of existing water resources is the other side, causing great concern. The quality of water is of vital concern for mankind, since it is directly linked with human welfare. It is generally recognized that the quality of groundwater in an area is as important as the quantity. Groundwater quality data provides important clues to the geologic history of rocks and indications of groundwater recharge, discharge, movement and storage (Walton, 1970).

Quality of water is the function of its physical, chemical, biological and geological parameters (Bhargava and Killender, 1988), which depend upon the soluble products of weathering and decomposition and the related changes that occur with respect to time and space (Raghunath, 1987). The cation and anion concentration depends upon the solubility of the minerals present in the formation and the time duration of water in contact with the rocks and the amount of dissolved CO_2 present in the water (Viessman et al., 1989).

Studies on the geochemical processes that control groundwater chemical composition in and around the river course may lead to improved understanding of hydrochemical systems in such areas. Such studies contribute to effective management and utilization of the groundwater resources. Exploitation of groundwater has been increased manifold level particularly for drinking and agricultural purpose. Poor quality of water adversely affects the plant growth and human health. Urban rivers have been associated with water quality problems and the practice of discharging untreated domestic and industrial waste into the water course has emerged (Hall 1984). The problems are associated with the quantity, quality and temporal distribution of the waste produced effected by different sources and is aggravated further by routing these directly into the catchment areas of the river. Various authors studied on the groundwater quality in different parts of the country with respect to drinking and irrigation purposes (Majumdar and Gupta, 2000; Sreedevi, 2004; Subba Rao and John Devadas, 2005). The chemical alteration of the Groundwater depends on several factors such as interaction with solid phases, residence time of Groundwater, seepage of polluted river water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Stallard and Edmond, 1983).

The water resource and Groundwater reserves have been contaminated by biological, organic and inorganic wastes (Joseph and Claramma, 2010). Chennai city groundwater quality has resulted in saline groundwater nearly 10 km inland of the sea and similar problems can be found in populated coastal areas around the world (UNEP, 1996). GIS technology has previously facilitated laborious procedures (Shamsi, 2005; Assaf et al., 2008; An, 2012). During the past two decades, various researches have reported its application in Groundwater modeling and quality assessment. Balakrishnan et al., (2011) demonstrated spatial variations in Groundwater quality using GIS and Groundwater quality information maps of the entire polluted area in India. Assessment of Groundwater quality through spatial distribution mapping for various pollutants utilizing GIS technology and the resulted information on quality of water could be useful for policy makers to take remedial measures (Nageswara Rao et al., 2007; Pradhan et al., 2001; Swarna Latha et al., 2007). In the present work involves Groundwater quality assessment of saline water intrusion using Geospatial techniques in the Ramanathapuram district.

The chemical alteration of the rain water depends on several factors such as soil-water interaction, dissolution of mineral species and anthropogenic activities (Umar and Ahmed, 2007). The study of relatively large number of groundwater samples from a given area offers clues to various chemical alterations which the meteoric groundwater undergoes, before acquiring distinct chemical characteristics. Knowledge on hydrochemistry is important to assess the quality of groundwater for understanding its suitability for domestic, irrigation and industrial needs. Various researchers carried out studies on the hydrochemical characteristics of groundwater and quality of groundwater in different basins as well as in urban areas (Raju et al. 2007). Further, recent advances in analytical methods have led to the determination of toxic trace elements which can have an impact on human health.

Study Area

Ramanathapuram is one of the coastal district 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° 50' North Latitude and 78° 10' and 79° 27' East Longitude Shows in Fig.1. 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 and has the total population of 11,87,604 including 5,83,376 males and 6,04,228 females.

Materials and Methods

In present study 39 Groundwater sampling locations (Table.1) were identified for data collection based on its administrative locations within Ramanathapuram district. Water quality data were collected from Tamil Nadu Water Supply and Drainage Board (TWAD) for the year 2016 and Survey of India toposheets in 1:50,000 scale were used. The collected toposheets were scanned and uploaded in GIS platform and geo referenced. After geo referencing, geo databases were developed and district boundary was digitized and interpolated for the Groundwater quality parameters.

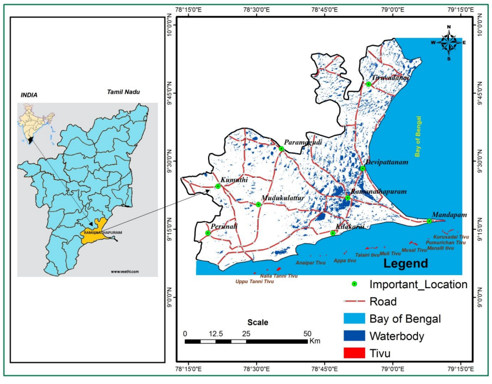

Fig.1 Location map of the Ramanathapuram district

Spatial Data Conversion

All the data were entered into spatial database and spatial variations of the results were developed using IDW method. Arc GIS software was applied for developing maps. IDW interpolation assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The IDW tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location.

Results and Discussion

The Groundwater quality data were shown in Table.1 during the year of 2016. All the data were interpolated for the spatial distribution of Groundwater quality in the Ramanathapuram district with the help of GIS. The spatial structures were also identified interpolating the scattered data, in order to have temporal series of spatially continuous maps of the parameters. We used Inverse Distance to a power gridding method as a smoothing interpolator. In this method data are weighted during interpolation such that the manipulation of one point relative to another declines with the distance. In particular, we use a quadratic law for computation of the weight, and a low value for smoothing parameters.

Table.1. Water Sample location in Ramanadhapuram coastal villages

Loc. No	Name of the Location	Ph	EC	TDS	Ca	Mg	Cl	TH	Na	K	SO4	CO3	HCO3	NO3
1	Ramanathapuram	8.1	1390	907	24	15.795	167	125	248	29	47	6	170.8	4
2	Uthirakosamangai	8.4	8630	4927	140	315.9	2552	1650	1265	164	48	2.6	137.3	4
3	Chitharakottai	8.2	560	307	6	25.515	82	120	71	8	46	2.5	107.3	4
4	Mandapam	8.2	1010	576	26	43.74	163	245	122	10	864	0	408.7	14
5	Idayarvalasai	8	920	517	10	47.385	128	220	106	19	384	0	823.5	22
6	Keelakarai	8.4	5900	3630	80	43.74	1276	380	1196	26	377	6	329.4	7
7	Ragunathapuram	8.2	880	489	26	46.17	96	255	85	15	175	18	689.3	16
8	Valantaravai	8	1650	1151	20	34.02	262	190	239	113	526	30	1024.8	15
9	Ponnalikopttai	7.8	600	327	36	29.16	57	210	39	4	81	12	616.1	6
10	Pondampuli	8.2	520	292	16	15.795	18	105	64	16	144	6	603.9	5
11	Thirupullani	8	5420	3162	80	140.94	1418	780	782	160	686	0	481.9	12
12	Mudukulathur	8	2240	1307	20	31.59	440	180	428	9	516	6	823.5	5
13	Manjur	8.1	1260	720	46	21.87	60	205	207	4	99	18	573.4	14
14	Parthibanur	9	10300	6133	180	60.75	2765	700	2070	14	69	18	256.2	22
15	Kilaramanadhi	8.3	7000	4096	200	376.65	1843	2050	644	176	912	0	298.9	14
16	Kiliyur	7.8	6450	3709	160	145.8	1914	1000	1058	21	302	18	353.8	11
17	Kadambakkudi	8.2	440	221	18	37.665	46	200	7	5	576	18	1043.1	112
18	Thirutheravalai	8	1360	763	18	37.665	291	200	219	14	3816	0	134.2	76
19	Ariyakudi	8.4	19530	11427	1000	194.4	6027	3300	2990	12	40	12	305	7
20	Sadurvedamangalam	8.2	19400	11304	800	243	5672	3000	3220	9	14	5.5	294.4	3
21	Kamutnakudi	8.2	440	221	18	37.665	46	200	7	5	37	2.1	137.9	3
22	Pambur	8.6	4120	2355	84	58.32	950	450	736	19	29	2.9	152	5
23	Veeravanur	8.1	1020	617	18	7.29	117	75	200	6	30	2.1	112.8	6
24	Chittrakkottai	8.2	560	307	6	25.515	82	120	71	8	24	8.4	141.3	4

25	Keelakarai (TP)	8.4	5900	3630	80	43.74	1276	380	1196	26	75	18	555.1	4
26	Panaydiyendal	8.2	6600	4072	64	184.68	1276	920	1035	168	71	3.5	236.4	2
27	Sikkal	8.1	900	491	26	38.88	170	225	99	13	49	0	372.1	4
28	Sayalgudi (TP)	8.5	2610	1495	52	106.92	567	570	322	47	180	6	219.6	3
29	Kamuthi (TP)	8.2	540	286	28	41.31	74	240	13	7	47	5.8	194.1	5
30	Merkkukottagudi	8.1	520	303	16	15.795	53	105	64	18	25	5.5	184.4	4
31	Thimmanathapuram	8.2	540	286	28	41.31	74	240	13	7	576	18	762.5	55
32	S.Tharaikudi	7.3	1180	667	38	147.015	131	700	166	32	26	8.1	216.7	5
33	Narippaiyur	8.2	1480	922	20	88.695	230	415	145	36	35	0	292.8	1
34	Mookkaiyur	8.4	2560	1496	76	51.03	567	400	396	35	324	0	786.9	82
35	Ervadi	8.4	3250	1938	64	174.96	496	880	313	82	141	18	378.2	22
36	Thaliyanendal	8.7	1360	769	12	31.59	184	160	244	3	72	0	292.8	5
37	Vellamarichchukkatti	8	2550	1564	48	68.04	425	400	327	149	312	12	323.3	11
38	Valantaravai	8	1650	1151	20	34.02	262	190	239	113	106	12	597.8	11
39	Pirappanvalasai	8.2	710	396	76	4.86	43	210	64	9	442	12	378.2	8

Hydrogen Ion Concentration

pH of groundwater is important in determining the hydrological processes. Processes such as carbon absorption, ion exchange, and flocculation may be affected by pH. The pH of water indicates its quality and provides information regarding types of geochemical equilibrium or solubility calculations (Hem, 1985). A taste of the acidity of water is pH, which is a measure of the hydrogen ion concentration. The pH scale ranged from 0 to 14. In general, water with a pH indicates neutral water < **7** is considered acidic and with a pH > **7** is considered basic. A one unit change in pH represents a 10 fold difference in hydrogen ion concentration. The pH of the water was taken by pH meter in the field. The hydrogen ion concentration (pH) in the water samples varies from 7.3 to 9 with an average of 8.19. As per the WHO standards, all the samples of both the seasons fall within the recommended limits (6.5 to 8.5) for human consumption Table.2 and Fig.2.

Table.2 pH – Limiting values with respect to WHO standard

Sr. No.	Limiting Values	Potability Nature
1	< 6.5	Not Potable
2	6.5 – 8.5	Potable
3	> 8.5	Not Potable

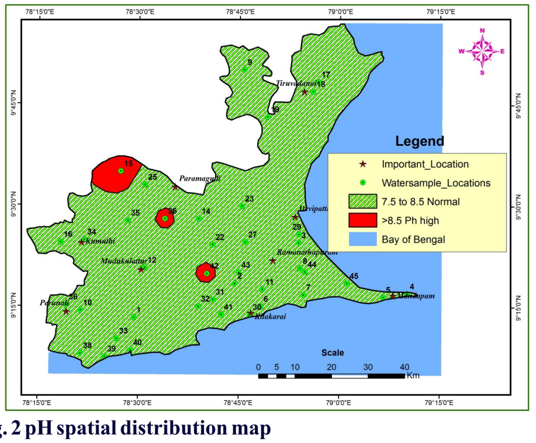

Fig. 2 pH spatial distribution map

Electrical Conductivity

Electrical conductivity is an important indicator of water quality assessment. EC of water is an indirect measure of its dissolved constituents. EC is expressed in terms of the specific electrical conductivity, which is defined as the reciprocal of electrical resistance in Ohm (Q), in relation to a water cube of edge length 1 cm at 25°C. This was noticed centre of the region. This may be due to the effluents from the industries as well as the domestic sewages are directed into the study area. The open and bore well EC results are given in Table 3.

Table. 3 EC - Limiting values with respect to WHO standards

Sr.No.	Limiting Values	Potability Nature
1	250-750	Good
2	750-2250	Medium
3	2250-4000	Bad

In practice, EC is often expressed in terms of milli Siemens (mS) and micro Siemens (p.S). The open well and bore well samples EC values ranged from 440 to 19530 µs/cm (average of 3434 µs/cm). As per the WHO (1984) standard, open and bore well EC values was found to be high in nine stations spatial map Fig.3.

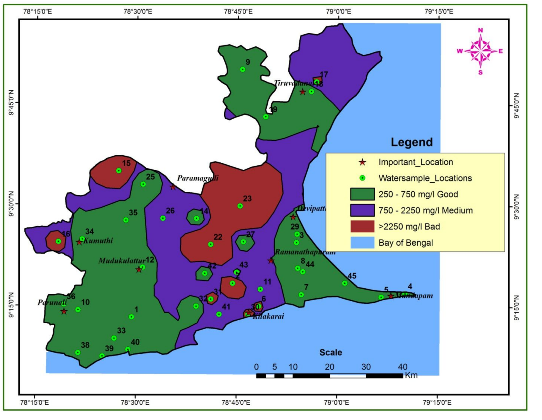

Fig.3 Electrical Conductivity spatial distribution map

The overall interpretation the EC was high at Ariyakudi, Veeravanur, Pambur, and Kilaramanadhi. The Ariyakudi EC value is above 19000 mg/l.

Total Dissolved Solids (TDS)

Total dissolved solids (TDS) refers to the total amount of all inorganic and organic substances including minerals, salts, metals, cations or anions that are dispersed within a volume of water. The principal constituents are usually the cations calcium, magnesium, sodium and potassium and the anions carbonate, bicarbonate, chloride and sulphate in groundwater. The concentration of Total Dissolved Solids ranges from 221 to 11427 mg/l with an average of 2023.87 mg/l. The limiting values of TDS are given in Table.4 and Fig.4.

Table.4 TDS - Limiting values with respect to WHO standards

Sr. No.	Limiting Values	Potability Nature
1	0 to 500	Not Potable
2	500 - 2000	Potable
3	>2000	Not Potable

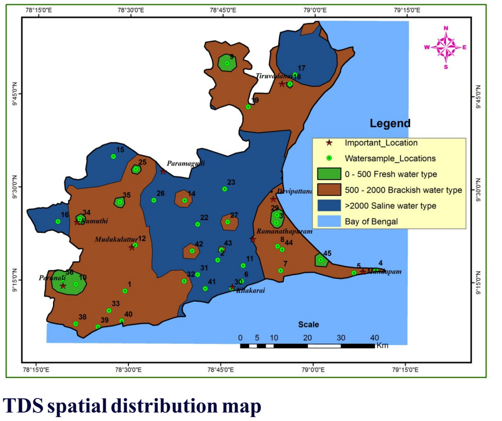

Fig.4 TDS spatial distribution map

Calcium (Ca)

The groundwater samples were estimated with high calcium hardness both in Island and mainland regions with respect to the recommendation of WHO (75–200 mg/l), which accounts for the existence of calcium rich minerals such as gypsum, limestone, etc. Calcium is the second dominate ion in the groundwater of the study area. Most samples fall within the acceptable and allowable limit, only two samples fall above the WHO's limitation values shown in Table.5. It is because of the rate of decomposition of feldspar group of minerals (Hem, 1985). If the presence of calcium is more in drinking water, it will cause formation of renal calculi (Kidney stones). The calcium concentration was more in sample 22 and 23. The calcium concentration was high in both open and bore well at Pambur and Veeravanur Fig.5

Table.5 Calcium limiting values with respect to WHO standards

Sr. No.	Limiting Values	Potability Nature
1	< 75	Acceptable Limit
2	75 – 200	Allowable Limit
3	>200	Not Potable

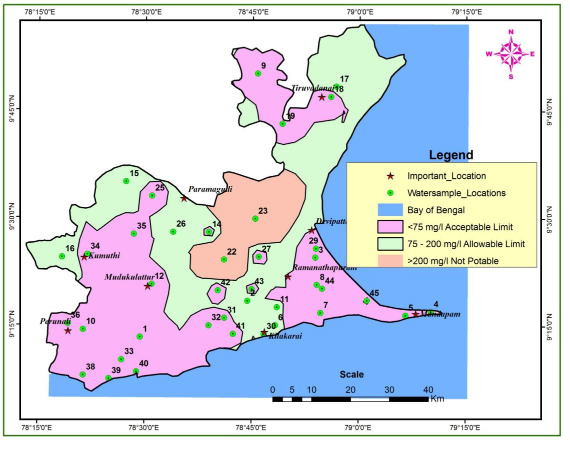

Fig. 5 Calcium spatial distribution map Magnesium

The desirable limit of magnesium in drinking water is 30 mg/l (ISI, 1996). Magnesium is the third dominating ion in the groundwater of the study area. The higher concentration of the magnesium due to rock water interaction and rest of the portion was observed in downstream portion. The limiting values for magnesium are given in Table.6. Magnesium concentration ranges from 4.86 to 376.65 ppm the spatial distribution map shown in Fig.6.

Table.6 Magnesium limiting values with respect to WHO standards

Sr. No.	Limiting Values	Potability Nature
1	< 30	Acceptable Limit
2	30–100	Allowable Limit
3	>100	Not Potable

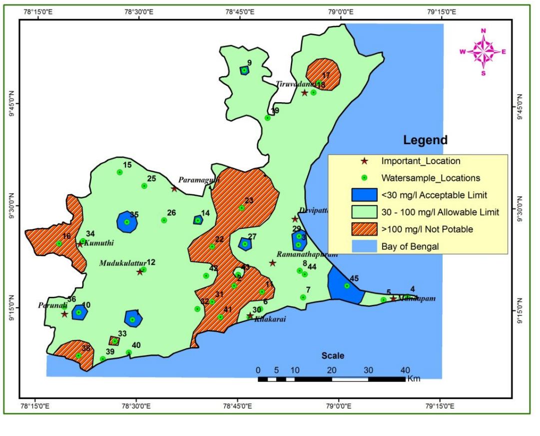

Fig.6 Magnesium spatial distribution map

Sodium

Sodium amount present in earth relatively small but significant amount of dissolved solids originating from the weathering of the rocks and soils, and from the dissolving lime, gypsum and other salt sources as water flows over or percolates through them. High Na % causes deflocculation and impairment of the permeability of soils. Sodium concentration is good if it is less than 250 mg/l (WHO, 1996) concentration. Sodium is found to be the most abundant ion in the groundwater of the study area. The open well sodium concentration in the groundwater of the study area ranged from 7 to 3220 mg/l, with an average value of 531.02 mg/l shown in the Table.7 and the spatial distribution map shown in the Fig.7.

Table.7 Sodium limiting values with respect to WHO standards

Sr. No.	Limiting Values	Potability Nature
1	< 250	Acceptable Limit
2	>250	Not Potable

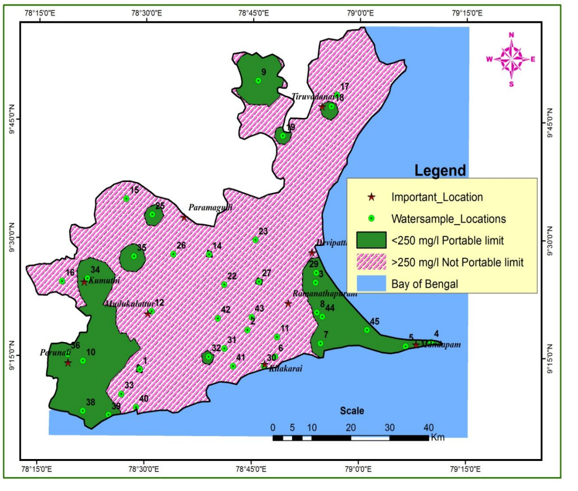

Fig.7 Sodium spatial distribution map

Potassium (K)

Potassium is nearly as abundant as sodium in igneous rocks and metamorphic rocks but its concentration in groundwater is one tenth or even one hundredth of sodium. The potassium is derived from silicate minerals like orthoclase, microcline, nepheline, leucite and biotite. Parity in concentrations of sodium and potassium is found only in water with less mineral contents. Two factors are responsible for the scarcity of potassium in groundwater one being the resistance of potassium minerals to decomposition by weathering and the other being the fixation of potassium in clay minerals formed due to weathering.

Among the cations, potassium occupies the last position in the order of abundance in the groundwater of the study area. Potassium concentration is good if it is less than 10 mg/l for domestic water (WHO, 1996). Potassium concentration ranges from 3 to 176 mg/l. Potassium classification is done in accordance with European standards. Potassium content in water more than 10 ppm is indicative of pollution as shown in the Table.8.

Table.8 Potasium limiting values with respect to WHO standards

Sr. No.	Limiting Values	Potability Nature
1	< 10	Acceptable Limit
3	>10	Not Potable

The maximum admissible level of potassium in drinking is 12 mg/l. Potassium concentration was very high in both open and bore well at Parthibanur, Keelakarai (TP) and Ponnalikopttai bore well samples Potassium spatial distribution map Fig.8. The concentration of potassium was high in this area because of the excess use of the potassium fertilizer.

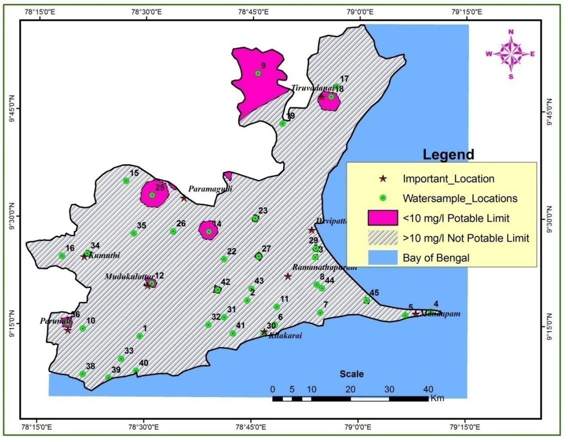

Fig.8 Potassium spatial distribution map

Chloride (Cl)

Chloride concentration ranges from 18 to 6027 mg/l. The high chloride concentration is noticed in 10 locations for both seasons. It is due to replacement of hydroxide to chloride in the hornblende biotite gneissic rocks (Kuroda and Sandell, 1953). Based on the WHO standards, twelve samples fall in not potable zone shown in Table.9.

Table.9 Chloride limiting values with respect to WHO standards

Sr. No.	Limiting Values	Potability Nature
1	< 250	Acceptable limit
2	>250	Not potable limit

Chlorides are not directly involved in corrosion, but they accelerate the rate of corrosion of steel and aluminum. In the investigation area high concentration may be due to sewage contamination Chloride spatial distribution map shown in Fig.9.

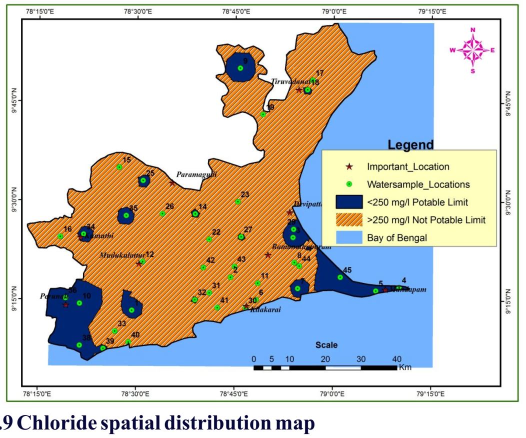

Fig.9 Chloride spatial distribution map

Chloride bearing rock minerals such as Sodalite and Chlorapatite, which are very minor constituents of igneous and metamorphic rocks and liquid inclusions which comprise very insignificant fraction of the rock volume, are minor sources of chloride in groundwater. Chloride salts, being highly soluble and free from chemical reactions with minerals of reservoir rocks, remain stable once they enter in solution. Most chloride in groundwater is present in sodium chloride, but the chloride content may exceed the sodium due to base-exchange phenomena. Chlorides in drinking water are generally not harmfull to human beings. High concentrations may affect some persons who already suffer from diseases of heart or kidnes.

Geochemistry - GIS Study

Using the WHO standards for the drinking use the classes were categorized. The erratic behaviour of groundwater geochemical elements was sorted. It shows that in the study area, Calcium, Potassium, Sodium, Chloride, Magnesium, Total Dissolved Solids (TDS), Ph and EC were observed in not potable limit. To find out the spatial distribution of these elements in the study area, GIS was employed. The geochemical locations were digitized and the corresponding values of its attributes were given as an input. Using this data, the interpolation raster maps were generated. Subsequently, these maps were classified with respect to our interest and converted in to vector maps. These maps were clipped with the boundary to arrive within the boundary of the study area. The result acceptable, allowable and not potable sea water intrusion zone limits were given through spatial distribution map SWI map Fig.10.

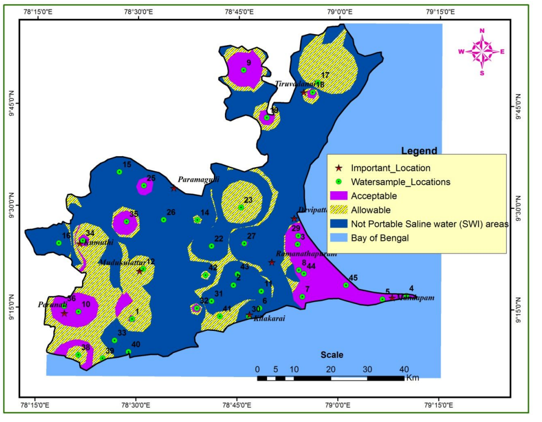

Fig.10 Final Integration spatial distribution (SWI) map

Conclusion

Groundwater is immensely important for water supply in both the urban and rural areas of developing nations. The groundwater in the study area is slightly alkaline in nature. Based on total dissolved solids, about 72% of the groundwater samples are within the desirable limit and 23% are within the permissible limits of drinking water, but 5% are unsuitable for drinking as well as for irrigation. The study has been concluded that the spatial distribution of Groundwater quality could be predict and assessed the distribution of Groundwater quality for the entire study area. It was found that the maximum parameters were highly distributed in entire Ramanathapuram district due to the geomorphology condition, soil formation and presence of gundar river deposition, salt water intrusion and also urbanization are the major factors to damage Groundwater quality. So the study area needs effective management planning strategies to conserve the eater potential for public utility.

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