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Assessment of Seawater Intrusion into Shallow Coastal Aquifer in Kanyakumari District, Tamilnadu, India

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Abstract**:** ***Improved use of groundwater is often causing intrusion of seawater. The intrusion of seawater also takes place in coastal areas. In this analysis, the distribution and the levels of intrusion in the research area (Kanyakumari district, Tamilnadu, India) are determined. The test was done using random samples at a period of 15 days in which 30 different samples were taken in 5 different locations with a certain distance from the seashore, then chemical analysis including pH, electrical conductivity (EC), total dissolved solids (TDS), chloride, sodium, calcium, magnesium, carbonate, and bicarbonate water quality parameters were carried out. Chloride Bicarbonate Ratio was used for the calculation of the penetration rate of the seawater, and subsequently chloride and electric conductivity were defined as type and quality of water characters. The results showed that the shallow aquifer was intruded by seawater at several sample levels, which was included in the normal to high intrusion classification. The sea water intrusion was classified as freshwater to saltwater, the concentrations in chloride ranged from 159 to 6021 mg / L. The ratio of bicarbonate chloride was 0.28 to 21.46, normally above 15.5, indicating that groundwater was disturbed. As a result, in comparison to standards or other seawater intrusion indicators, Rajakamangalam-well 1 (RM-W1) has been affected by seawater intrusion highly.***

Keywords**:** ***Aquifer; Hydrochemical parameters;Groundwater; Indicator; Seawater intrusion***

I. INTRODUCTION

For the existence of living things, water is very necessary. The water is needed for all life on Earth plants, animals and human beings. Groundwater is an important water source. Drilling or digging groundwater can be used quickly and cost-effectively [1-3]. Recently, use of groundwater in line with population growth has increased. The groundwater is used for the needs of residents, industry, and farmers. Due to differences in geography, weather and land use, the distribution of groundwater supplies is limited and unevenly distributed over time and space [4,5]. In regard to the productive capacity of an aquifer, constant extraction of groundwater reduces the surface of the groundwater.

Intrusion of seawater into groundwater aquifers in the land called the intrusion of seawater is a result of continuous extraction of groundwater [6-9]. The intrusion of seawater is a problem in the coastal regions. The state of the coastal network is shown in Figure 1. An ideal hydrogeological cross section is indicated by a freshwater aquifer system that is hydraulically connected to sea water. The standard hydraulic slope (interface), from earth to sea level, exists (Figure 1a). The interface moves to the land and produces seawater intrusion into the freshwater aquifer at land as illustrated in Figure 1b, with a decreased freshwater flow into the water. The interface line to the sea is pushing up a rise in the freshwater flow [10].

Excessive extraction of groundwater, particularly from coastal areas, resulting in seawater intrusion, is a global problem [11,12]. Measurement has been performed by means of a number of methods and techniques, including geoelectrical resistivity [13-15], analytical design methods [16-19] as well as the commonly used quantitative model of simulation [20-24]. The Chloride Bicarbonate Ratio method was used in this study to determine the occurrence of seawater intrusion, using an ion ratio method. The main ion in seawater is chloride and trace in groundwater, while the dominant ion in groundwater and the lowest level of bicarbonate are in seawaters [25-28]. The value of the level of chloride to the amount of carbonate and bicarbonate determines the level of intrusion by groundwater. Different processes contribute to invasion of seawater, such as irrigation, unpredictable control of the aquifer, tidal effect, sea-level rise, seasonal flood variations [29].

In addition to the growing need for groundwater, together with the increase in the population, and also due to the transformation of land into settlements, infrastructure, and industries, the groundwater balance will today and probably in future be increasingly distorted. It decreases the area where water is deposited so that there is less water reaching the ground to offset the water coming out of the soil. On the other hand, the level of forest encroachment as a runoff catchment area in the downstream region would gradually reduce the availability of groundwater. Furthermore, structure and geological conditions in the groundwater aquifer are influencing the question of intrusion by seawater. This research aims to find: distribution, intrusion rate and category of water, control measures in the field of research.

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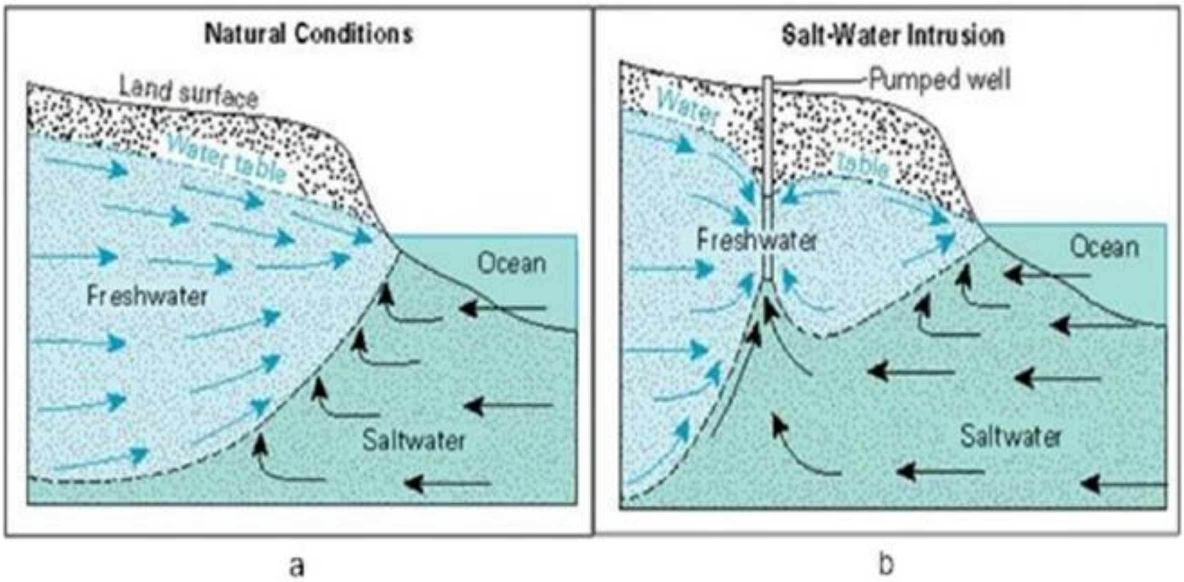

Fig 1. Condition of coastal aquifer (a) before and (b) after seawater intrusion [10]

II. STUDY AREA AND METHOD

The intrusion of the seawater in the Kanyakumari region has caused further coastal areas problems. Water quality is found to be degraded due to salinity. This has an effect on drinking water and improvements in agricultural plant patterns. The yield is also low due to saltwater. Freshwater reduction also leads to people migrating from one place to another. By the way, we choose from a well near the coast and analyze whether they are affected by the intrusion of seawater.

Fig 2. Study area and sample collection locations

Kanyakumari is a town of Tamil Nadu, located at the southernmost tip of India. The town was known as Cape Comorin during the British rule and has an area of 25.89 Km^2. Kanyakumari is the meeting point of three oceans the Bay of Bengal, the Arabian Sea and the Indian Ocean. In here the two wells with various lengths from sea samples collected for the analyze. The two samples were collected 360m and 850m from the seashore and the depth is 7.2m and 17.95m respectively. About 30 Km (18.75 miles) from Kanyakumari is a pristine stretch of golden sand, Colachel

Beach, Tucked away in a breathtaking natural setting of plunging ravines of red soil and lush green scrubs. Drive through red rock cliffs and verdant gorges that succumb to a fine sandy beach.

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In here the two wells with various lengths from sea samples collected for the analyze. The two samples were collected 150m and 750m from the seashore and the depth is 4.02m and 19.82m respectively. Muttam is small village situated in the Kanyakumari District of Tamil Nadu. Its distance from Kanyakumari is 22 Km. Muttam is becoming a center of attraction for many nature lovers because of the magnificent beach, surrounded by rocky hills and coconut grooves. The beach is located at a distance of 40 Km from Kanyakumari and is an excellent spot for picnic and excursions. In here the two wells with various lengths from sea samples collected for the analyze. The two samples were collected 250m and 400m from the seashore and the depth is 4.6m and 18.88m respectively. Manavalakurichi is around 25 Km north of Kanyakumari. It is located between 8.13°N North latitude and 77.3°E East longitude. In here the two wells with various lengths from sea samples collected for the analyze. The two samples were collected 550m and 950m from the seashore and the depth is 5.7m and 14.82m respectively. Rajakamangalam is 18 Km north of Kanyakumari. Here are no more beaches like Kanyakumari In here the two wells with various lengths from sea samples collected for the analyze. The two samples were collected 450m and 1000m from the seashore and the depth is 9.15m and 20.48m respectively.

The water quality sampling which has been carried out for every 15 days with various depth and different lengths in Jan to Feb 2019. The water samples are collected from different locations. These water samples are brought to the water quality lab and tested. The samples are mainly collected from Shallow aquifer. The test results of these parameters help us to found out the intruded area. The result of the water quality sampling is further demarcated by using the intrusion permissible parameters such as Na, Mg, Ca, TDS, EC, and Cl. By visiting the field, the information of the different well location, depth, length and the type of well were gathered. The data are gathered, given in the Table 1.

Table 1. Details of shallow wells 1 and 2

Place	Shallow well No	Aquifer type	Distance from seashore (m)	Depth of well (m)
Colachel (CL)	CL-W1	Sand	150	4.02
	CL-W2	Sandy clay	750	19.82
Muttam (MM)	MM-W1	Clay	250	4.60
	MM-W2	Sandy clay	400	18.88
Manavalakurichi (MI)	MI-W1	Clay	550	5.70
	MI-W2	Clay	950	14.82
Rajakamangalam (RM)	RM-W1	Sandy clay	450	9.15
	RM-W2	Sandy clay	1000	20.48
Kanyakumari (KI)	KI-W1	Clay	360	7.20
	KI-W2	Sandy clay	850	17.95

III. RESULTS AND DISCUSSION

The dominance of Na and Cl with total dissolved solids of approximately 35,000 mg/l characterizes seawater. Na/Cl ratio is 0.86 in seawater, and Cl is above the alkaline (Na) ions, while the Mg / Ca ratio is between 4.5 and 5.2 in seawater and excess of Mg [30]. In contrast, continental fresh groundwater is characterized by a highly variable chemical composition, although the predominant anions are HCO_3, SO_4 and Cl [32,33]. Generally, the total dissolved solids are usually between 150 mg/l and 1500 mg/l for fresh groundwater. Thus, from total dissolved solids (>2000 mg/l), Cl (>1000 mg/l), and some minor ions, the mixing patterns between seawater and groundwater can be understood. Mixing can also occur when the groundwater conductivity (EC) is above 3000 µs/cm [33]. Mixing can also be identified. The approved chloride values of 250 mg/l, pH as 6.5 to 8, TDS as 600 mg/l, and electrical conductivity up to 150 µs/cm was recommended under the global environmental surveillance system under the United Nations Environment Program (EPA) for 200 mg/l of total alkalinity. Since the parameters of water quality or hydrochemical parameters are being debated, a brief idea of an approach has been given to monitoring and managing seawater intrusions.The different indicator used as the permissible limit of the intrusion is given in the Table 2. The indication is used for shallow wells; the samples were taken for 15 days interval of 3 times in the study areas. At the same time the samples were collected in the same area in a different length with respect to 1st and 2nd well. By the comparison of the chemical parameters with each other for the above permissible limit.In determining the degree of water intrusion, the water quality ratio between the chloride and the total carbonate and bicarbonate was a determinative factor in the classification of groundwater. The ratio of intrusion was classified in to six different categories like normal or no intrusion (<0.5); low (0.5-1.3); moderate (1.3-2.8); rather high (2.8-6.6); high (6.6-15.5); and seawater (>15.5). In the meantime, chloride-based water types consisted of three categories: freshwater (0-200); brackish water (200-600) and saltwater (>600) [34].

Table 2. Water quality parameters of shallow well 1

Place	Days	Water quality parameters								
		pH	EC	TDS	CO_3	HCO_3	Ca	Mg	Na	Cl
	Unit	-	µs/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
CL-W1	15	7.40	120.10	110.00	0.00	622.20	2.53	1.80	46.00	172.30
	30	7.36	131.90	126.70	0.00	603.90	2.62	1.92	61.00	201.68

	45	7.24	135.30	130.20	0.00	611.50	2.64	2.02	72.00	214.98
MI-W1	15	7.13	137.30	180.00	0.00	262.30	3.70	2.80	104.30	272.60
	30	7.02	125.80	175.70	0.00	390.40	3.82	2.96	105.00	289.50
	45	7.09	138.70	195.00	0.00	452.00	3.94	3.17	106.20	295.70
MM-W1	15	7.15	127.90	760.00	0.00	567.30	2.82	2.50	139.80	445.47
	30	7.15	126.80	820.00	0.00	439.20	2.93	2.20	131.40	480.20
	45	7.23	115.80	830.00	0.00	573.80	3.01	2.34	143.30	462.80
RM-W1	15	6.38	198.60	6090.00	0.00	335.30	0.54	1.07	512.80	5904.09
	30	6.42	195.50	6110.00	0.00	280.60	0.62	0.87	516.30	6021.50
	45	6.25	187.50	6070.00	0.00	295.85	0.59	0.92	515.70	5982.00
KI-W1	15	7.26	141.50	630.00	0.00	268.40	3.08	2.90	115.60	314.71
	30	7.31	145.50	782.00	0.00	241.40	3.13	2.87	117.90	324.15
	45	7.19	146.20	820.00	0.00	311.50	3.25	2.93	118.70	335.82

Table 3. Water quality parameters of shallow well 2

Place	Days	Water quality parameters								
		pH	EC	TDS	CO_3	HCO_3	Ca	Mg	Na	Cl
	Unit	-	µs/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
CL-W2	15	6.20	135.60	130.00	0.00	219.60	4.76	5.30	123.40	159.57
	30	6.19	141.20	120.00	0.00	187.52	4.17	4.25	123.90	320.62
	45	5.85	176.20	230.00	0.00	182.30	4.44	5.01	132.00	334.65
MI-W2	15	6.32	143.20	620.00	0.00	286.70	4.88	3.82	103.60	385.83
	30	6.54	164.90	650.00	0.00	192.30	5.71	4.83	136.30	325.05
	45	6.26	137.40	740.00	0.00	219.00	6.25	4.09	116.90	246.00
MM-W2	15	6.27	150.60	180.00	0.00	235.50	3.64	3.52	97.30	359.03
	30	6.27	159.30	330.00	0.00	156.50	4.00	3.92	95.10	357.56
	45	6.38	165.50	580.00	0.00	247.00	3.48	2.72	99.60	310.80
RM-W2	15	5.92	172.90	940.00	0.00	156.70	3.57	2.56	212.20	1125.86
	30	5.92	191.90	1040.00	0.00	185.70	3.51	3.21	220.90	1041.64
	45	5.95	172.30	1540.00	0.00	198.40	5.00	3.82	225.30	984.02
KI-W2	15	6.74	138.60	710.00	0.00	272.50	3.33	1.78	124.70	226.06
	30	6.72	143.30	720.00	0.00	207.40	3.17	4.02	164.47	264.27
	45	6.69	140.20	835.00	0.00	896.70	3.81	4.20	128.70	274.12

Table 4. Seawater intrusion Indication parameters of shallow well 1

Place	Days	Seawater intrusion Indication parameters					
		EC	TDS	$Cl/(HCO_3+CO_3)$	Na/Cl	Na/(Ca+Mg)	Mg/Ca
	Unit	µs/cm	mg/l	-	-	-	-
CL-W1	15	120.10	110.00	0.28	0.27	10.62	0.71
	30	131.90	126.70	0.33	0.30	13.44	0.73
	45	135.30	130.20	0.35	0.33	15.45	0.77
MI-W1	15	137.30	180.00	1.04	0.38	16.05	0.76
	30	125.80	175.70	0.74	0.36	15.49	0.77
	45	138.70	195.00	0.65	0.36	14.94	0.80
MM-W1	15	127.90	760.00	0.79	0.31	26.28	0.89
	30	126.80	820.00	1.09	0.27	25.61	0.75

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	45	115.80	830.00	0.81	0.31	26.79	0.78
RM-W1	15	198.60	6090.00	17.61	0.09	318.51	1.98
	30	195.50	6110.00	21.46	0.09	346.51	1.40
	45	187.50	6070.00	20.22	0.09	341.52	1.56
KI-W1	15	141.50	630.00	1.17	0.37	19.33	0.94
	30	145.50	782.00	1.34	0.36	19.65	0.92
	45	146.20	820.00	1.08	0.35	19.21	0.90

Table 5. Seawater intrusion Indication parameters of shallow well 2

Place	**Days**	**Seawater intrusion Indication parameters**					
		EC	**TDS**	**Cl/(HCO_3+CO_3)**	**Na/Cl**	**Na/(Ca+Mg)**	**Mg/Ca**
	Unit	**µs/cm**	**mg/l**	-	-	-	-
CL-W2	15	135.60	130.00	0.73	0.77	12.27	1.11
	30	141.20	120.00	1.71	0.39	14.71	1.02
	45	176.20	230.00	1.84	0.39	13.97	1.13
MI-W2	15	143.20	620.00	1.35	0.27	11.91	0.78
	30	164.90	650.00	1.69	0.42	12.93	0.85
	45	137.40	740.00	1.12	0.48	11.31	0.65
MM-W2	15	150.60	180.00	1.52	0.27	13.59	0.97
	30	159.30	330.00	2.28	0.27	12.01	0.98
	45	165.50	580.00	1.26	0.32	16.06	0.78
RM-W2	15	172.90	940.00	7.18	0.19	34.62	0.72
	30	191.90	1040.00	5.61	0.21	32.87	0.91
	45	172.30	1540.00	4.96	0.23	25.54	0.76
KI-W2	15	138.60	710.00	0.83	0.55	24.40	0.53
	30	143.30	720.00	1.27	0.62	22.87	1.27
	45	140.20	835.00	0.31	0.47	16.07	1.10

Table 6. Level of intrusion and category of water in shallow well 1

Place	**Days**	**Ratio of Cl/(HCO_3+CO_3)**	**Level of Intrusion**	**Chloride (mg/l)**	**Category of Water**
CL-W1	15	0.28	Normal	172.30	Fresh water
	30	0.33	Normal	201.68	Brackish water
	45	0.35	Normal	214.98	Brackish water
MI-W1	15	1.04	Low	272.60	Brackish water
	30	0.74	Low	289.50	Brackish water
	45	0.65	Low	295.70	Brackish water
MM-W1	15	0.79	Low	445.47	Brackish water
	30	1.09	Low	480.20	Brackish water
	45	0.81	Normal	462.80	Brackish water
RM-W1	15	17.61	Seawater	5904.09	Saltwater
	30	21.46	Seawater	6021.50	Saltwater
	45	20.22	Seawater	5982.00	Saltwater
KI-W1	15	1.17	Low	314.71	Brackish water
	30	1.34	Moderate	324.15	Brackish water
	45	1.08	Low	335.82	Brackish water

Table 7. Level of intrusion and category of water in shallow well 2

Place	Days	Ratio of Cl/(HCO3+CO3)	Level of Intrusion	Chloride (mg/l)	Category of Water
CL-W2	15	0.73	Normal	159.57	Fresh water
	30	1.71	Moderate	320.62	Brackish water
	45	1.84	Moderate	334.65	Brackish water
MI-W2	15	1.35	Moderate	385.83	Brackish water
	30	1.69	Moderate	325.05	Brackish water
	45	1.12	Low	246.00	Brackish water
MM-W2	15	1.52	Moderate	359.03	Brackish water
	30	2.28	Moderate	357.56	Brackish water
	45	1.26	Low	310.80	Brackish water
RM-W2	15	7.18	High	1125.86	Saltwater
	30	5.61	Rather High	1041.64	Saltwater
	45	4.96	Rather High	984.02	Saltwater
KI-W2	15	0.83	Low	226.06	Brackish water
	30	1.27	Low	264.27	Brackish water
	45	0.31	Normal	274.12	Brackish water

Figure 4 clearly shows that the colloidal particles which affect the EC values that cause increase in Electrical conductivity (EC) values. Here the EC value varies between 100-150 µs/cm in the CL, MI, MM, KI except RM were more than 150 µs/cm. This change in the EC value is mainly due to environmental factors.

TDS shows that, region of RM values higher than the permissible limit. The various set of readings were taken and in the other places there is no intrusion except Rajakamangalam. These values have differed with combined content of inorganic and organic substances contained in that water. The readings were compared to each location, CL and MI readings are lower than the other three. Here the values are also compared to the permissible limit and the values are found greater at RM. So the intrusion has occurred when TDS permissible value is more than 2000 mg/1.

In these parameters, the analyzed values show that there is no intrusion except in RM at the 1st well near the sea shown in fig 4. Here the values of RM have greater values compared to all others and permissible value. Other readings had slight variation with the environmental factor, this shows there will be no intrusion in those areas other than the RM 1st well.

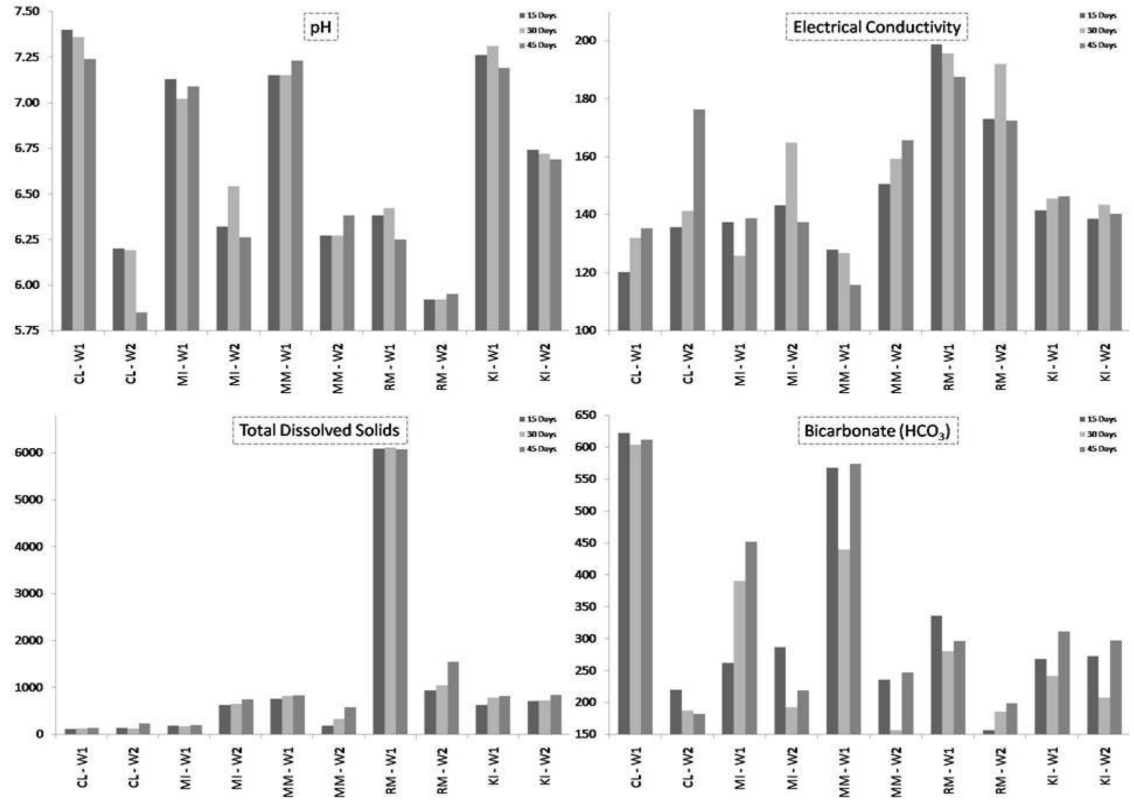

Fig 3. pH, EC, TDS and bicarbonate plots of shallow well 1 and 2

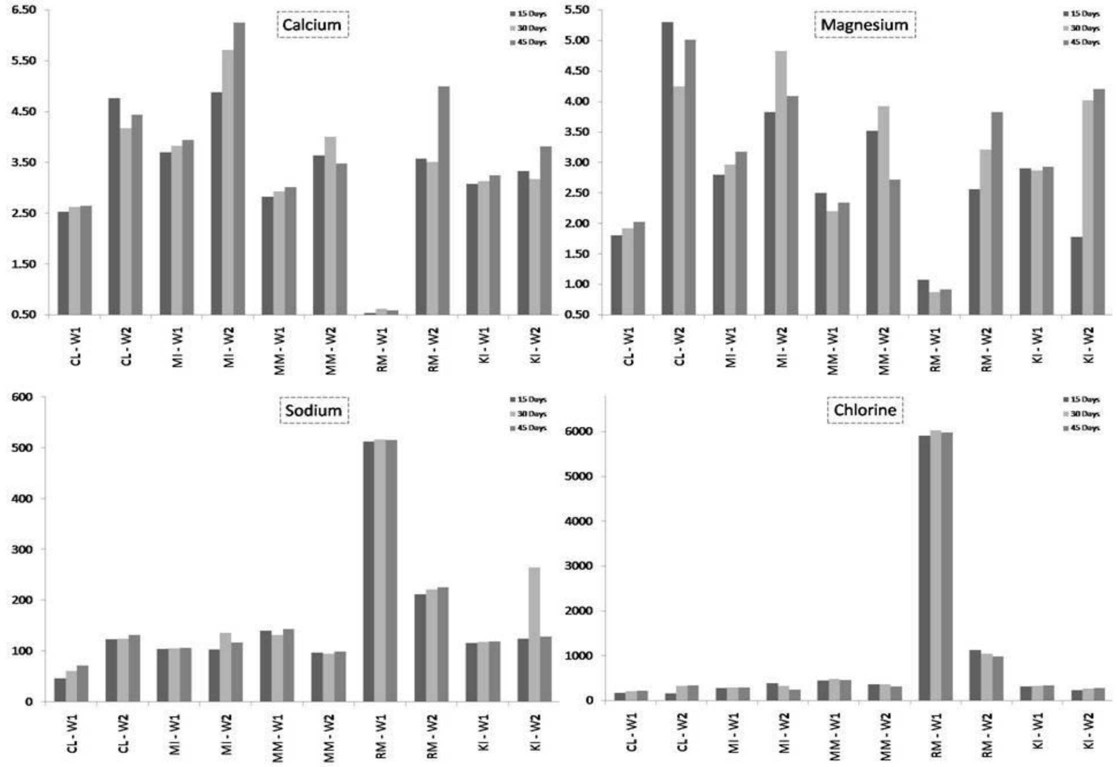

Fig 4. Ca, Mg, Na and Cl plots of shallow well 1 and 2

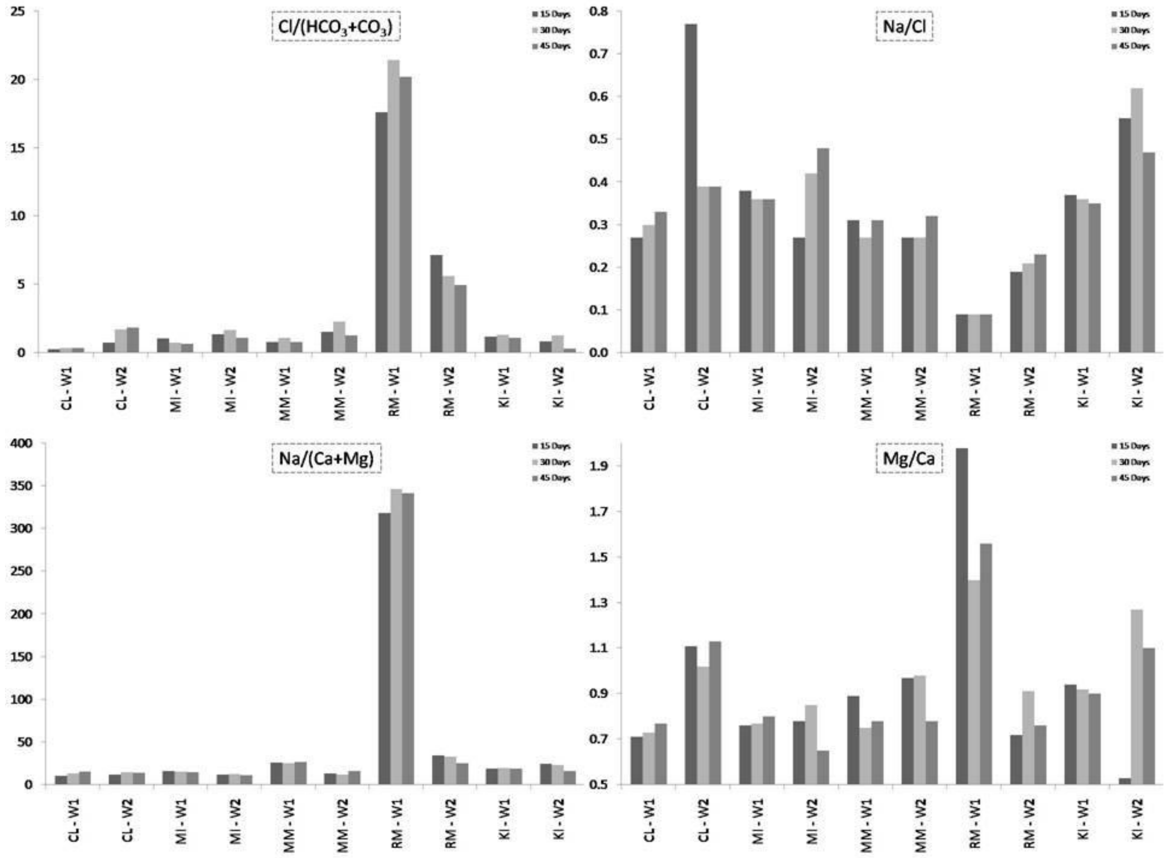

Fig 5. Seawater intrusion Indication parameters of shallow well 1 and 2

From analyzing C1/(HCO3+CO3) ratio of 1st well shows that, intrusion was took place in the region because of recharge process is high so the intrusion is low then only the value comes below the permissible limit shown in fig 5. Here the readings were below the permissible value, then the readings in each location show different values. Here there are values beyond permissible limit, because of intrusion. The variation in these readings is due to environmental factors. There will be the recharge process and if it's high, the intrusion will be low, then the values come below the permissible limit.

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From chloride parameters, category of water is always fresh to saltwater level in all places. In some places (RM-W1 and W2) Chlorides values higher than 600 mg/l, it means seawater intrusion was occurred in rather high to saltwater levels.

IV. CONCLUSION

From the above study, it has been found that the parameters causing seawater intrusion are greater than the standards (ie) TDS and Cl values are greater than standard values corresponding to shallow well 1 and 2 in Rajakamangalam, other well locations were within allowable limits. All other water quality physical and chemical parameters were within limits in all shallow well locations in the studied area. Seawater intrusion Indication parameters like EC, TDS, Na/Cl, Mg/Ca, Na/(Ca+Mg) and $Cl/(HCO_3+CO_3)$ are in optimum standard ranges in all locations wells except well 1 and 2 in Rajakamangalam. Level of intrusion and category of water were analyzed in all locations shallow wells. From these results, it has been concluded that seawater intrusion occurred at Rajakamangalam (RM) is greater, compared to all other stations. The groundwater gets polluted to a greater extent in this area and so nowadays groundwater cannot be used for drinking purposes.

Intrusion control methods vary greatly according to the source of saltwater, intrusive extent, local geology, water utilization, and economic factors. The categories of saltwater intrusion control methods are, non-engineered and engineered prevention methods. In non engineered prevention such as conservation/reduced pumpage, leak control, financial incentives/disincentives, variable water rates, pumping pattern management and engineered prevention such as relocated wells - same and alternative aquifer, increased surface water use, active and passive aquifer recharge, induced recharge wells, physical, hydraulic and electrical barriers, saltwater interception, flownet modification, combined extraction/injection and aquifer storage/recovery.

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