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SEASONAL DEVIATION OF SALTWATER INTRUSION IN THE SHALLOW AQUIFERS OF KOCHI MUNICIPAL CORPORATION, KERALA, INDIA

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ABSTRACT:

Quality Water is one of the precious and diminishing resources of the world and saltwater intrusion is a threat to fresh water sources. The study area Kochi, is the heart of Kerala, a state on India's tropical Malabar Coast, with nearly 600km of Arabian Sea shoreline. Being a thickly populated coastal metro-city, with increase in water demand and decline potential ground water recharge, shallow aquifer of Kochi also affected by saltwater intrusion. The present study is to estimate the level of saltwater intrusion in the Kochi Corporation area, represented as Total Dissolved Solid (TDS), in open well water samples at various climatic conditions. 35 well water samples were collected within the corporation boundary in four different seasons between July 2014 and April 2015. The TDS gradient maps were plotted using Geographic Information System (GIS) for the area.

The GIS plotting were compared with geological map of the area and rain fall recording of the period. The clayey soil stratum of Kochi area is the major positive factor which precludes saltwater intrusion in spite of high water abstraction of the area. Natural ground water recharges during monsoon season considerably suppress saltwater intrusion even in the coastal regions of the city. A severe effect of saltwater intrusion is seen in Kalvathi, place very near to Arabian coast and concentration of dissolved solids found to rise about 5-6 times in summer season compared to rainy season. Detailed assessment of well water quality at Kalvathi, during July 2015 to July 2016, revealed the influence of rain fall in suppressing the saltwater intrusion of ground water table.

Keywords: Geographic Information System, Saltwater intrusion, Seasonal variation, Shallow Aquifer, Total Dissolved Solids.

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1. INTRODUCTION

With two thirds of the earth's surface covered by water and the human body consisting of 75 percent of water, it is evidently clear that water is one of the prime elements responsible for life on earth [1]. But, only 3% of the Earth's water is fresh water and a major percentage of that water is in ice caps and groundwater. Kerala, known as "God's own country" by its rich natural beauty, is blessed with an average annual rainfall of 3107mm, which was good nourishment to the ground water sources. Urbanization changed the land use pattern, increased the water demand and reduced the natural wetland. The chance of ground water recharge was blocked by hard impermeable surfaces and increased runoff, which flushed the fresh rainwater into sea. Increase in water abstraction and reduction in recharge, affected the groundwater resources of Kochi by saltwater intrusion.

Coastal zones contain some of the most densely populated areas in the world as they generally present the best conditions for productivity [2]. In coastal areas, fresh groundwater from inland sources mixes naturally with saline groundwater beneath the ocean floor to some extent. When the mixing of saltwater with freshwater beneath the surface occurs in an area that was previously fresh, the process is referred to as saltwater intrusion. [3, 4]

The fresh groundwater flows from inland areas towards the coast, where water levels are at lower elevation. Because saltwater has a higher concentration of dissolved salts and minerals, it is denser than freshwater, causing it to have higher hydraulic head than freshwater. At the saltwater and freshwater interface, mixing occurs through dispersion and diffusion. [5] Normally the inland extent of the saltwater wedge is limited because fresh ground water levels, or the height of the freshwater column, increases as land elevation gets higher. The first physical formulations of saltwater intrusion were made by W. Badon-Ghijben (1888, 1889) and A. Herzberg (1901), thus called the Ghyben–Herzberg relation. Thickness of fresh water zone below sea level, Z = 40 h represents Ghyben–Herzberg relation. Here h represents the head of fresh water table available above sea level. The terms of relation is represented in Fig. 1. [6, 7]

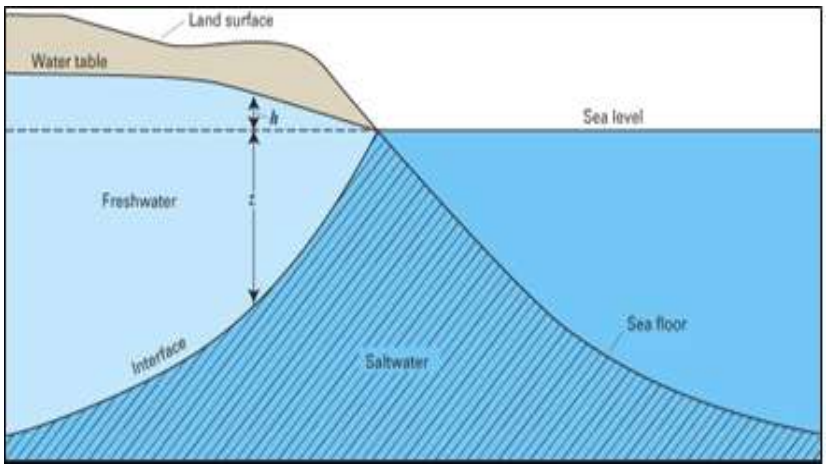

Figure 1 Ghyben–Herzberg relation of saltwater intrusion [3, 7]

The severity of saltwater intrusion increases with decrease of ground water recharge and increase of water demand especially during summer season. [8] When fresh water is pump out rapidly, water table in the freshwater aquifer forming a cone of depression. The saltwater rises 40 times more of freshwater depression and forms a cone of ascension. Cumulative effect of cone of depression and cone of ascension increase the threat of saltwater intrusion known by the name Upconing. [9] Fig. 2 represents the development of upconing of saltwater freshwater interface, inducing saltwater intrusion.

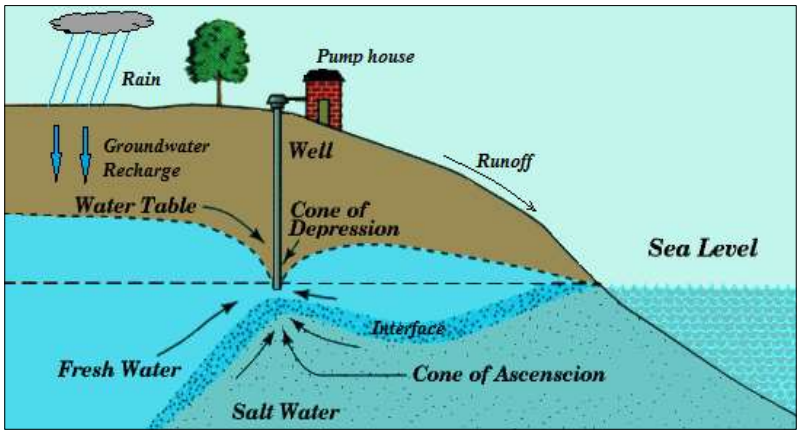

Figure 2 Upconing of saltwater by extensive pumping [10]

2. LOCATION OF STUDY AREA

The study area is Kochi Corporation, situated in Ernakulam District, Kerala state, India. It spans over 94.88km^2, with an estimated population of 633,553 (2011 Census). The population growth rate in Kochi has declined dramatically over the past three decades, due to the high literacy rate and various family planning programs. [5, 11, 12] Kochi region is a fast growing urban agglomeration on the coast of Arabian Sea in India. Fig 1.3 gives the exact location and division map of Kochi Corporation. Extend of the study area lies between 9°53'–10°03'N and 76°13'–76°20'E

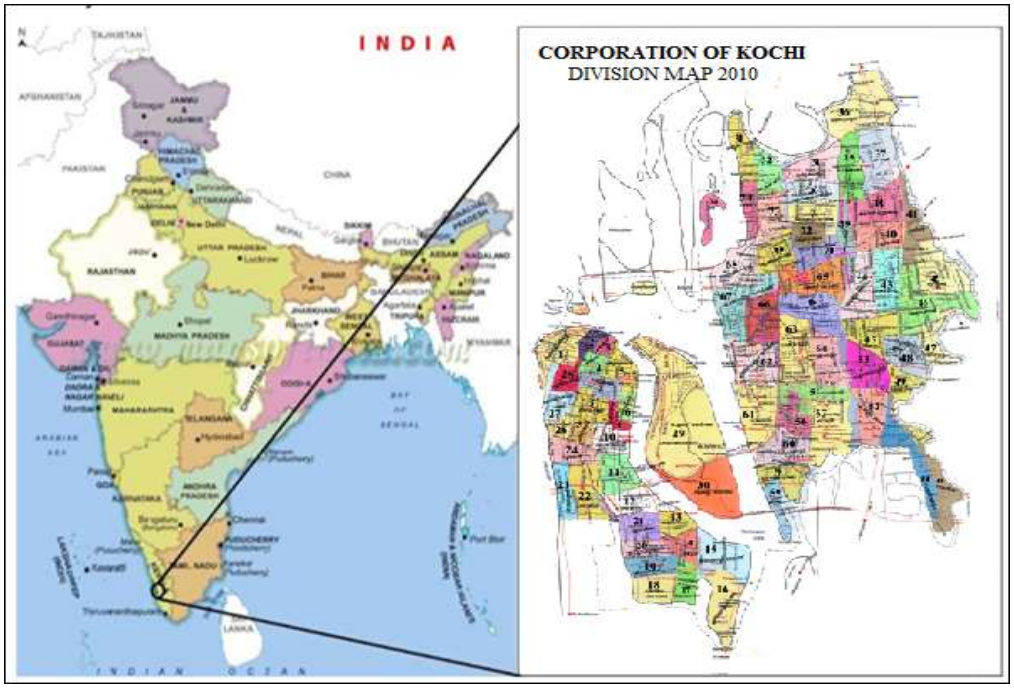

Figure 3 Location and divisional map of Kochi Corporation

3. EXPERIMENTAL INVESTIGATIONS

Kochi corporation area is divided into 74 administrative wards, out of which samples from 35 wards are collected. Sample collection was concentrated over four major seasonal variations available in Kerala. Most parts of ward 29 & 30 are restricted areas by Cochin Port Trust and Southern Naval Command, Kochi and other omitted wards are in the city center with maximum commercial establishments. Real availability of usable water is much less than estimated, due to deterioration of water resources. Well density of in other wards are at a rate of about 200/km^2. It would mean that there is almost enough number of wells to cater to the water needs of residences. Yet, the water supply is woefully inadequate across the length and breadth of area. This is because the water is contaminated with excessive biological pollutants, chemical pollutants, presence of salinity etc.

3.1. Chemical Analysis of Samples

Salinity is the total concentration of all dissolved salts in water. While salinity can be measured by a complete chemical analysis, this method is difficult and time consuming. More often, salinity is not measured directly, but is instead represented as measurement of Total Dissolved Solids (TDS). In this study, first stage of evaluation was based on measurement of TDS using water quality Analyzer.

3.2. Application of Q-GIS for TDS Mapping

Saltwater intrusion level of first stage study represented using, gradient mapping of TDS in the selected area using Q-GIS. Mapping was done in 5 steps: In the First step, Divisional Map of Kochi Corporation (collected from Kochi Corporation) was Geo-referenced based on known Junctions in the area using Q-GIS. Then the boundary of the area was isolated (Shape File). The sampling stations were located within the geo-referenced boundary based on Latitude and Longitude of each station. Each stations were assigned with corresponding TDS values of different seasons in stages. Gradation in Mapping was done by linear interpolation of the assigned data based on the specific sampling location. The Gradation map was trimmed against shape file to get the TDS Gradation map Kochi Corporation.

3.3. Detailed Evaluation of water Samples from Kalvathi

During this stage of investigation well water samples were collected from Kalvathi (Ward – 2) at 28-day interval from July 2015 to July 2016. Samples were analyzed in detail, for chemical characteristics like Chloride, Sulphate, Sodium, Calcium, Potassium Iron and COD along with TDS.

4. RESULTS AND DISCUSSIONS

Seasonal status of Kerala can be divided into four—winter, summer, South-West Monsoon and North-East Monsoon. Winter season in Kerala begins from the later part of November lasting till the middle of February. Hot sunny daytime and cool nighttime is the specialty of this season. Starting from March, temperature starts climbing and this marks the commencement of summer in Kerala. Summer season continues till the end of May or the beginning of June and is concluded with the outset of monsoons. Southwest monsoon is the main rainy season in Kerala. Monsoons contribute almost 85% of the rains received in Kerala. The southwest monsoon in Kerala lasts till the end of September. North East Monsoon is in the months of October and November. Heavy afternoon rains accompanied by thunder and lightning is the main characteristic of the season. [13] Days are warm and humid but there is not much variation in temperature. Four set of open well water samples were collected from 35 wards of Kochi Corporation, during July 2014, October 2014, January 2015 and April

2015. Samples were analyzed for Total Dissolved Solids (TDS). Table 1 gives the sampling (well) locations and TDS values of water samples collected during 4 different seasons of Kerala.

Table 1 TDS values of well water samples taken at different seasons

Ward No	Ward Name	Location		TDS (mg/L)			
		Latitude (N)	Longitude (E)	July 2014	October 2014	January 2015	April 2015
1	Fortkochi	9°57'56.80"	76°14'31.61"	840	428	465	878
1	Vypin	9°58'22.85"	76°14'39.66"	357	321	378	378
2	Kalvathi	9°58'6.42"	76°14'56.51"	917	840	4846	4560
3	Eraveli	9°57'53.84"	76°15'7.00"	428	538	649	653
5	Matanchery	9°57'19.23"	76°15'36.80"	428	392	523	560
6	Kochangadi	9°57'11.47"	76°15'20.08"	465	286	541	392
7	Cheralayi	9°57'27.84"	76°15'8.16"	575	501	501	664
8	Panayappilly	9°56'46.98"	76°15'28.98"	650	575	233	575
9	Chakamadam	9°57'17.25"	76°15'28.44"	364	687	432	428
10	Karuvelippady	9°56'20.52"	76°15'42.01"	428	392	582	575
11	Thopumpady	9°56'7.00"	76°15'33.00"	353	286	446	332
15	Edakochi North	9°54'59.04"	76°17'28.88"	328	279	314	286
16	Edakochi South	9°53'52.43"	76°17'43.35"	233	216	342	374
17	Perumpadap	9°54'33.73"	76°16'48.01"	296	240	356	364
18	Konam	9°54'9.93"	76°16'33.23"	332	251	261	346
20	Nambyapuram	9°54'56.43"	76°16'18.71"	279	286	465	425
25	Chullickal	9°56'51.68"	76°15'23.77"	275	286	782	770
26	Nazrath	9°56'35.43"	76°14'47.27"	465	428	392	538
27	Fortkochi Veli	9°56'54.64"	76°14'36.84"	392	612	465	446
28	Amaravathi	9°57'36.48"	76°14'39.45"	538	465	501	519
31	Vaduthala	10°0'55.21"	76°16'31.54"	410	360	382	403
37	Edappaly	10°1'25.23"	76°18'41.84"	282	251	279	261
42	Vennala	9°59'18.69"	76°19'12.53"	293	279	279	289
49	Vytla	9°57'59.95"	76°19'00.53"	202	202	209	212
50	Chambakkara	9°57'14.45"	76°19'36.56"	314	328	339	332
51	Poonithura	9°56'31.21"	76°19'58.93"	328	328	340	335
52	Vytila Janatha	9°57'41.98"	76°18'49.66"	279	279	314	328
57	Kadavanthra	9°57'26.32"	76°18'05.36"	435	417	293	479
58	Konthuruthy	9°56'33.84"	76°18'05.36"	317	300	356	356
59	Thevara	9°56'21.90"	76°17'45.08"	389	265	268	268
60	Perumanoor	9°56'54.22"	76°17'36.65"	300	275	293	279
61	Ravipuram	9°57'50.21"	76°17'14.29"	353	321	417	483
68	Ayyapankavu	9°59'49.52"	76°18'10.13"	205	216	407	223
67	Ernakulam North	9°59'31.49"	76°17'11.28"	202	385	251	275
69	Thrikkanarvattam	9°59'37.02"	76°16'41.96"	378	332	382	468
70	Kaloor North	9°59'47.75"	76°16'58.80"	385	353	356	428
73	Pachalam	10° 0'5.63"	76°16'46.29"	472	367	346	457

TDS Values visibly show a rise during winter and summer period, when the daytime temperature is high to have higher water demand and lowest range of precipitation to recharge the ground water. Lower TDS values during monsoon period evidently shows the restriction to saltwater intrusion due to lower water demand and fresh water recharge to ground water table.

4.1. Q-GIS Mapping of TDS values in Kochi Corporation Area

Kochi Corporation map (as per Kochi corporation record) was Geo-referanced using the Q-GIS software taking known Latitude and longitude of 4 Station in the area. Based on the Geo-Referenced Map of Kochi Corporation, Boundary of the area and relative locations of sampling stations (as given in Table 1) were marked. Fig. 4 represent the boundary of Kochi Corporation and the sampling location. Figure was plotted to their relative location based on latitude and longitude. Extend of the plot lies between 9.88°N to 10.06°N and 76.22°E to 76.35°E, at a grid of 0.02° x 0.02°

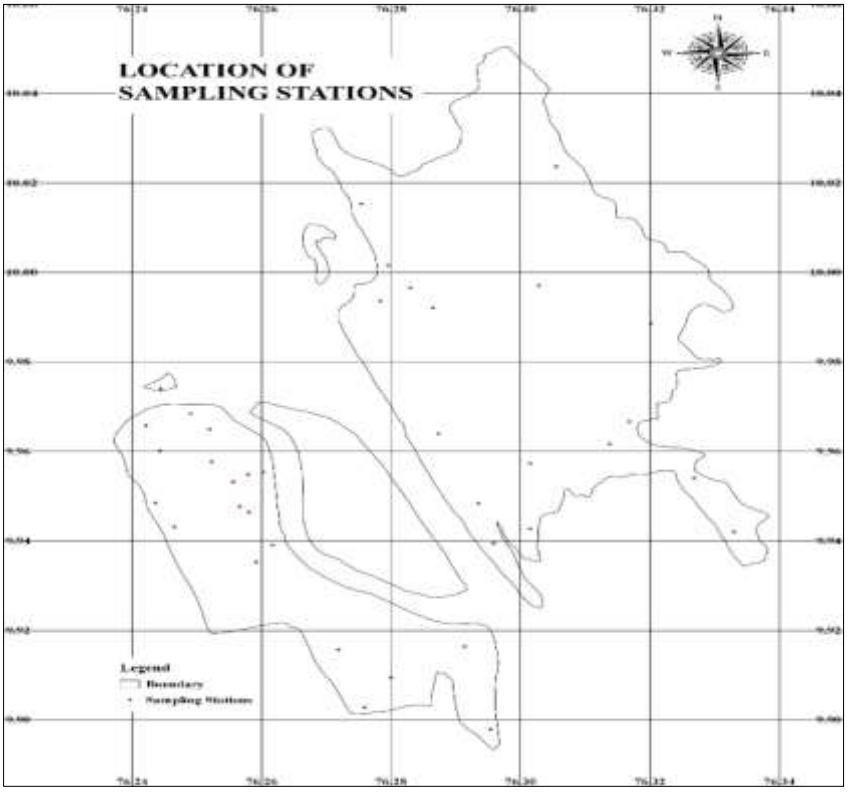

Figure 4 Locations of Sampling Stations within Kochi Corporation Boundary

Sampling Stations were assigned with TDS values as attributes and mapping was done by linear interpolation. Extraction of interpolated map was done based on Boundary shape file to get the salt concentration gradient of ground water. Separate maps were plotted corresponding to each seasons. Fig. 5, Fig. 6, Fig.7 and Fig.8 represents the TDS concentration levels of ground water during July 2014, October 2014, January 2015 and April 2015 respectively.

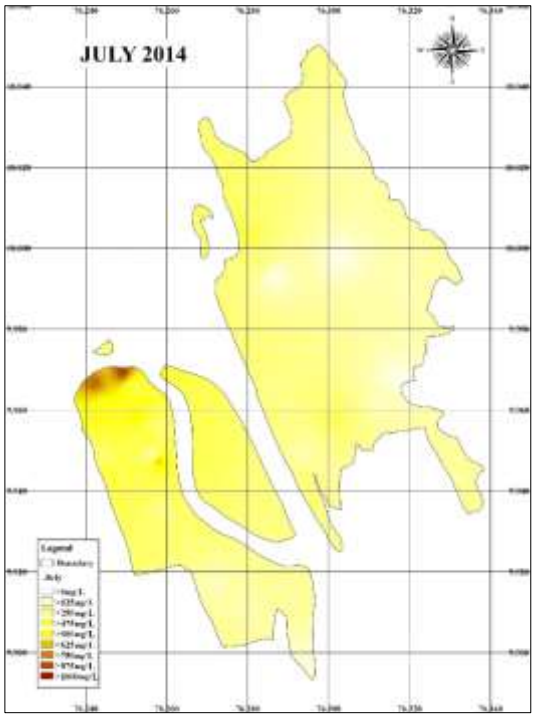

Figure 5 TDS Gradient Map - July 2014

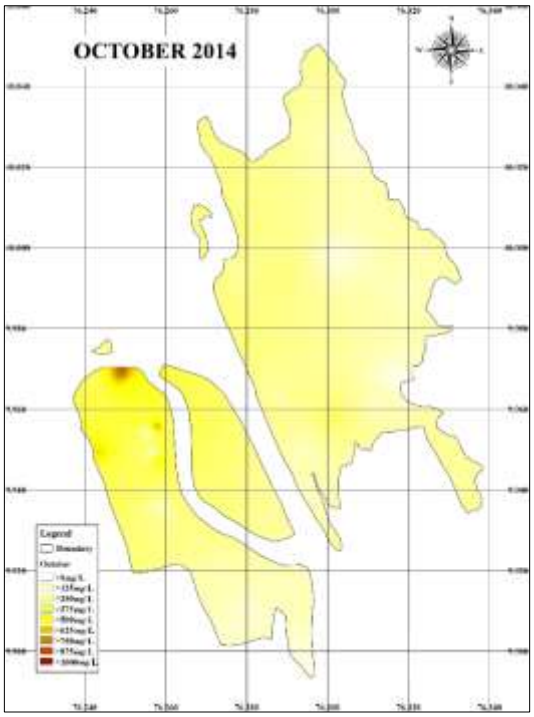

Figure 6 TDS Gradient Map - October 2014

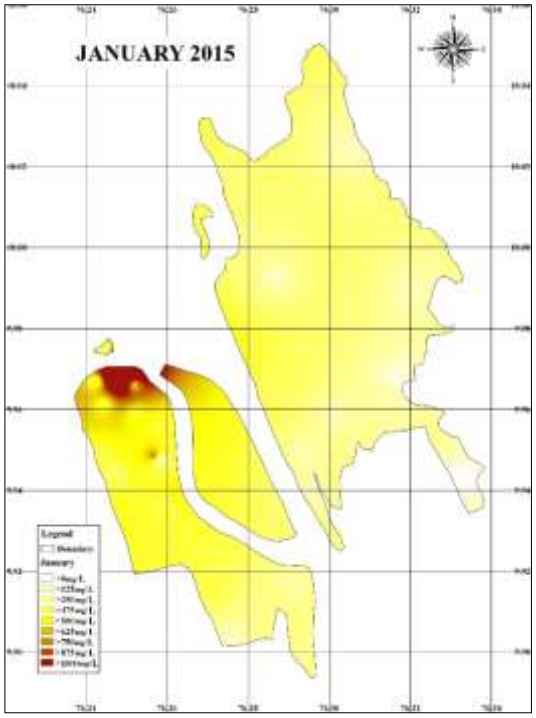

Figure 7 TDS Gradient Map - January 2015

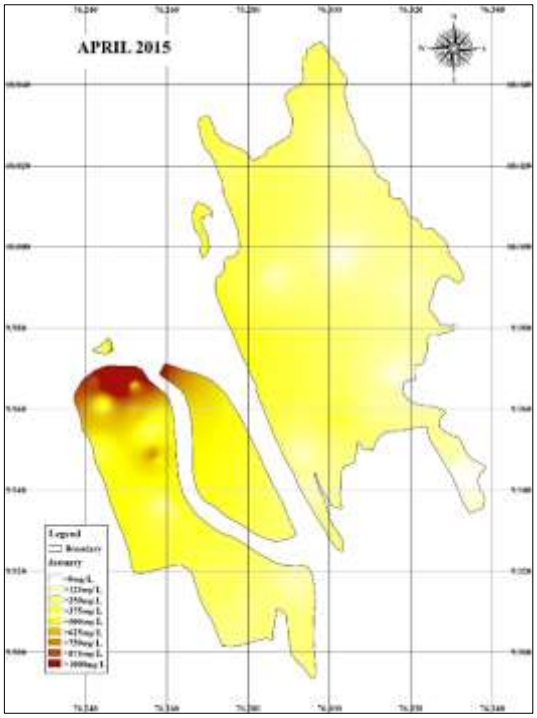

Figure 8 TDS Gradient Map -April 2015

A colour variation in different figures clearly shows the variation in TDS levels at different seasons. Summer and winter season shows higher TDS levels compared to Monsoon period. As per Table 1, slight reduction in peak TDS levels at summer compared to winter was observed due to the availability of Summer shower during March – May 2015. Fortkochi & Kalvathi area of Kochi Corporation Shows maximum level of saltwater Intrusion compared to other regions. When compare the Fig. 7 and 8, it is seen that influential region of saltwater

intrusion was spread to a larger extend as the summer intensified in April in places are nearer to shore line.

Fig. 5, 6, 7 and 8 show identical characteristics of ground water in the central regions of Kochi, an area with zero indication of saltwater intrusion even in the extreme summer climate. This must be the influence of thick marine clay deposit under Kochi strata as reported by Anitha (2014) [14] Jose et al. (1987) [15] and Jose (1989) [16]. King (1884) perhaps was the earliest to report on the geology of the area as part of his studies on mud banks off the coast of Kochi and Alappuzha. According to him, 2500 years back the land between the Western Ghats and the present coastal line once well above the sea and was subsequently submerged. The area from Kudungallur ($10^0$13'28"N, $76^0$11'52"E), to Kollam ($8^0$53'36"N, $76^0$36'51"E) was uplifted again by volcanic action and again partially covered by sea water. [17] Thus deposited Clayey layer of region retards the spreading of saltwater into the interior regions of the area, even with the presence of larger number of tidal canals and high water table in Kochi. Heavy rainfall available during Monsoon season, also effectively prevents intrusion of saltwater water to shallow aquifers of Kochi.

4.2. Detailed Investigation on Groundwater of Kalvathi

As per table 1 well water sample from Kalvathi reported with highest TDS values and about 5times escalation in TDS Value during summer season. Kalvathi (76°14'56.51"N, 9°58'6.42"E) is a thickly populated area very near to coastline belt (less than 1km from shore).Sample was collected from a household protected well, water source for a colony other than Municipal water supply. Table 2 represent the chemical characteristics of water samples collected during July 2015 to July 2016 at 28 day interval. Table clearly indicate rise in Chloride, Sodium and Hardness according to the rise of TDS concentration. All samples were with pH ranging from 6.5 to 8. COD values found to be zero, indicating well water was free from organic contamination.

Table 2 Characteristic fluctuation of well water at Kalvathi

Sampling Date	TDS (mg/L)	Chloride mg/L	Hardness mg/L	Sulphate (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
11-07-15	1001	410	360	46	183	39	49	57
08-08-15	1044	470	370	36	191	40	55	56
05-09-15	1300	590	428	43	232	46	59	67
03-10-15	695	304	268	30	140	35	40	40
31-10-15	937	460	350	29	184	40	49	55
28-11-15	1580	820	520	63	273	47	76	79
26-12-15	1508	770	496	51	223	40	79	72
23-01-16	2928	1959	906	61	382	55	141	133
20-02-16	2375	1432	742	52	336	54	139	95
19-03-16	2369	1428	740	50	328	53	138	95
16-04-16	2033	1022	600	42	287	49	105	81
14-05-16	1491	670	460	33	232	44	67	70
11-06-16	763	360	308	30	169	37	44	48
09-07-16	570	260	250	31	135	35	40	36

Fig.8 plotted the variation in TDS values against monthly average rainfall record of Ernakulum District available from the website of India Meteorological Dept. (Customized Rainfall Information System - CRIS) [18]. The figures clearly indicate influence of rainfall in suppressing the saltwater intrusion of the area.

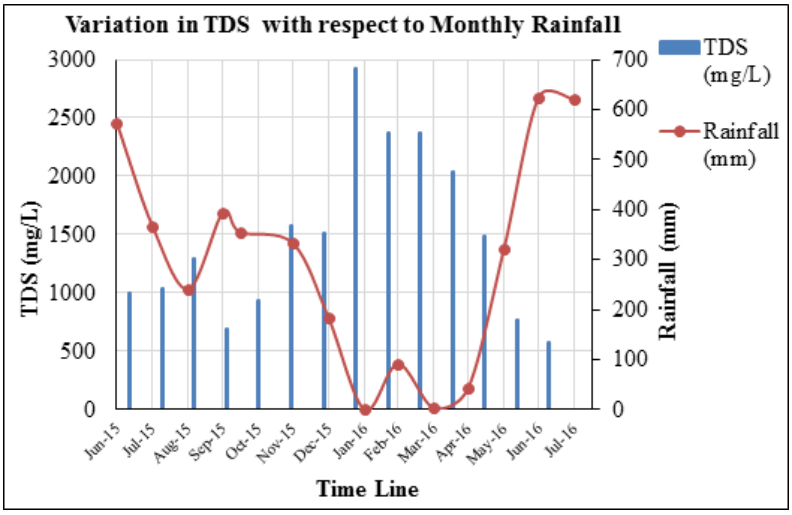

Figure 8 Variation of TDS concentration with respect to rainfall

5. CONCLUSION

The present study reveal that Kalvathi – Fort Kochi regions of Kochi Municipal Corporation only shows extreme increase in TDS concentration levels, whereas other regions shows do not show any sign of saltwater intrusion even during non-monsoon period. Detailed study in Kalvathi regions indicate that monsoon period in Kerala, effectively prevents the influence of saltwater intrusion, even with natural recharge. Along with lower ground water recharge, the higher levels water demands activate the chances of saltwater intrusion. The clayey strata of Kochi region effectively prevents higher levels of saltwater intrusion into the inland regions of Kochi, despite of the presence of large number tidal canals in the area. This study also reveals the importance of groundwater recharging. If artificial well recharging methods are adopted during monsoon, saltwater intrusion can be prevented to greater extend in non-monsoon periods.

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