IJASRM

International Journal of Advanced Scientific Research and Management, Volume 3 Issue 11, Nov 2018

www.ijasrm.com

ISSN 2455-6378

Delineation of Sensitive and Insensitive Zones of Saline Intrusion Along The Fresh Water Coastal Aquifers of Central Kerala, S. India Using Quality Depth Index (QDI) Studies

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Abstract

Critical analysis of the variation in quality depth index (QDI) values, with respect to the TDS and Chloride values and distance from the salt water body for the entire study area is presented. The study reveals an exponential decrease in QDI values with distance. Based on this, the entire study area was categorized into sensitive and insensitive zones. The study reveals that in general, a distance of 250 m from salt water body is the risk zone. Beyond that QDI values are insensitive. The study indicates, 30% of the aquifer, mostly belong to the northern zone (sector II)namely Palapetty and Ponnani are more polluted than the southern zone of sector I. 10% of the sample stations are in safer zone even though their distance from the saline water body is less than 200m.

***Keywords**: QDI,* Saline water intrusion, Coastal region, Pollution

1. Introduction

The coastal stretch of Azhikode in Thrissur district to Ponnani of Malappuram district, forming an integral part of the Arabian Sea coast, and extending to 64km. in length and 2.5 km. in average width in the area under taken for the present study. It lies between the North latitude 10^0 10'49'' and 10^0 46'53'' and East longitudes 75^0 54'06'' and $76^0$09'12'' and covers 1608 sq.km.

Withdrawal of fresh water from shallow unconfined aquifer adjacent to shore, particularly during pre monsoon, cause lowering of fresh water table. This follows with landward advancement of saline water interface considerably and reducing the fresh water storage space. This increases the salt content in the potable water due to transverse or lateral diffusion/ dispersion of oceanic salts. Studies in this regard were carried out in many parts of the world. A conceptual model about the coastal aquifer system was suggested by Kallloras et.al., (2006). Rahman and Bhattacharya (2014) carried out a detail study on saline water inclusion of coastal aquifers. The management and control aspect of saline water intrusion were carried out by Kayode et.al. (2017). According to Ghyben-Herzberg's concept of seawater intrusion in coastal aquifers, there exist a transition zone of certain width where the density varies between sea water to that of fresh water (Todd 1959). The density is proportional to the dissolved salt content in it. This means total TDS, chloride and other salt content distribution across the fresh water lens will also be the same nature as that of density distribution. Hence it is obvious that the average density (D) and consequently average TDS, chloride and other

International Journal of Advanced Scientific Research and Management, Volume 3 Issue 11, Nov 2018

www.ijasrm.com

ISSN 2455-6378

individual salt contents of the floating fresh water lens available at that point remains same (Basak and Vasudev, 1983). Hence it is logical to expect (i) At any point of time, average salinity of the freshwater lens should increase as one approaches to the shore (ii) At all point in the coastal aquifer, salinity of the fresh water lens should increase with the lowering of the fresh water table (iii) The rate of increase of salinity with the lowering of the fresh water table should increase as one goes nearer to the shore (iv) Beyond a critical distance from the salt water body, the salinity of the fresh water lens should be independent of the depth to the water table and its temporal fluctuations.

2. Methodology

For convenience the entire study area, ie. The coastal tract extending from Azhikode of Thrissur District to Ponnani of Malappuram district was divided into two sectors and 6 zones. Sector I include Azhikode,Peringanam and Nattikazone and sector II comprises Chavakkad, Palappatty and Ponnani Zones. These representative zones were parallel to the coast line and the different sample stations in a zone are almost equally spaced. Six observation wells referred as 'sample stations' were identified in each of the six zones selected. Details of various zones are summarized in Table 1 and its locations are depicted inFig.1.

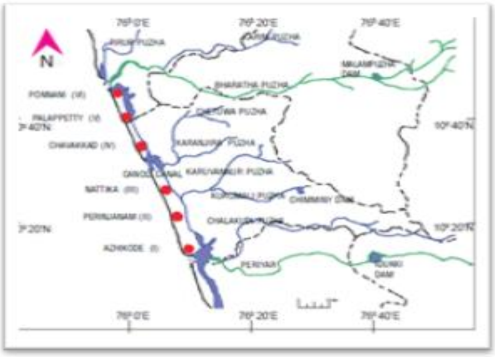

Figure 1: Location map of sample stations

Table 1: The coastal zones within the study area

NO	NAME	CODE	N LATTITUDE	E LONGITUDE	DISTRICT
1	AZHIKODE	I	10010'49'' 10012'49''	76009'12'' 76010'15''	Thrissur
2	PERINJANAM	II	10017'47'' 10019'35''	76007'18'' 76008'21''	Thrissur
3	NATIKA	III	10024'09'' 10025'50''	76004'59'' 76006'33''	Thrissur
4	CHAVAKKAD	IV	10029'32'' 10030'39''	76002'39'' 76003'58''	Thrissur
5	PALAPPETTY	V	10040'20'' 10042'26''	75056'57'' 75058'16''	Malappuram
6	PONNANI	VI	10045'33'' 10046'53''	75054'062' 75055'40''	Malappuram

3. QUALITY DEPTH INDEX (QDI)

QDI values were evaluated using standard methods of Basak and Vasudev (1983). Accordingly season wise values of TDS and Chloride, for the sample stations of the entire zone, with respect to the corresponding depth of water table were plotted and are used for the determination of QDI (Table 2). These values were correlated with distance of sample stations from the nearest salt water body. Station wise values of TDS and Chloride with respect to the corresponding depth of water table were plotted and slope of each line ie. Slope of TDS Vs water table depth and slope of chloride Vs water

3.1. Azhikode Zone

Graphs depicting TDS and Chloride values with water table depth (Fig 2 & Fig 3) explicit that TDS and chloride values in Azhikkod zone varies linearly with the depth of water table. From these plots QDI values of the Azhikkod zone are evaluated and represented in Table 2. Variations of QDI –TDS and QDI - Chloride with distance from salt water body along Azhikode zone is depicted in Fig.14 and Fig 15. These curves indicate an exponential decrease of QDI with increase in distance from the salt water body. A critical analysis of this graph shows that up to a distance of 200m from the salt water body is very delicate and hence there is the risk of saline intrusion at greater speed. Hence this region can be considered as 'Sensitive Zone'. At greater distance QDI is insensitive to the change in depth of the water table.

table depth were calculated.

Table 2: QDI at Azhikode zone

Sample station	QDI (TDS) (ppm/m)	QDI (Chloride) (ppm/m)	Distance from salt water body
1.WS1	5	8	655
1.WS2	11	15	310
1.WS3	4	5	10
1.WS4	56	45	15
1.WS5	15	16	250
1.WS6	13	7	415

3.2. QDI variations along Perinjanam zone

Graphs depicting TDS and Chloride values with water table depth (Fig 4&5) explicit that TDS and chloride values in Perinjanam zone varies linearly with the depth of water table. This means with an increase in the depth of water table there is a corresponding deterioration of water quality. From these plots QDI values of the Perinjanam zone are evaluated (Table 3). QDI values with respect to TDS values of Perinjanam zone varies between 5ppm/m at sample station II.WS1 to 72ppm/m at sample station II.WS4. With respect to chloride, QDI values varies from 15ppm/m at sample station II.WS1 to 83 ppm/m at sample station II.WS2. Fig.16& Fig 17 represents the variation of QDI (TDS and Chloride) with the distance from the salt water body. As seen from the graph, the 'Sensitive zone' is up to a distance of 200m from the salt water body. At greater distance, QDI is insensitive to the change in depth of the water table.

Table 3: Perinjanam zone

Sample station	QDI (TDS) (ppm/m)	QDI (Chloride) (ppm/m)	Distance from salt water body
II.WS1	5	15	1075
II.WS2	70	83	65
II.WS3	11	18	390
II.WS4	72	64	36
II.WS5	35	45	295
II.WS6	18	23	645

3.3. QDI variation along Nattika zone

Relationship between TDS and depth of the water table and chloride and water table of Nattika zone are represented in Fig 6&7 respectively. These figures depict that the water quality parameters (TDS and Chloride) in Nattika zone varies linearly with the depth of water table, even though variation exists between different sample stations. Thus an increase in the depth of water table is associated with the deterioration of the quality of water. QDI values of Nattika zone varies between 18 ppm/m at sample station III.WS6 and 82 ppm/m at sample station III.WS4 with respect to TDS; and 22 ppm/m at sample stations III.WS6 and 115 ppm/m at sample station III.WS4 with respect to chloride. Fig 18 & Fig 19 the variation of QDI (TDS and Chloride) with the distance from the salt water body. As in earlier discussed zones these curves too indicate an exponential decrease of QDI with distance of the salt water body. When the trend of these graphs were critically analyzed, we can divide the Nattika zone into 'sensitive zone' (300m for QDI TDS and chloride) and 'insensitive zone'. Thus up to a distance of 300m from the salt water body there is high risk of saline intrusion and hence considered as the 'sensitive zone'. Beyond this distance QDI is not very sensitive to change in depth of
the water table.

Table 4: QDI at Nattika zone

Sample station	QDI (TDS) (ppm/m)	QDI (Chloride) (ppm/m)	Distance from salt water body
III.WS1	27	35	310
III.WS2	63	70	155
III.WS3	59	79	175
III.WS4	82	115	38
III.WS5	55	62	125
III.WS6	18	22	625

3.4. QDI variations along Chavakkad zone

Fig 8 & Fig 9 depicts the relationship between depth of water table and TDS and Chloride values. From the figures it is clear that the water quality parameter, TDS and Chloride, varies linearly with the depth of water table. This means water quality deteriorates with increase in the depth of water table. Table 5 shows that the QDI values of Chavakkad varies between 5ppm/m at sample station IV.WS5 and 194ppm/m at sample station IV.WS4 with respect to TDS and 18ppm/m at station IV.WS6 and 182ppm/m at sample station IV.WS4 with respect to Chloride. Fig 20 & Fig 21 represents the variation of QDI (TDS and Chloride) along with the distance from the nearest salt water body.

These curves indicate an exponential decrease of QDI with decrease in the distance from the salt water body. From a critical analysis of the graph we can infer that distance up to 300m from the salt water body is the 'Sensitive Zone' and beyond that distance is the 'Insensitive Zone'

3.5. QDI variations along Palapetty zone

Fig 10 & Fig 11 are the graphical representations of TDS, and Chloride values with respect to water table depth for Palapetty zone. During the entire season, it shows a linear variation. Thus increase in depth of water table is associated with corresponding deterioration of quality of water. Table 6, shows that the QDI values of Palapetty zone varies between 25 ppm/m at sample station V.WS4 and 252 ppm/m at sample station V.WS1 with respect to TDS. 15 ppm/m at sample station V.WS4 and 243ppm/m at sample station V.WS1 with respect to chloride. Variation of QDI (TDS and Chloride) along with the distance from the salt water body is depicted in Fig 22 & Fig 23. An exponential decrease of QDI with increase from the salt body is explicit in curve. From these curves we can infer that a distance up to 200 m from the salt water body is the 'sensitive zone' and beyond that distance is the 'insensitive zone'.

Table 5: QDI at Chavakkad zone

Sample station	QDI (TDS) (ppm/m)	QDI (Chloride) (ppm/m)	Distance from salt water body
IV.WS1	38	42	1050
IV.WS2	42	39	600
IV.WS3	150	159	30
IV.WS4	194	182	32
IV.WS5	5	20	350
IV.WS6	26	18	800

Table 6: QDI at Palapetty zone

Sample station	QDI (TDS) (ppm/m)	QDI (Chloride) (ppm/m)	Distance from salt water body
V.WS1	252	243	15
V.WS2	154	158	25
V.WS3	136	140	36
V.WS4	25	15	510
V.WS5	121	201	5
V.WS6	26	16	356

3.6. QDI variations of Ponnani Zone

Relationship between TDS and Chloride values and depth of the watertable is represented in Fig 12 & Fig 13. From this figures it is clear that the water quality parameters (TDS and Chloride) of the Ponnani zone also varies, linearly with the depth of water. Table 7 shows that the QDI values of Ponnani zone varies between 15ppm/m at sample station IV.WS2 and 245ppm/m at sample station VI.WS6 with respect to chloride. Fig 24 & Fig 25 represents the variation of QDI (TDS and Chloride) with the distance from the salt water body. These curves indicate an exponential decrease of QDI with distance of the salt water body. As seen from the graph a distance upto 250m from the salt water body, there is the risk of the 'sensitive zone'. At greater distance QDI is 'insensitive' to the change in depth of the water table.

4. Result and discussion

Fig 26 & Fig 27 representthe variations in QDI value with respect to TDS and chloride and distance from the salt water body for the entire study area. These figures clearly indicates an exponential decrease of QDI values with distances. Thus we can divide the entire area into 'sensitive zone' and 'insensitive zones'. From the curves, in general, we can infer that a distance upto 250m from the salt water body is the risk zone or the 'Sensitive zone' for the entire study area. Beyond that distance the QDI values are insensitive to the change in depth of the water table. From an overall evaluation 30% of the sample stations of the study area is characterized by high QDI values ie above 100 ppm/m. hence it can be concluded that about 30% of the aquifers of the study area are polluted due to saline intrusion. It is also found that more number of affected sample stations belong to the northern part of the study area, compared to that of the southern part. Critical analysis shows that out of the 6 zones, most affected sample stations of the study area belongs to Ponnani and Palapetty zones of the northern region. From Fig 26 & Fig 27 it can be seen that about 10% of the sample stations are situated in safer zones even though their distance from the saline water bodies are below 200m.

Table 7: QDI at Ponnani Zone

Sample station	QDI (TDS) (ppm/m)	QDI (Chloride) (ppm/m)	Distance from salt water body
VI.WS1	193	204	15
VI.WS2	15	12	450
VI.WS3	165	193	12
VI.WS4	103	187	135
VI.WS5	75	80	225
VI.WS6	245	272	5

5. Conclusion

QDI studies reveal that deterioration of water quality has a direct relation with increase in depth of water table. TDS and chloride values are increasing linearly with depth of water table. Closeness to the salt water body is the main factor

Appendix

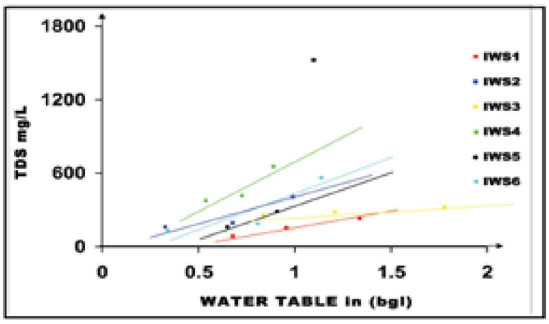

FIGURE:2 SEASONAL VARIATION OF TDS AND WATER TABLE DEPTH OF AZHIKKOD ZONE

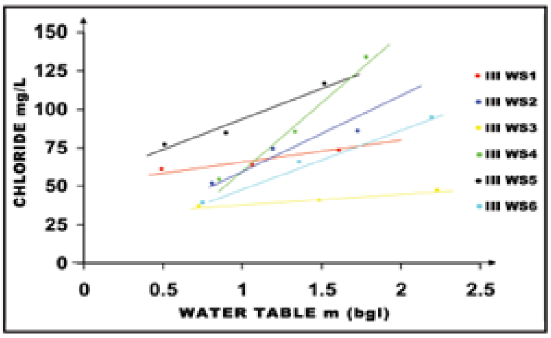

FIGURE:3 SEASONAL VARIATION OF CHLORIDE AND WATER TABLE DEPTH OF AZHIKKOD ZONE

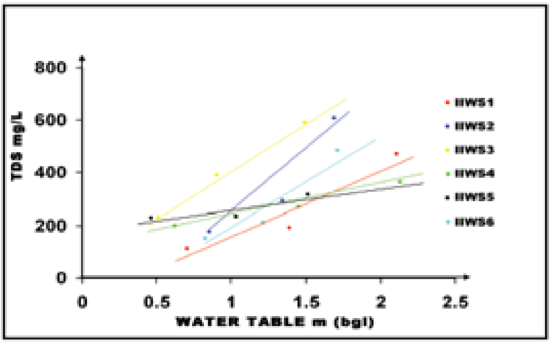

FIGURE:4 SEASONAL VARIATION OF TDS AND WATER TABLE DEPTH OF PERINJANAM ZONE

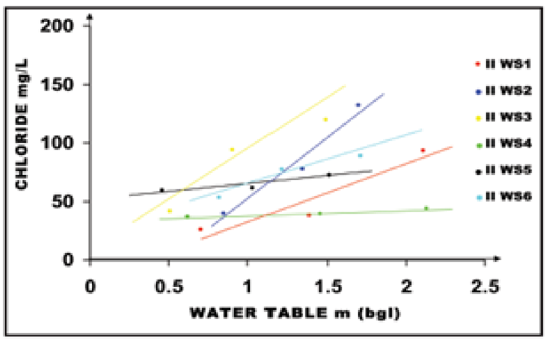

FIGURE:5 SEASONAL VARIATION OF CHLORIDE AND WATER TABLE DEPTH OF PERINJANAM ZONE

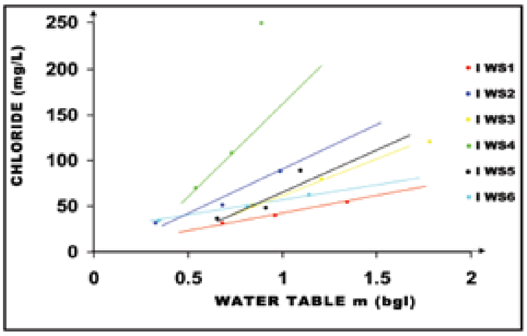

FIGURE:6 SEASONAL VARIATION OF TDS AND WATER TABLE DEPTH OF NATTIKA ZONE

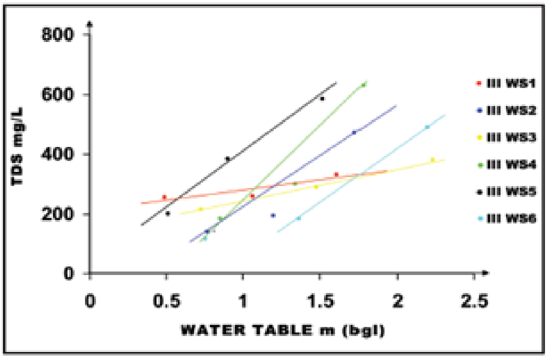

FIGURE:7 SEASONAL VARIATION OF CHLORIDE AND WATER TABLE DEPTH OF NATTIKA ZONE

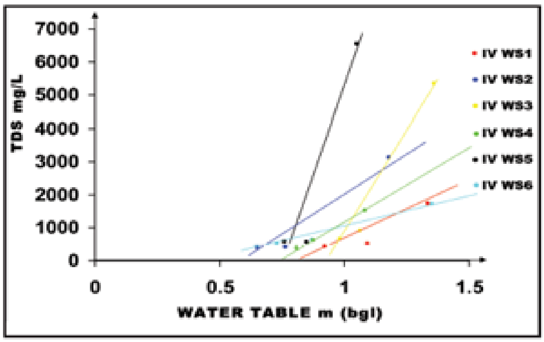

FIGURE:8 SEASONAL VARIATION OF TDS AND WATER TABLE DEPTH OF CHAVAKKAD ZONE

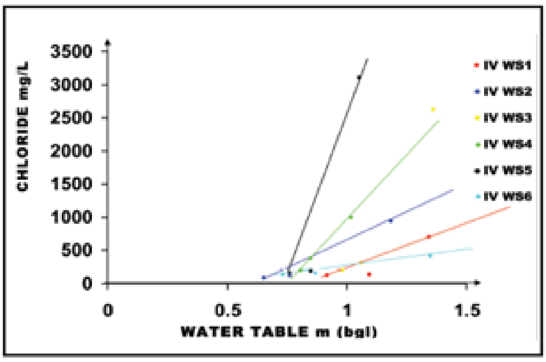

FIGURE:9 SEASONAL VARIATION OF CHLORIDE AND WATER TABLE DEPTH OF CHAVAKKAD ZONE

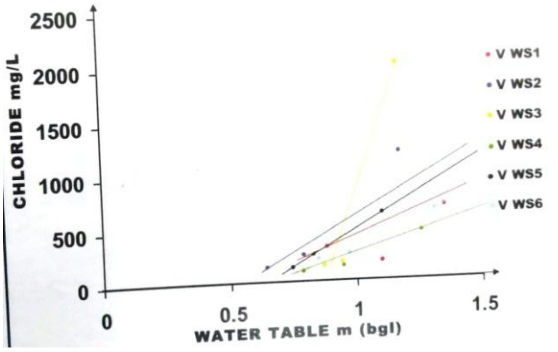

FIG 10. SEASONAL VARIATION OF CHLORIDE (MG/L) AND WATER TABLE DEPTH (BGI IN M) OF PALAPPETTY ZONE

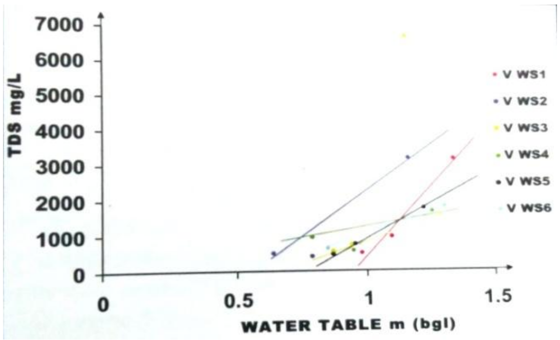

FIG 11. SEASONAL VARIATION OF TDS (MG/L) AND WATER TABLE DEPTH (BGI IN M) OF PALAPPETTY ZONE

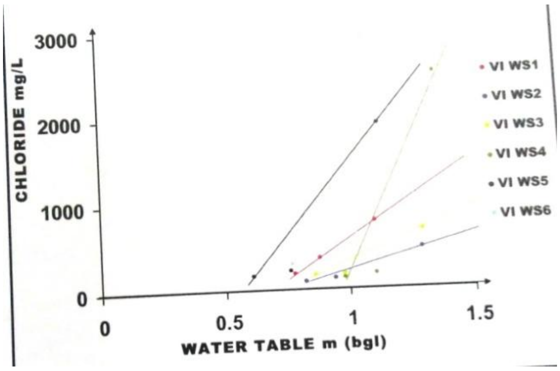

FIG 12. SEASONAL VARIATION OF CHLORIDE (MG/L) AND WATER TABLE DEPTH (BGI IN M) OF PONNANI ZONE

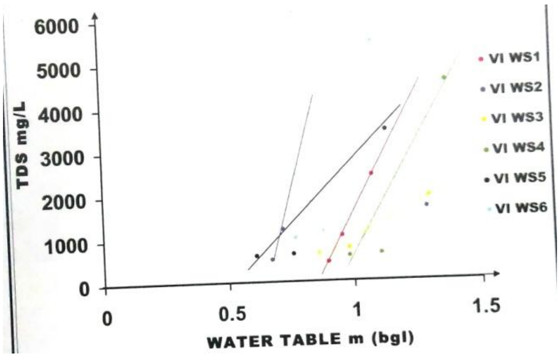

FIG 13. SEASONAL VARIATION OF TDS (MG/L) AND WATER TABLE DEPTH (BGI IN M) OF PONNANI ZONE

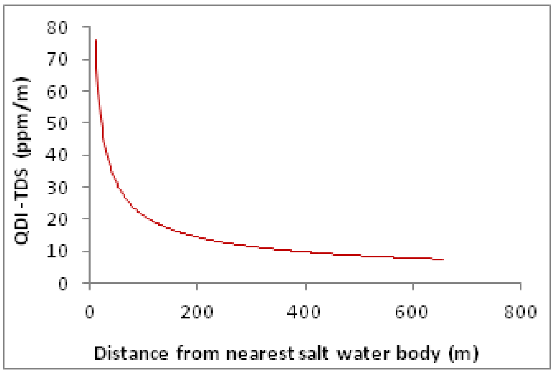

FIGURE:14 VARIATION OF QDI-TDS WITH DISTANCE FROM SALT WATER BODY ALONG AZHIKKODE ZONE

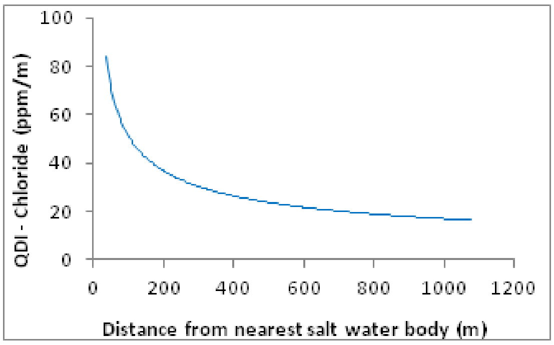

FIGURE:15 VARIATION OF QDI-CHLORIDE WITH DISTANCE FROM SALT WATER BODY ALONG AZHIKKODE ZONE

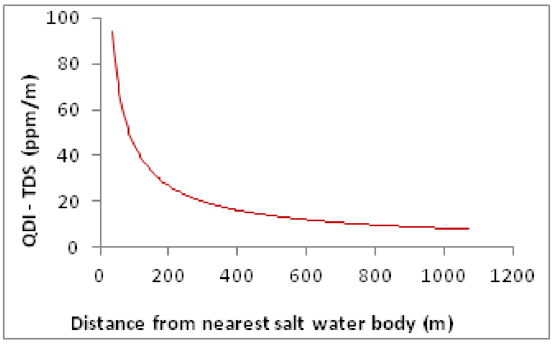

FIGURE:16 VARIATION OF QDI-TDS WITH DISTANCE FROM SALT WATER BODY ALONG PERINJANAM ZONE

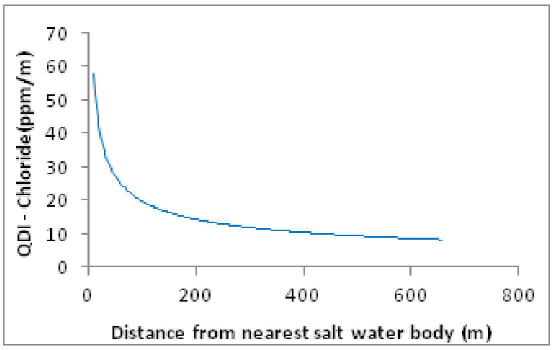

FIGURE:17 VARIATION OF QDI-CHLORIDE WITH DISTANCE FROM SALT WATER BODY ALONG PERINJANAM ZONE

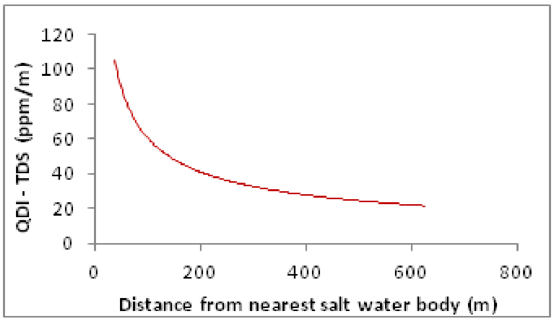

FIGURE:18 VARIATION OF QDI-TDS WITH DISTANCE FROM SALT WATER BODY ALONG NATTIKA ZONE

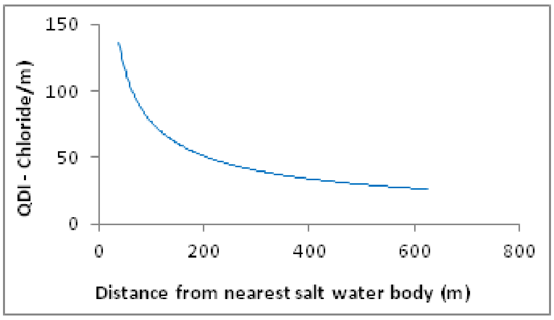

FIGURE:19 VARIATION OF QDI-CHLORIDE WITH DISTANCE FROM SALT WATER BODY ALONG NATTIKA ZONE

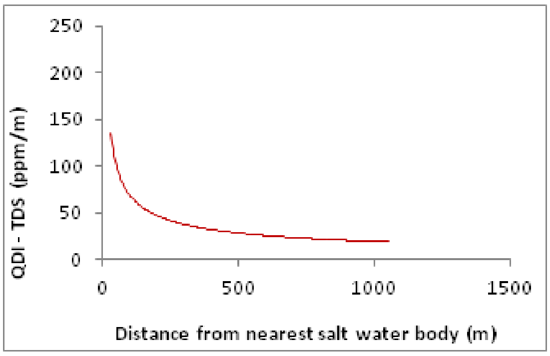

FIGURE:20 VARIATION OF QDI-TDS WITH DISTANCE FROM SALT WATER BODY ALONG CHAVAKKAD ZONE

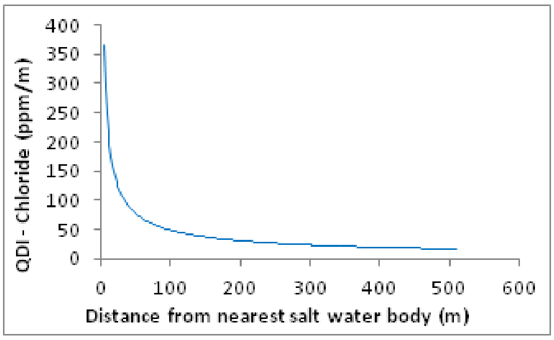

FIGURE:21 VARIATION OF QDI- CHLORIDE WITH DISTANCE FROM SALT WATER BODY ALONG CHAVAKKAD ZONE

International Journal of Advanced Scientific Research and Management, Volume 3 Issue 11, Nov 2018

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ISSN 2455-6378

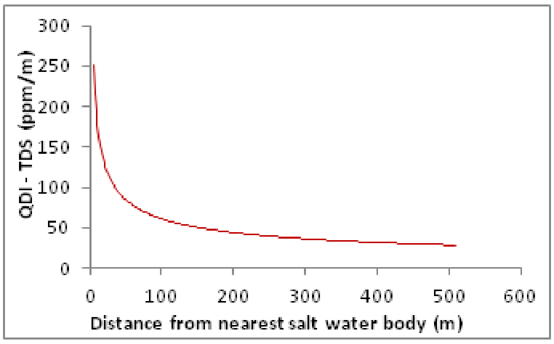

FIGURE:22 VARIATION OF QDI-TDS WITH DISTANCE FROM SALT WATER BODY ALONG PALAPPETTY ZONE

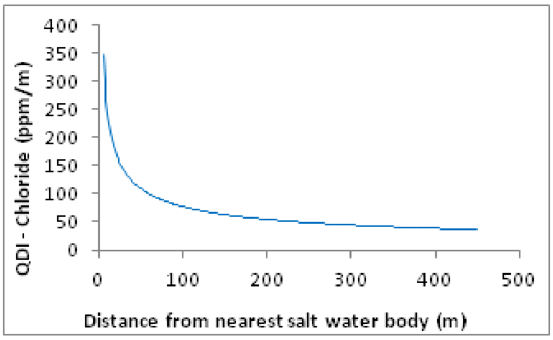

FIGURE:23 VARIATION OF QDI-CHLORIDE WITH DISTANCE FROM SALT WATER BODY ALONG PALAPPETTY ZONE

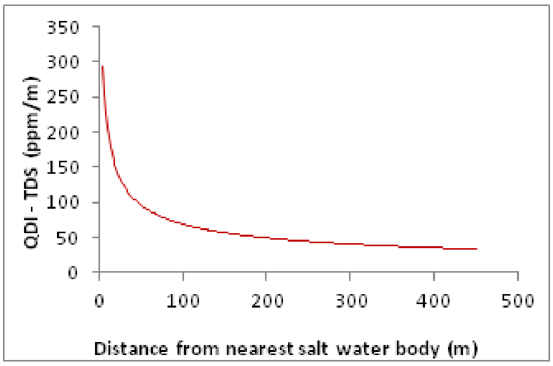

FIGURE:24 VARIATION OF QDI-TDS WITH DISTANCE FROM SALT WATER BODY ALONG PONNANI ZONE

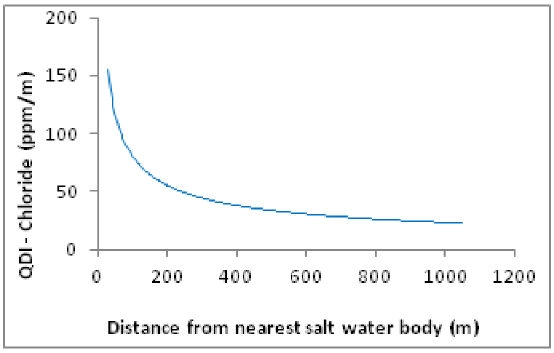

FIGURE:25 VARIATION OF QD- ICHLORIDE WITH DISTANCE FROM SALT WATER BODY ALONG PONNANI ZONE

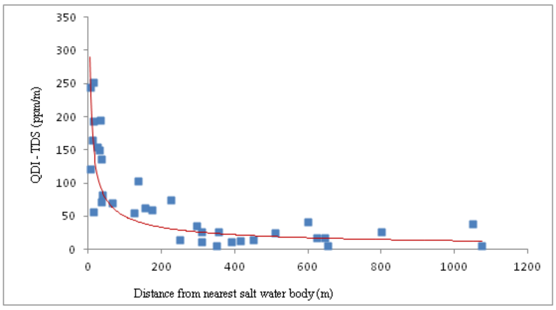

FIGURE:26 VARIATION OF QDI – TDS WITH DISTANCE FROM SALT WATER BODY ALONG THE ENTIRE STUDY AREA

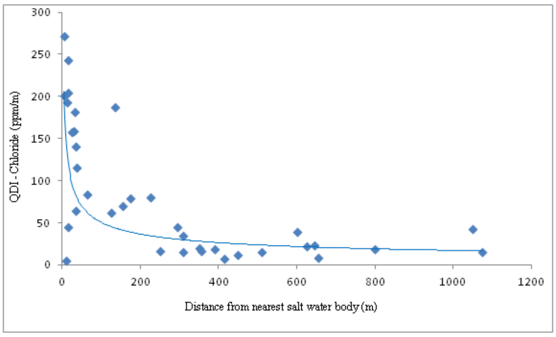

FIGURE:27 VARIATION OF QDI – CHLORIDE WITH DISTANCE FROM SALT WATER BODY ALONG THE ENTIRE STUDY AREA

in determining the quality of water. The QDI values are extremely important, because from these values the local inhabitance of a particular coastal region can judge the quality of water prior to well digging in an area. The planners and executing hydro geologists will also be able to effectively propose a plan for the optimum extraction of ground water resource of the coastal aquifers.

TABLE 8: SEASONAL VARIATIONS OF TDS AND CHLORIDE WITH DEPTH OF WATER TABLE ALONG THE ENTIRE STUDY AREA

ZONES	SAMPLE STATION	TDS(MG/L)			CHLORIDE			WATER TABLE DEPTH		
		PRE MONSOON	MONSOON	POST MONSOON	PRE MONSOON	MONSOON	POST MONSOON	PRE MONSOON	MONSOON	POST MONSOON
I	I.WS1	230	89	156	55	31	40	1.35	0.68	0.69
	I.WS2	403	156	192	88	32	51	0.99	0.33	0.96
	I.WS3	322	251	284	121	51	80	1.78	0.84	1.21
	I.WS4	653	377	418	250	70	109	0.89	0.54	0.73
	I.WS5	1518	159	289	89	37	48	1.10	0.65	0.91
	I.WS6	570	136	186	62	34	49	1.14	0.34	0.81
II	II.WS1	471	114	114	93	26	38	2.11	0.70	1.39
	IIWS2	608	176	176	132	39	78	1.69	0.85	1.34
	IIWS3	591	232	232	119	41	94	1.49	0.51	0.90
	IIWS4	363	200	200	44	36	39	2.13	0.62	1.45
	IIWS5	316	228	228	73	59	61	1.51	0.46	1.03
	IIWS6	485	152	152	89	53	77	1.71	0.82	1.21
III	III.WS1	332	254	261	74	61	64	1.61	0.49	1.06
	III.WS2	470	143	196	86	52	75	1.73	0.81	1.19
	III.WS3	379	217	291	47	37	41	2.23	0.73	1.48
	III.WS4	632	184	301	134	54	86	1.78	0.85	1.33
	III.WS5	584	201	383	117	77	85	1.52	0.51	0.90
	III.WS6	489	118	183	95	39	66	2.20	0.75	1.36
IV	IV.WS1	1742	429	525	694	126	134	1.34	0.92	1.09
	IV.WS2	3164	364	429	935	91	122	1.18	0.65	0.76
	IV.WS3	5350	654	925	2630	216	311	1.36	0.98	1.06
	IV.WS4	442	298	307	103	67	89	1.06	0.74	0.81
	IV.WS5	6567	553	588	3117	147	177	1.05	0.76	0.85
	IV.WS6	1732	521	633	406	128	158	1.35	0.73	0.87
V	V.WS1	3236	528	959	695	151	182	1.35	0.98	1.10
	V.WS2	3267	509	952	1197	131	249	1.17	0.64	0.79
	V.WS3	6813	585	758	2024	139	178	1.16	0.87	0.94
	V.WS4	1695	442	593	453	100	144	1.26	0.79	0.95
	V.WS5	433	250	282	131	91	105	1.12	0.71	0.81
	V.WS6	1847	654	766	651	206	252	1.31	0.85	0.97
VI	VI.WS1	439	297	312	128	83	94	1.08	0.69	0.81
	VI.WS2	1649	491	657	457	106	122	1.29	0.82	0.94
	VI.WS3	1877	616	755	670	156	191	1.30	0.86	0.98
	VI.WS4	4491	553	620	2496	133	185	1.38	0.98	1.11
	VI.WS5	3431	591	620	1913	170	227	1.14	0.61	0.76
	VI.WS6	5465	1002	1159	2939	311	370	1.09	0.77	0.88

Acknowledgment

Our gratitude goes to the authorities of Adama Science and Technology University, Adama, Ethiopia (ASTU) and Dr.Jose Thekken (Late) former principal, Christ College Irinjalakuda, for giving permission for publications and for the facilities provided for the study and we would also like to acknowledge Dr. Solomon, chairperson, Department of Applied Geology, School of Natural Sciences (ASTU).

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