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Assessing Aquifer Vulnerability to Seawater Intrusion in the Poombuhar Coast

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ABSTRACT: Saline water intrusion is mainly caused by lowering level of ground water table in the coastal aquifers. This can be caused by two factors viz., a negative balance in recharge and withdrawal of ground water, and a relative rise in sea level. Of these two, the former plays a significant role in saline water intrusion since the relative sea level rise is comparatively a slower process. A negative balance in ground water recharge and withdrawal occurs mainly due to human consumption of freshwater available within the coastal aquifers for domestic purposes. Hence in this study an attempt was made to evaluate the existing groundwater situation, and evaluated the aquifer vulnerability index (AVI) of the coastal aquifer in Poombuhar coast.

KEYWORDS: Saline water, aquifer vulnerability, GALDIT model, Ground water.

I. INTRODUCTION

In India, around 17% of the population resides along the coast. They majorly depend on the coastal resources for their development and economy. Due to increasing population in such coastal areas results in rapid depletionof the groundwater resources and also leads to saline water intrusion.This saline water in many places turns those areasslowly into non-habitable. Apart from these, in recent years the culmination of aquaculture ponds and a significant growth of salt pans have played a major role in saline water intrusion. Industrial effluent discharge into natural waterways has further aggravated the situation – as the river finally discharges into the deltaic region and result in the infiltration of waste water into coastal aquifers.Development of such a scenario is expected to cause severe economic loss. Therefore, evaluation of saline water intrusion, and the vulnerability of the coastal aquifers for such damage is important. With the above considerations, this work is aimed at

(i)Making an assessment of existing groundwater contamination by saline water intrusion.
(ii) Evaluating the vulnerability of the Poombuhar coastal aquifer system for saline water intrusion using GALDIT model.

II. STUDY AREA

This study focuses on a coastal area Poombuhar (11°8'33"N79°51'5"E) – a coastal town located along the east coast of TamilNadu in the Nagapattinam district. It is known as Kaveri poompattinam.Poombuhar is one of the most important and ecologically fragile places along the coastal Tamilnadu which lies in the eastern part of the Cauvery Delta. The soils in this area are very deep, moderately drained, clay to sandy clay loam in texture with deposits of sand in intermittent layers. The soils are somewhat saline in nature due to the influence of tidal waves.The annual temperature of the study area ranges from 19.3°C to 40.6°C. The relative humidity is high during the period of October to November and ranges from 70-77%. The average annual rainfall recorded at Poombuhar is 1500 mm.The major economic activities include fishing, agriculture, and aquaculture. Many places of coastal Poombuhar have turned saline due to the presence of swamps and over exploitation of ground water.

III.SAMPLE COLLECTION

For the assessment of existing groundwater situation, groundwater samples were collected. These samples were collected in five stretches perpendicular to the coastline. The details pertaining to sampling locations are given in Table-1. These five stretches were chosen in such a way so as to cover all the land uses categories viz., the coastal plain, settlement, agricultural field, and areas nearby river banks. The first sample was collected within 500 m of the coastline and from that each sample location was chosen to be approximately 1 km apart. Thus, the total distance for furthest sample was around 10 km from the coast. In total, 30 groundwater samples were collected. All the samples were collected in polyethylene containers and brought to the laboratory for further analysis. These samples were analysed for pH, Electrical conductivity, chloride, carbonate, bicarbonate and total hardness using standard procedures (Standard Analytical Procedures for Water Analysis, 1999)

Table -1: Details pertaining tosampling locations

Sample	Location	Location Details		
		Nature of area	Latitude	Longitude
1	Kannagi statue	Tourist	11:8:46.014	79:50:34.7856
2	Opp. Petrol bunk	Residential	11:8:48.3684	79:51:26.4276
3	Dharmakulam main road	Residential	11:8:49.8444	79:50:07.5912
4	Mathavi arch	Residential	11:8:49.8660	79:49:38.1036
5	Kangi arch	Residential	11:8:49.5204	79:49:38.9400
6	School	Residential	11:8:39.1488	79:51:01.1484
7	Vanagiri	Coastal	11:8:56.3784	79:48:59.0976
8	Vanagiri temple	Residential	11:8:56.3784	79:48:59.0976
9	Killperumpallam	Residential	11:7:48.3060	79:51:13.5288
10	Killperumpallam	Residential	11:7:55.4628	79:50:52.1664
11	Melaperumpallamlibrary	Residential	11:8:02.5908	79:50:16.0038
12	Temple	Agricultural	11:8:13.4052	79:49:23.6460
13	Chinnamedu School	Residential	11:5:37.2516	79:51:18.0828
14	Marudampallam	Residential	11:5:36.8016	79:51:19.4868
15	Temple	Agricultural	11:5:54.2652	79:49:47.1612
16	Kalamanalur shop	Residential	11:5:54.2652	79:49:47.1612
17	Temple	Agricultural	11:5:58.8660	79:49:18.4836
18	Mamakudi house	Residential	11:5:59.0568	79:49:17.7492
19	Vepanchery	Coastal	11:4:55.0380	79:51:03.5820
20	Vepanchery colony	Colony	11:4:54.7572	79:50:53.0090
21	Kaiyapanalur	Intake	11:4:54.6024	79:50:38.9724
22	power plant opp.	Agricultural	11:4:54.3720	79:50:38.4216
23	Temple	Agricultural	11:4:51.2976	79:49:52.6764
24	Near thirukadaiur	Residential	11:4:51.2976	79:49:52.6274
25	Temple	Coastal	11:3:57.2616	79:51:11.6316
26	Prawn culture ponds	Coastal	11:3:57.2616	79:51:11.6316
27	Tharangambodidanish fort	Coastal	11:1:30.6084	73:51:18.0756
28	Tharngambodi Bus stand	Coastal	11:2:01.4352	79:49:49.3572
29	SathangudiEcr road	Coastal	11:2:04.1496	79:49:47.9388
30	ErukatancheriEcr road	Coastal	11:2:04.3008	79:49:47.8884

IV. ESTIMATION OF AQUIFER VULNERABILITY INDEX USING GALDIT MODEL

The GALDIT model developed by Chachadi and Lobo-Ferreira (2001) was employed to calculate the aquifer vulnerability index. GALDIT model provides an assessment of aquifer vulnerability index (AVI) based on a set of parameters that are found to have an impact on saline water intrusion on coastal aquifers. This model considers the following factors to be most important in controlling seawater intrusion:

- ⇨ Groundwater Occurrence (aquifer type; unconfined, confined and leaky confined) (G)
- ⇨ Aquifer hydraulic conductivity (A)
- ⇨ Depth to groundwater level above the sea (L)

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- ⇨ Distance from the shore (D)
- ⇨ Impact of existing status of seawater intrusion in the area (I)
- ⇨ Thickness of the aquifer (T)

A detailed description of the above mentioned factors is given here:

i) Groundwater occurrence or, aquifer type (G): The nature of the aquifer has the potential to influence seawater intrusion. In the GALDIT model, a rating of 8 is assigned to leaky confined aquifer, 9 is assigned to unconfined aquifer, and 10 to confined aquifer. The aquifers in the study area are confined, and a rating of 10 is given for this factor.

ii) Aquifer hydraulic conductivity (A): Hydraulic conductivity is the ability of the aquifer to transmit water and it mainly depends on the number of interconnected pores within the sediments and the intensity of fractures in consolidated rocks. If hydraulic conductivity is high, then the movement of seawater front into the coastal aquifer shall be fast, provided there is no impervious layer in between, such as clay that prevents this flow. The aquifers in the Nagapattinam district have a hydraulic conductivity ranging from 4 to 12 m/day. Thus, a rating of 2 is given to hydraulic conductivity as per the GALDIT model.

iii) Depth to groundwater level above mean seal level (L): If the level of groundwater table with respect to the Mean Sea Level (MSL) is higher, then due to water column pressure a hydraulic head develops that prevents seawater incursion into the coastal groundwater. The Ghyben–Herzberg relation estimates that for every meter of freshwater stored in the coastal aquifers above the mean sea level, 40 m of freshwater is stored below it down to the interface. However, the interface between freshwater and saline water frontiers in the aquifers shall oscillate due to recharge and withdrawal events and a suitable rating should be given for this factor based on these observations. In the GALDIT model, use of average groundwater table during the pre-monsoon period is recommended since, in the monsoon period normally a positive hydraulic gradient is set by the freshwater front onto the seawater front due to freshwater percolation into the aquifer, and saline water intrusion is prevented. Thus, by assigning the average pre-monsoon groundwater level, a safety margin is given for the estimated vulnerability index. In this study, the samples were collected during pre-monsoon period and the depth to the groundwater table was obtained by subtracting the mean elevation of Poombuhar from the observed groundwater depth below ground level. These observed water table levels were found to be within the range of average 10 year (1997- 2007) pre-monsoon water table levels (0.67 m above MSL to 11.7 m below MSL) monitored by the Public Works Department (PWD) of the Government of Tamilnadu. The ratings for each sample were assigned based on the observed ground water depth from the mean sea level for the computation of GALDIT score.

iv) Distance from the shore (D): One of the factors that control the seawater intrusion is the hydraulic gradient available for the seawater to intrude into the coastal aquifer. For the given hydraulic head, this is depended on the distance from the shore. The ratings for this factor were assigned based on the distance of each sample location as per the GALDIT model.

v) Impact of existing status of seawater intrusion (I): The already existing saline water regime has an influence on the calculation of aquifer vulnerability index. For identification of saline stress, the ratio of chloride to total alkalinity is considered. The GALDIT model proposes three distinct ratings based on this ratio: (a) Groundwater samples showing the ratio of $Cl^-/[HCO_3^-+CO_3^{2-}] > 2$ epm where seawater intrusion is observed in all seasons. (b) Groundwater samples having a ratio $1.5 < Cl^-/[HCO_3^-+CO_3^{2-}] < 2$ epm where seasonal saline water intrusion is observed. (c) Groundwater samples exhibiting a ratio of $Cl^-/[HCO_3^-+CO_3^{2-}] < 1.5$ epm where no saline water intrusion is observed for any season.For calculation of this ratio and assigning relevant rating to this factor, the analytical results obtained from this study was utilized.

vi) Thickness of the aquifer being mapped (T): Aquifer thickness plays an important role in saline water intrusion. When the aquifer thickness is high, the chances for saline water intrusion are also high. In the case of unconfined aquifers, the water saturated thickness is taken into account for this purpose. Based on the reported aquifer thickness of 30 m to 70 m reported for the study area, a rating of 10 is given for this factor for all the samples collected in this study.

Thus, in the GALDIT model, each one of the above six factors has a predetermined fixed relative weight reflecting its relative importance to aquifer vulnerability for seawater intrusion. Using GALDIT factors, a numerical ranking system to assess seawater intrusion potential is adopted (Table-2). Each GALDIT factor is evaluated against the other to determine the relative importance of each factor. Thus, each GALDIT factor is assigned a relative weight, ranging from 1 (least significant) to 4 (most significant). Further, except factor G (groundwater occurrence; rating is between 8 and 10), all other factors are rated from 1 to 10 depending on the field conditions. The computation of GALDIT score – the aquifer vulnerability index (AVI) - then starts by multiplying each factor weight by the assigned rating. The sum of all such individual scores yields the GALDIT score and this is known here as aquifer vulnerability index (AVI). This index represents the vulnerability of the coastal aquifer for saline water intrusion.

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Thus, aquifer vulnerability index to seawater intrusion is calculated as given in the following equation:

$$\text{GALDIT Score} = (1\times G) + (3 \times A) + (4 \times L) + (2 \times D) + (1\times I) + (2 \times T)$$

Table-2: GALDIT Model – Ratings for different factors (after Chachadi and Lobo-Ferreira, 2001)

Parameter	G	A (m/day)	L (m)	D (m)	I (epm)	T(m)
Weights	**1**	**3**	**4**	**2**	**1**	**2**
Rating						
1		0 to 4	> 2	>1000	$Cl^-/[HCO3^- + CO3^{2-}] < 1.5$	1
2		4 to 12	1.75 to 2.00	800 to 1000		1-2
3			1.50 to 1.75	700 to 800		2-3
4		12 to 28	1.25 to 1.50	600 to 700		3-4
5			1.00 to 1.25	500 to 600	$1.5 < Cl^-/[HCO3^- + CO3^{2-}] < 2$	4-5
6		28 to 41	0.75 to 1.00	400 to 500		5-6
7			0.50 to 0.75	300 to 400		6-7
8	Leaky confined	41 to 81	0.25 to 0.50	200 - 300		7-8
9	Unconfined		0.00 to 0.25	100 to 200		8-9
10	Confined	> 81	<= 0	< 100	$Cl^-/[HCO3^- + CO3^{2-}] > 2$	>10

GALDIT Model Parameter Description

G	Groundwater Occurrence	A	Aquifer Conductivity (m/day)
L	Groundwater Level above Mean Sea Level (m)	D	Distance from Coast (m)
I	Impact of Existing Intrusion (EPM)	T	Aquifer Thickness (m)

After computation of GALDIT score, the resulting values are utilized for classification of the groundwater aquifers into i) not vulnerable, ii) moderately vulnerable, iii) vulnerable and, iv) highly vulnerable categories (Table-3).

Table-3:Classification of CoastalAquifersUsing GALDITScores
(afterChachadiandLobo-Ferreira, 2001)

S.No	GALDITScore	Vulnerability class
1	>90	Highlyvulnerable
2	60to90	Vulnerable
3	30to60	Moderatelyvulnerable
4	<30	Notvulnerable

V. RESULTS AND DISCUSSION

The analytical results of the 30 groundwater samples are given in Table-4. The average pH of the samples varied from 6.2 to 7.1in the samples. The large spatial variability associated with conductivity points tochange in aquifer characteristics or its environmental conditions. Some of the possible reasons for such a high variability in conductivity include difference in saline water intrusion, variability in the nature of aquifer formations, nature of fractures associated with the aquifer, differences in the quantity of groundwater extraction that modulates the piezometric head, and the presence of geological barriers.The chloride concentration varies from 32.4 to 2459.2 mg/L. This shows the sea water intrusion occurs in nearby areas of the coast. Also in particular stretch perpendicular to coast also higher chloride concentration when compared to fresh water. This shows that the

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particular area is affected by seawater intrusion.The total hardness of ground water is due to calcium and magnesium ions. Since the area is contaminated by saline water intrusion, the calcium and magnesium ions are expected to be at higher concentration. The highest hardness value found was 1148.9 mg/L.

The calculated GALDIT scores are presented in Table-4. The results indicate that all localities fall under vulnerable and moderately vulnerable category. However, it should be noted that if the aquifer thickness becomes less than 10 m, the GALDIT score shall decrease. Thus, in places where the freshwater lenses of smaller thickness (< 10 m) have formed, those places are likely to be less vulnerable to saline water intrusion. Such places include sand dunes where pockets of freshwater can occur due to recharge from runoff during rainy season. There are a few other factors that acts against the saline water intrusion in this area: i) The hydraulic conductivity of the geological formationsis less due to their nature; ii) Depth to the groundwater is less due to continuous recharge of the groundwateraquifer by freshwater from the adjacent rivers during monsoon season. Under this scenario, by constructing artificial recharge structures, it should be possible to pushawaythesalinewaterincursionoftheaquiferstowardsthecoast.Such artificial groundwater recharge structures may utilize the rain water for this purpose.

Table-4: Analytical results of groundwater samples along with calculated GALDIT scores

Sample	pH	Conductivity	Chloride	Carbonate	Bicarbonate	Hardness	Distance from coast	Depth to groundwater above MSL	GALDIT score AVI
		(ms)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	Km	m	
1.	6.63	10.20	2431.7	-	1000	1000	0.5	4.5	60
2.	6.72	2.03	304.9	-	500	191.4	1.5	3.9	43
3.	6.42	0.53	72.4	-	200	106.3	2.25	5.4	43
4.	6.32	2.42	534.8	-	300	531.9	3.78	7.2	47
5.	7.39	2.18	324	2000	3750	63.8	4.25	7.2	43
6.	6.80	0.30	32.4	-	200	63.8	5	3	43
7.	6.84	9.33	2459.2	-	750	382.9	0.3	3.6	64
8.	6.71	2.28	312.4	-	450	434.0	1.3	3.6	43
9.	6.69	3.17	651.0	-	650	736.1	2.4	3	43
10.	6.67	4.94	1037.1	-	700	425.5	3.1	3	47
11.	6.26	3.68	922.2	-	250	642.5	3.9	3	52
12.	6.79	2.52	412.3	-	500	334.1	4.6	3.6	43
13.	6.90	2.82	437.3	-	500	234.0	0.8	4.8	45
14.	7.10	2.86	499.8	-	500	438.2	1.2	3.6	43
15.	6.96	1.30	137.4	-	900	120.2	2.3	3.3	43
16.	6.68	5.87	1229.6	-	650	519.1	3.1	3.9	47
17.	6.65	3.73	709.7	-	450	539.9	4.2	3.3	47
18.	6.74	1.51	184.9	-	900	744.6	4.9	3	47
19.	7.01	3.14	534.8	-	650	680.8	1.1	3	43
20.	6.88	4.33	549.8	-	650	489.3	1.7	3	43
21.	6.72	2.66	514.8	-	350	276.5	2.1	3.6	47
22.	6.82	0.51	501.8	-	400	148.9	3.4	3.9	43
23.	6.63	4.26	504.8	-	250	382.9	3.9	4.2	47

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24.	6.73	6.40	507.3	-	350	1148.9	4.5	4.8	43
25.	6.93	1.68	287.4	-	300	255.3	0.7	3.3	49
26.	7.31	1.89	287.4	-	450	744.6	2.1	3.3	43
27.	6.80	1.27	1299.5	-	550	957.4	2.4	3.9	52
28.	7.20	2.08	264.7	-	450	170.2	3.1	5.1	43
29.	7.10	0.91	74.9	-	350	191.4	4.1	4.2	43
30.	6.79	2.32	307.4	-	400	412.7	3.9	3.6	43

VI. CONCLUSION

Thirty groundwater samples were collected during pre-monsoon period along two tracts perpendicular to Poombuhar coast in Nagapattinam District of Tamil Nadu. These samples were analysed for pH, carbonate, bicarbonate and total hardness. For each sample, the depth to groundwater, and distance from the coast was measured. From the analytical results of the samples and application of GALDIT model, the following facts were revealed:

- ⇨ Higher pH, Conductivity and total hardness pointed to saline water intrusion in the area.
- ⇨ This is further corroborated by a higher ratio for Cl^-/ [HCO_3-+CO_3^{2-}] > 2 epm, indicating that for all the seasons saline water intrusion is prevalent in the study area.
- ⇨ In the groundwater samples collect nearby river, the saline water intrusion is found to be more. This is possibly due to the percolation of saline water into the overexploited aquifer during high tides.
- ⇨ TheapplicationofGALDITmodelrevealedthattheentirestudyarea is vulnerableand moderately vulnerable for saline water intrusion.
- ⇨ Construction of artificial recharge wells along the coastal tract is suggested to prevent further deterioration of the situation. In the long run, such an artificial recharge may desalinize the aquifer.

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