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Studies on the use of geology, pumping test of coastal Dakshina Kannada district for logical examination of saltwater intrusion.

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Abstract: Dakshina Kannada district is situated in the peninsular region of India. The peninsula is composed of geologically ancient rocks of diverse original and most of them have undergone metamorphism. The early Precambrian tonalitic gneisses invaded by granites, granulates and dolerite dykes. Granulates are mostly restricted to areas south of Mangalore City. High grade alumina rich (corundum bearing) metamorphic schists have been encountered and younger alkaline intrusive rocks like Aegerine syenites have been reported. There are five rivers and estuaries. Number of lineaments cut across each other and some lineaments are parallel to each other. The Arabian Sea class is the largest among other land cover features in the study area. The groundwater table goes down at a faster rate after the south west monsoon and dries up during early summer months. At present the problem of saltwater intrusion along the coastal Dakshina Kannada districts is not fully scientifically assessed. The GALDIT- index based method applied in the region to assess the vulnerability of the area to seawater intrusion.

Key words: GALDIT method, rock types, water table, water quality, pumping test, granulates.

INTRODUCTION

As per the United Nation estimations,by the year 2030,over 60%of the world population will live in cities (UNCHS,2001). This will put enormous stress on fresh water aquifers in the coastal region, resulting into increasing groundwater exploration, and seawater intrusion is being predictable in most of the locations of Dakshina Kannada district. It is one of the fast growing districts of Karnataka. It is fourth largest city in Karnataka, India. Due to increase in population, fast urbanization and industrialization, the coastal region of the district is facing severe shortage of fresh water resources, specially during the summer season.

The Dakshina Kannada is a maritime district, located in the south-western part of Karnataka adjoining the Arabian sea. The district spreading from the Western Ghats towards the Arabian sea to the west, is bounded by Udupi district in the north Shimoga, Chickmagalur and Hassan districts in the east. Kasaragod (Kerala State) and Kodagu districts in the south. Its geographical area is 4770 sq.km extending between $13^0$11’00” and $74^0$35’00” E. The districts is drained by Netravathi, Gurupura, Nandini, Kumaradhara, Payasvini and Shambhavi rivers which originate in the Western Ghats and flow westwards to join the Arabian sea. Geomorphologically, Dakshina Kannada districts can be divided into three well defined physiographic units viz, (i) coastal plain (ii) upland pedi-plain and (iii) eastern hilly region forming part of the Western Ghats.

Weathered and fractured gneiss, granite and schist are the major water bearing formations of the region.The alluvial formation of limited thickness and aerial extent is found along the courses of major rivers. The recent alluvium and colluvial deposits occur along the river bed and sea coast. The exposures of crystalline rock are found as isolated hills along the shore and off shore. The soil in the districts is lateritic type, found distributed in the pediplain area characterized by high iron and aluminium content. The lateritic soil is red in colour and yellow loamy, but pale to bright red colours are also seen.

The average maximum and minimum temperature in the area are about 36.6^{0}C (May) and 21^{0}C (December) respectively. The weather is highly humid throughout the year, particularly during the south-west monsoon period. A maximum of 100% humidity is recorded in June and July every year. The average rainfall of the districts is 3790 mm and is received mainly during the southwest monsoon season extending from June to September. The year has been divided into three seasons i.e., monsoon (June to September), post-monsoon (October to January) and pre-monsoon (February to May) for the present investigation.

The coastal aquifer extending from Talapady to Mulky (Fig.1) The length of the coastline is about 40 km. The sea waves approach the shore line of this area from west-northwest and northwest during postmonsoon season with maximum wave heights of 2 to 2.5 meter. The groundwater table goes down at a faster rate after the south-west monsoon and dries up during early summer months. At present the problem of saltwater intrusion along the coastal

Dakshina Kannada districts is not fully scientifically assessed. However growing population, urbanization and developmental activities necessiate the need for such a study to plan for future developments.

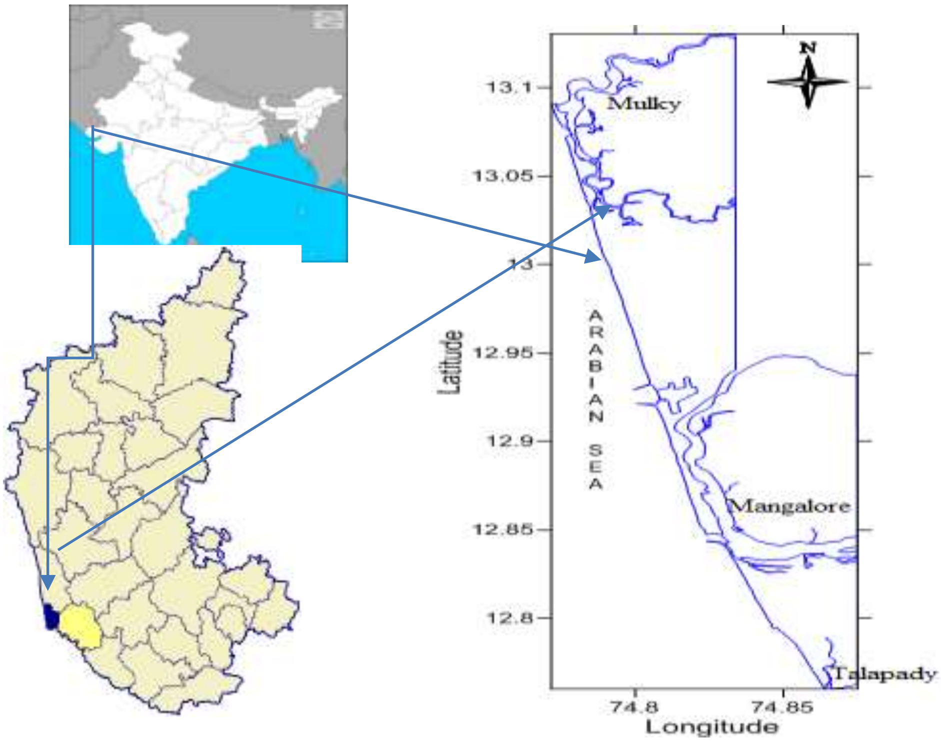

Fig.1 Study area

LITERATURE REVIEW

Groundwater is the primary source of water for domestic, agricultural and industrial uses in many countries and it is contamination has been recognised as one of the most serious problem.The pumping test is one of the methods to evaluate aquifer parameters. In analyzing the pumping tests data from unconfined aquifers, one often finds that the drawdown vary at different rates from those predicted by the traditional Theis (1935) equation. A semi-empirical, mathematical model capable of reproducing all three segments of the time drawdown curve in an unconfined aquifer was introduced by Boulton (1954, 1963). Singh (2006) proposed a simplified semi analytical model for the drawdown due to pumping a large diameter, partially penetrated well which can take into account pumping and recovery phases. The model yields transient drawdown in the well storage and aquifer storage contributions including from the well bottom.

Koukadaki et al.,(2007) estimated the hydraulic conductivity from field measurements of electrical conductivity near the city Brisbane, Australia. The parameter of the aquifer were identified through comprehensive geophysical and hydrogeological surveys that were conducted in the eastern coast of UAE Sherif et al., (2006). Saha et al., (2002,2005) conducted a geophysical survey comprising electrical resistivity and seismic refraction methods for investigating the nature and status of subsurface saline water contamination in coastal belt of Digha, West Bengal (India). The subsurface geologic formations and thickness of saline zones were identified.

Sherif et al., (2006) conducted geoelectrical studies for delineating saltwater intrusion in the outlet of Wadi Ham, UAE. Two dimensional DC resistivity profiling was carried out, and resistivity models were created which was used to detect water zones of different salinities. The relations obtained between earth resistivity and TDS, together with inverted 2D resistivity depth sections were used to identify the average TDS at any point along the 2D resistivity profile. Cimino et al., (2007) studied VES surveys and carried out chemical analysis of groundwater in the coastal plain of Acqedolci, Italy. Heavy pumping associated with geological factors such as grain size can cause a landward migration of fresh saltwater interface. As a result intense anthropogenic activity influences coastal hydrologic system, leading to groundwater pollution by seawater intrusion (Chachadi et al., (2003), Demirel (2004), Cheng (1998), Melloud and Goldenberg (1997), Polemio et al., (2006).

Adekunle et al., (2008) reported that saline intrusion into coastal aquifers has become a major concern in Lekki peninsula. Nigeria, salinization of fresh groundwater is highly associated with groundwater withdrawl worldwide Lee et al., (2007), Georgescu et al., (2010) established that saltwater was horizontally displaced in sedimentary beds having higher permiability, a a gradual decrease in salt concentration due to mixing with fresh water of both cone shaped intrusion and its deeper horizontal part of black sea shore. South eastern Europe, (Europe). Nur Islami (2011) has conducted geoelectrical resistivity salt/brakish water in the subsurface, north Kelantan-Malaysia. Khalil et al., (2012) conducted VES surveys in shallow depths for which a joint inversion algorithm was applied for the electric profile and the nearby electromagnetic profile.

At the global level, in many of the river flow series, a general decreasing trends was observed. The future prediction was also carried out on evaporation, sea level rise and soil moisture changes by several researchers. Adrian et al., (2012) presented seawater intrusion as a global issue exerted by sea level rise, climate change and an increasing dependency on coastal fresh groundwater resources for water suply Post (2005), White and Falkland (2010), Wenner (2010), Barlow and Reichard (2010).

The GALDIT method Ferreira et al., (2007) appears to be the only example of a large scale indexing approach for assessing coastal aquifer vulnerability to seawater intrusion. The acronym GALDIT stands for Groundwater occurrence, (aquifer type; unconfined, confined and leaky confined), Aquifer hydraulic conductivity, Height of groundwater Level above sea level, Distance from the shore (distance inland perpendicular from shore line), Impact of existing status of saltwater intrusion in the area and Thickness of the aquifer which is being mapped. The parameter values associated with the six GALDIT controlling factors are converted to “importance” scales of 2.5 to 10 and then aggregated to produce vulnerability scores using subjective “significance” weightings in their analysis.

Tuma et al., (2011) have conducted a study on dynamics of land use change in the Florid (USA) using GIS optimization models. The western Panhandel region of Florida experienced greater development in the year 200-2010 than the previous 40 years and greater than nearly all other parts of the United States. The GIS optimization model developed determined the spatial and temporal status relationships between the drives and resulting patterns of landuse due to climate change.

OBJECTIVES

1. The characterization of the coastal aquifer to undserstand the regional groundwater dynamics which is to be achieved through:

2. Characterization of the coastal aquifer using the field test such as pumping test and water level and quality analysis.

3. Vulnerability assessment of the region for saltwater intrusion using an index based method (GALDIT) involving six prominent hydrogeological parameters.

AQUIFER CHARACTERIZATION

The Indian coastline extends to about 5700 km on mainland and the coastal aquifers constitute important sources of freshwater. The water table in the region rapidly decreases during the post monsoon season leading to acute water shortage during the summer months. The analysis is done to estimate the transmissivity, hydraulic conductivity and specific yield of water table (unconfined) aquifers.

The well inventory for the present study consist of 30 open wells from which water table and water quality analysis are being carried out on fortnightly basis during the period September 2017 to April 2019 to establish ground water table fluctuations and salinity assessment in the area (Fig.2). The groundwater table contour and the drinking water quality analysis were carried from the sample collection from the wells.

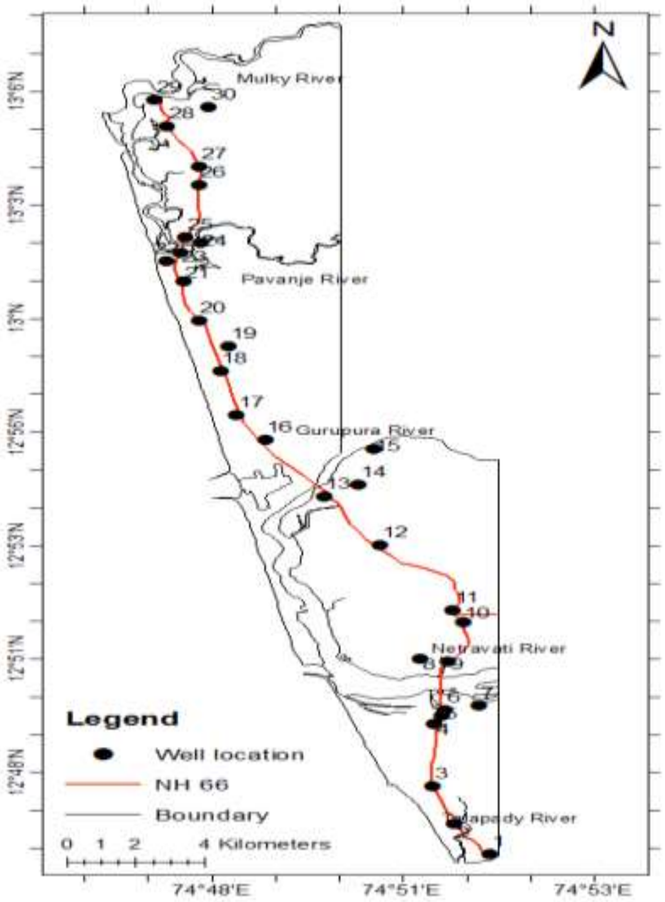

Fig.2 Well locations

In the present study, 10 pumping tests were carried out. The pumping wells are fitted with 2 HP and 3 HP motors. Well number 1,2,3,4 and 9 are fitted with 3 HP motors and well number 5, 6,7,8 and 10 are fitted with 2 HP motor. The drawdown observations to made during pumping test along with discharge rate.

The time drawdown and recovery data for well number 1 are listed in Table 1. The transmissivity and specific yield are estimated using the Aquifer Win 32 (version 4) software, which are presented in Fig.3.

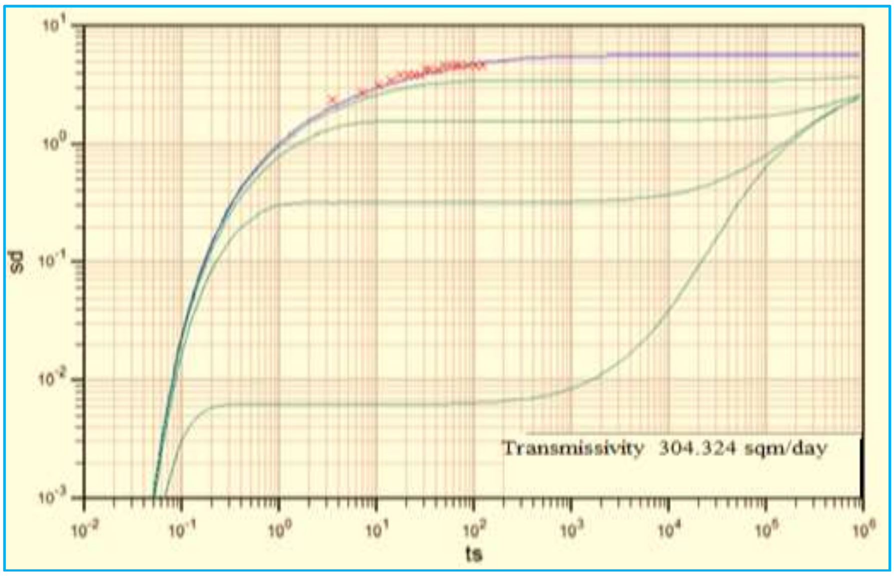

Fig.3 Time drawdown graph for pumping well no.1

Table1. Time –drawdown, recovery data for well no.1

Time (min)	Waterlevel (below groundlevel)(m)	Drawdown (m)		Time (min)	Waterlevel (below groundlevel)(m)	Residual drawdown (m) S_2
0	2.73	0.00		0	2.85	0.12
1	2.73	0.00		1	2.85	0.12
2	2.79	0.06		2	2.84	0.11
3	2.80	0.07		3	2.79	0.06
4	2.81	0.08		4	2.75	0.02
5	2.82	0.09		5	2.74	0.01
6	2.83	0.10		6	2.73	0.00
7	2.83	0.10				
8	2.83	0.10				
9	2.83	0.10				
10	2.84	0.11				
12	2.84	0.11				
15	2.84	0.11				
18	2.85	0.12				
20	2.85	0.12				
25	2.85	0.12				
30	2.85	0.12				
35	2.85	0.12				
40	2.85	0.12				

From the pumping test results Table 2, it can be noticed that transmitivity values range from 17.12m^2/day. The aquifer is having to good groundwater potential. The transmissivity values increases towards northern part of the basin with a patch of high transmissivity found near the coast Fig.4. The highest values are found in the south-east region adjoining Gurupur river. The aquifer is having average to good yield. The aquifer yield distribution for the study area is shown in Fig5. Lowest specific yield values are found near the coast and highest values are found near the eastern boundry of the area. This is also confirmed from the earlier studies conducted by Raghunath et.al., (2001).

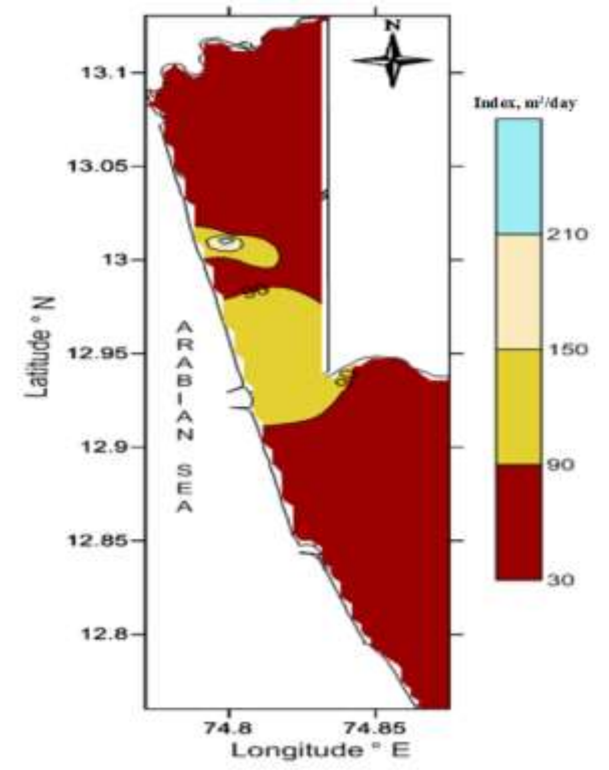

Fig.4. Transmissivity contour of the study area

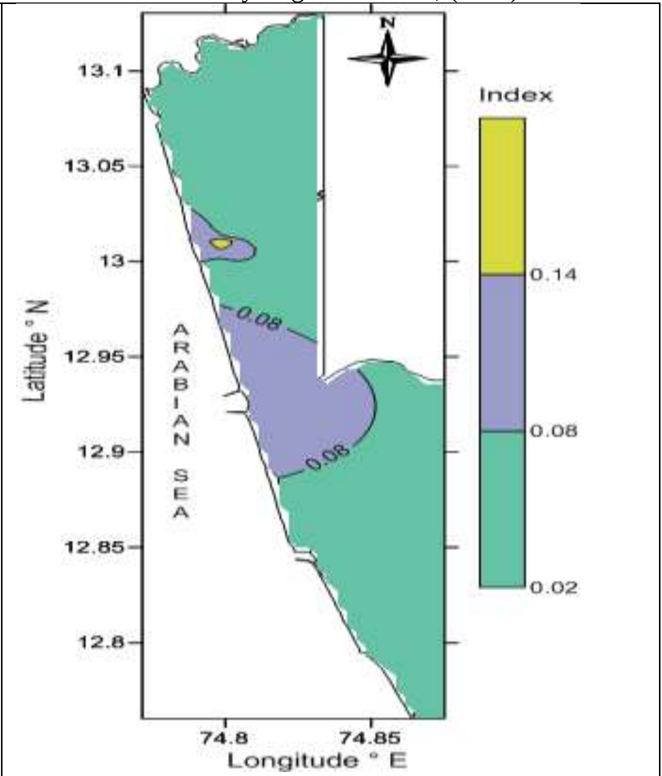

Fig. 5. Specific yield contour for the study area

Table 2. Aquifer parameters evaluated from the puming test for the study area

Well no.	Saturated aquifer thickness(b) m	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)	Specific yield
1	4.37	304.32	69.64	0.003158
2	2.67	14.50	5.43	0.001321
3	0.9	40.00	44.44	0.005208
4	2.15	36.82	17.12	0.006711
5	2.05	33.77	16.45	0.006101
6	2.21	58.88	26.64	0.009966
7	1.64	74.43	45.40	0.012602
8	1.48	77.43	52.32	0.011090
9	2.48	108.08	43.58	0.012665
10	1.07	91.58	85.59	0.014309

Vulnerability Assessment

Aquifer vulnerability defined as the susceptability of a given aquifer or hydrogeological setting to be contaminated. Susceptibility may be defined as a function of hydrogeological factors such as aquifer characteristics. Soil and geological materials and recharge rates, whereas specific vulnerability is a function of contaminant factor such as contaminant characteristics, its source and associated anthropogenic activities (Chachadi and Ferreria. 2001). To carryout the assessment of aquifer vulnerability to saltwater intrusion. GALDIT method (Chachadi and Ferreria. 2003) was used. The most important factors that control the saltwater intrusion are found to be the following (Chachadi. Et. Al., 2002).

- Groundwater occurrence (aquifer type; unconfined,confined and leaky confined)
- Aquifer hydraulic conductivity
- Height of groundwater level above sea level.
- Distance from the shore (distance inland perpendicular from shore line)
- Impact of existing status of saltwater intrusion in the area
- Thickness of the aquifer which is being mapped.

The system contains three significant components- weights, ranges and importance ratings. Each GALDIT factor has been evaluated with respect to the other to determine the relative importance of each factor. The basic assumption made in the analysis is that the bottom of the aquifer lies below the mean sea level.

The most significant indicators have weights of 4 and the least weight of 1 indicating the parameter of less significance in the process of saltwater intrusion. As the indicator weights are derived after elaborate discussions and deliberations among the experts, academicians, researchers etc., they must be considered for general applications and may not be changed under normal circumstances. Each of the indicators is subdivided into variables according to the specified attributes to determine the relative significance of the variable in question on the process of saltwater intrusion. The importance ratings range between 2.5 and 10. Higher importance rating indicates high vulnerability to saltwater intrusion in Table 3.

Table 3 The summary of GALDIT parameter weights, rates and ranges (Chachadi 2005)

Sl.No.	Indicator	Weight	Indicator Variable		Importance ratings
			Class	Ratings	
1	Groundwater occurrence/Aquifer type	1	Confined Aquifers		10
			Unconfined Aquifers		7.5
			Leaky confined Aquifers		5
			Bounded Aquifer (recharge and /or impervious boundary aligned parallel to the coast)		2.5
2	Aquifer Hydraulic Conductivity(m/day)[3]	3	High	>40	10
			Medium	10-40	7.5
			Low	5-10	5
			Very low	<5	2.5
3	Height of Groundwater Level above MSL (m)	4	High	<1.0	10
			Medium	1.0-1.5	7.5

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			Low	1.5-2.0	5
			Very low	>2.0	2.5
4	Distance from shore/river	4	Very small	<500	10
			Small	500-750	7.5
			Medium	750-1000	5
			Far	>1000	2.5
5	Impact status of existing saltwater intrusion Cl-/[HCO_3^- 1+$CO_3 2^-$]	1	High	>2	10
			Medium	1.5-2.0	7.5
			Low	1-1.5	5
			Very low	<1	2.5
6	Aquifer Thickness (saturated) in m.		Large	>10	10
			Medium	7.5-10.0	7.5
			Small	5-7.5	5
			Very small	<5	2.5

Impact of existing status of saltwater intrusion, I

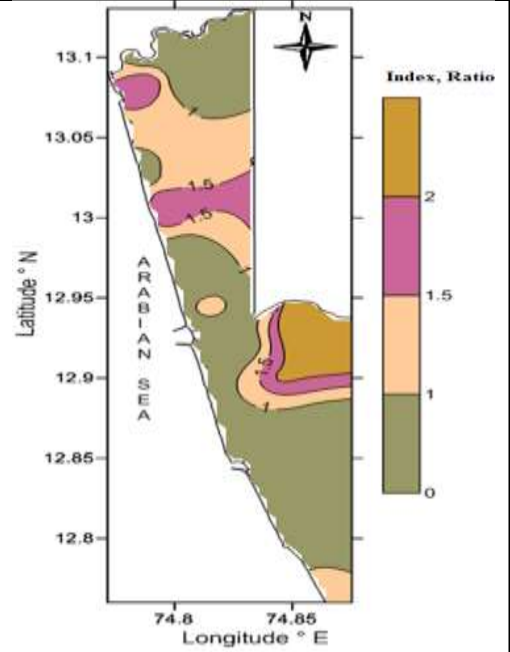
The chloride concentration of groundwater defines the existing extent of saltwater intrusion. The chloride concentration is in the range of 40 to 300 mg/l indicates saltwater intrusion. Edet et al., (2011). Chloride concentration greater than 250 mg/l is considered unfit for drinking purpose. The present results in Table 4 infer the status of the aquifer water which is contaminated with saltwater (as Cl^-) or not. The chloride ion is the most abundant ion in saltwater, is in higher proporations in the affected wells. The HCO_3^- ion which is the most dominant ion in fresh groundwater occurs generally in small amounts in saltwater. Hence, Cl/HCO_3 is considered to a parameter to reflect the existing status of seawater intrusion. The value of the ratio >1.5 is satisfactory.

Table 4 Ratio of Cl/HCO_3 in the study area

Well No.	September 2017	December 2017	April 2018	September 2018	December 2018	April 2018
1	1.22	2.45	7.41	1.19	1.17	4.95
2	1.15	2.30	1.86	1.20	1.84	0.77
3	0.71	2.00	0.63	0.68	1.41	1.12
4	0.29	0.79	0.69	0.5	0.97	0.91
5	0.29	1.10	6.69	0.47	0.84	6.94
6	0.33	0.34	0.21	0.26	0.46	0.56
7	0.43	0.50	0.43	0.26	0.93	1.55
8	0.14	1.50	0.85	0.78	0.80	0.81
9	0.17	0.34	0.30	0.15	0.41	0.60
10	0.79	0.76	0.64	0.75	0.80	0.65
11	0.15	0.21	0.16	0.16	0.48	0.24
12	2.15	2.10	2.04	1.37	2.22	1.26
13	0.25	0.39	0.80	0.23	0.48	0.61
14	1.39	0.85	0.67	2.78	1.48	1.14
15	0.43	0.68	3.87	0.35	0.87	1.34
16	1.41	1.54	1.40	0.64	2.86	0.86
17	0.32	0.61	0.42	0.70	0.52	0.88
18	0.49	0.66	0.77	0.70	0.70	1.03
19	0.84	0.67	0.87	0.75	1.19	0.48
20	1.81	2.24	1.76	2.28	1.76	1.82
21	1.59	1.21	0.80	1.48	1.11	0.80
22	0.53	0.85	0.58	0.70	0.78	0.71
23	0.94	7.25	2.46	3.24	3.47	1.19
24	2.17	1.90	0.95	2.08	1.48	0.80
25	0.84	3.72	3.27	0.82	2.48	2.00
26	0.70	0.74	0.65	0.67	0.77	0.95
27	0.41	0.74	1.76	0.32	1.11	0.80
28	0.14	0.48	1.15	1.45	1.43	0.28
29	0.51	0.26	0.42	0.26	0.46	0.18
30	0.53	0.43	0.27	0.88	0.32	0.38

RESULTS

From Table 4 we can observe that well nos.1 (Talapady), 2 (Uchilla), 12 (Kuntikana), 16 (Panambur), 20(Marigudi), 21 (NITK, Surathkal) and 24 (Haliyangadi) are found to be intrusion affected (ratio >1.5) for most of the time of the year. The wells 2 (Uchilla), 3 (Kotekar), 5 (Tokkuttu), 14 (Kubar), 15 (Tokur), 25 (pavanje), 27 (Kolnad) and 28 (Mulky) are found to be seasonally affected is mostly during the summer months. The remaining wells 4,6,7,8,9,10,11,13,17,18,19,22,23,26,29 and 30 are not found to be affected by seawater intrusion. Fig. 6 and Fig.7 show the contour of existing status of seawater intrusion during the summer month (September 2017 and April 2018). The wells 1,5,12,15,23 and 25 are found to be affected by seawater intrusion in both seasons.Well no.14,20,23 and 24 are high in seawater intrusion for the month of September 2018 and the well nos.12,16,23 and 25 are high in seawater intrusion. All these wells are situated in Gurupur and Pavanje river basins. The well nos are 1,5 and 25 are high in saltwater intrusion for the month of April 2019. During the study period, the values of Cl/HCO_3 range from 0.14 to 7.41 well no. 12 located close to Gurupur river and well no. 24 and 29 are very near to Pavanje river.



	Parameter I (Cl /bicarbonte)	
	Range	Rating
🟫	>2	10
🟪	1.5-2	7.5
🟧	1-1.5	5
🟩	<1	2.5

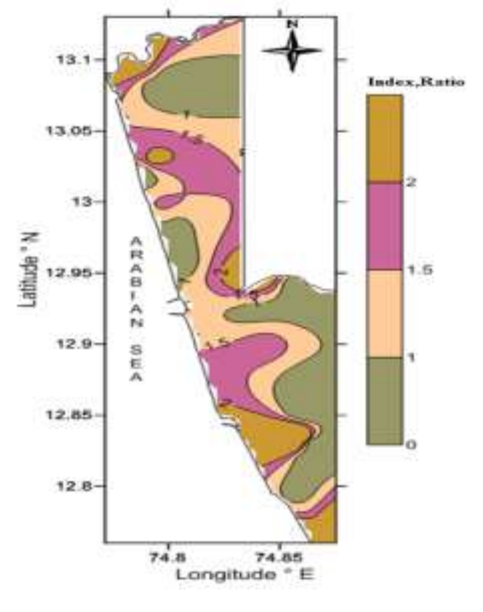


Fig.6 **Fig.7**

Distribution of chloride bicarbonate ratio in the study area in September 2017& April 2018

Computation of the GALDIT Index

Each of the six indicators has a predetermined fixed weight that reflects its relative importance to saltwater intrusion. The GALDIT index is then obtained by computing the individual indicator scores and summing them as per the following expression Chachadi and Ferreira (2001).

GALDIT Index = $\sum_{i=1}^{6}\{(Wi)R\}/\sum_{i=1}^{6} Wi$ (1)

Where W_i is the weight of the i^{th} indicator and R_1 is the importance rating of the i^{th} indicator.

Thus the user can use hydrogeological and geological information from the area of interest and close variables to reflect specific conditions within that area choose corresponding importance ratings and compute the indicator score. This system allows the user to determine a numerical value for any hydrogeological setting by using this additive model. The maximum value of GALDIT –index is obtained by substituting the maximum importance ratings of the indicators as shown below;

Max = $\{(1)*R_1+(3)*R_2+(4)*R_3+(4)*R_4+(1)*R_5+(2)*R_6\}/\sum_{i=1}^{6} Wi$

$=\{(1)*10+(3)*10+(4)*10+(4)*10+1*10+(2)*10\}/15=10$ (2)

Similarly, the maximum GALDIT-index is obtained by substituting the minimum importance rating of the indicators as shown below;

Min = $\{(1)*R_1+ (3)*R_2+ (4)*R_3+ (4)*R_4+ (1)*R_5+ (2)*R_6\}/\sum_{i=1}^{6} Wi$

$= \{(1)* 2.5 + (3)* 2.5 + (4)* 2.5 + (4)* 2.5+ (1)* 2.5 + (2)* 2.5/15 =2.5$ (3)

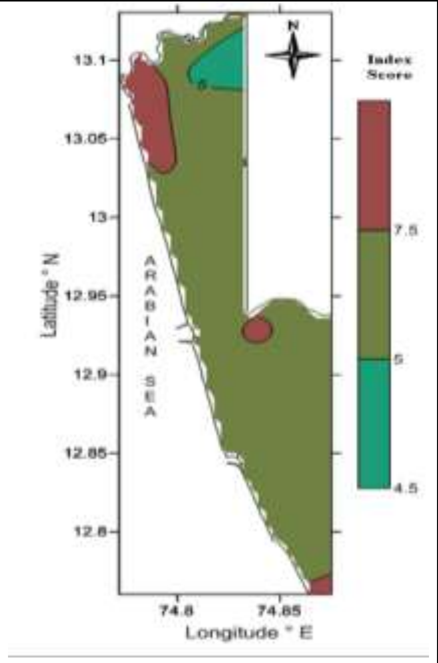
Therefore, the GALDIT - index varies between 2.5 and 10. The vulnerability of the area to saltwater intrusion is assessed based on the magnitude of the GALDIT-index. In a general way, lower the index less vulnerable to saltwater intrusion.

Decision criteria

Once the GALDIT-index has been computed, it is possible to classify the coastal area into various categories of saltwater intrusion vulnerability. The range of GALDIT-index scores (ie 2.5 to 10) is divided into 3 groups as shown in table 6.2. All the six indicators categorized into these groups. The summary of GALDIT parameter weights, rates and ranges are given in table 3.

Vulnerability Assessment

The GALDIT scores for all parameters were obtained by analyzing the generated data of each well on fortnightly basis and one set of results for each season are given in table 4. The spatial distribution of GALDIT-index presented in Fig.8 for monsoon (September 2017) and Fig.9 summer (April 2018) seasons. Based on the GALDIT analysis, the vulnerability of aquifers of the study area is divided into three classes as, highly vulnerable, moderately vulnerable and low vulnerable with respect to saltwater intrusion. Most of the study area comes under moderately vulnerable and highly vulnerable category. Hence, any developmental activities related to groundwater need to be carefully implemented to avoid overstressing of the aquifer.



GALDIT Vulnerability classes

	Range	Class
🟥	>7.5	High
🟫	5-7.5	Medium
🟩	<5	Low

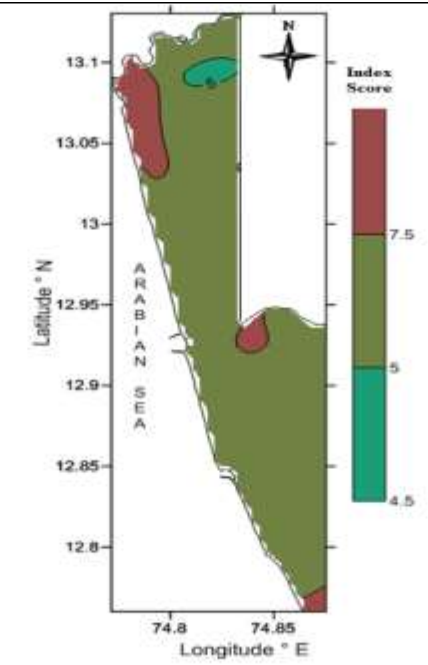


Fig.8 **Fig.9**

Saltwater intrusion vulnerability map as depicted by the GALDIT scores for normal sealevel in september 2017 andApril 2019

Table 5. Ratio of Cl/HCO_3 in the study area

Well No.	September 2017	December 2017	April 2018	September 2018	December 2018	April 2019
1	9.5	9.83	9.83	9.50	9.50	9.83
2	5.5	5.83	5.66	5.50	5.66	5.33
3	5.33	5.66	5.33	5.33	5.33	5.50
4	5.33	5.33	5.33	5.33	5.33	5.33
5	5.33	5.50	5.33	5.33	5.33	5.83
6	6.00	6.00	5.33	6.00	6.00	6.00
7	7.33	7.33	7.33	7.33	7.33	7.66
8	6.66	6.83	6.50	6.00	8.00	8.00
9	6.00	6.00	6.00	6.00	6.00	6.00
10	5.33	5.33	5.33	5.33	5.33	5.33
11	5.33	5.33	5.33	5.33	5.33	5.33
12	5.83	5.83	5.66	5.50	5.83	5.50
13	7.33	7.33	7.33	7.33	7.33	7.33

14	8.16	8.00	8.33	8.50	8.16	8.16
15	7.33	7.33	7.83	7.33	7.33	7.50
16	5.50	5.66	5.66	5.33	5.83	5.50
17	5.33	5.33	5.33	5.33	5.33	5.33
18	5.33	5.33	5.33	5.33	5.33	5.33
19	5.33	5.33	5.50	5.33	5.50	5.33
20	5.66	5.83	5.83	5.83	5.66	5.66
21	5.66	5.50	5.50	5.50	5.50	5.33
22	6.00	6.00	6.00	6.00	6.00	6.00
23	7.33	7.83	7.83	7.83	7.83	7.83
24	9.83	9.66	9.83	9.83	9.50	9.50
25	7.33	7.83	7.83	7.33	7.83	7.83
26	5.33	5.33	5.33	5.33	6.66	7.00
27	5.33	6.00	5.33	5.33	6.16	8.00
28	5.33	5.33	5.50	5.50	5.50	5.50
29	7.16	6.66	6.66	6.66	6.66	6.83
30	5.33	5.33	5.33	5.33	5.33	5.33

From Fig.8 and Fig.9, it was found that, in the monsoon season, wells 1,14 and 24 are highly vulnerable to saltwater intrusion since the GALDIT index is found to be greater than 7.5. These wells are likely to saline during other seasons, in the pre-monsoon season (April 2018). The wells of the coastal stretches the study area, wells 1,14,15,23,24 and 25 are found to be highly vulnerable. In post-monsoon season (December 2017), the wells 1,14,23,24 and 25 are found to be highly vulnerable. Thus the present study indicates that the groundwater system at selected locations within the study area is under the threat of saltwater intrusion. The dominance of high vulnerability class demands for a coordinated and coherent approach in the management of coastal aquifer of the study area. Hence, detailed assessment through modeling of groundwater flow and contaminant transport is very essential.

We can observe from table 6.3 that the study area falls under three categories of vulnerability- low, moderately and highly vulnerable to saltwater intrusion.The study area falls under highly vulnerable and moderately vulnerable categories in December 2018 and April 2019. The northern side of the area viz., Mulky, Pavanje, Mukka and Haleyangadi are highly affected by seawater intrusion in the summer and post-monsoon season due to the proximity to tida river Pavanje and the sea.

GALDIT analysis

In the pre-monsoon season, coastal stretches viz., Mulky, Pavanje, Mukka and Haleyangadi are highly vulnerable to saltwater intrusion. In the post-monsoon season (December 2018) the southern coastal stretches of the study area ie., Talapady and Kavoor are also highly affected. In the monsoon season (September 2017) the southern coastal stretches of the study area i.e., Talapady, Kubar and Haleyangadi are highly afected. All the wells are affected and GALDIT value is >5 is found in the analysis.

CONCLUSION

The index based method is applied in the region to assess the vulnerabality of the area to seawater intrusion. The method was scientifically evolved considering six most influential parameters that affects the process seawater intrusion and has been successfully applied in many other parts of world. The chloride biocarbonate ratio, which is one of the parameters in the GALDIT analysis presents the existing status of seawater intrusion in the area. This parameter indicated 6 and 24 number of wells out of 30 monitoring wells are affected seasonally and throughout the year respectively. The region falls under moderately vulnerable to highly vulnerable category during most part of the year.

REFERENCES

1. Adekunle, A. A. (2008). “Delineation of saltwater intrusion into the freshwater aquifer of Lekki peninsula, Lagos, Nigeria”, Proc. 3rd Int. Conf. Water Resour. Arid Env. of the 1st Arab Water Forum, The Netherlands, Kluwer Acad., Pub. 927-933.
2. Adrian, D., Werner, J.D., Ward, L. K., Morgan, C. T., Simmons, N. I., Robinson, M. D. and Teubner, M. D. (2012). “Vulnerability indicators of seawater Intrusion.” Ground Water 50 (1), 48-58.
3. A.Edet., T.N.Naganje., A.J.Ukpong., A.S.Ekwere (2011).”Groundwater chemistry and quality of Nigeria: A Status review”African Journal of Environmental Science and Technology Vol.5(13), pp. 1152-1169,
4. Boulton, N. S., (1954). “Unsteady radial flow to a pumped well allowing for delayed yield from storage”, Intern. Assoc. Sci. Hydrol. Rome. Publ. 37, 472-477.
5. Chachadi, A. G. and Lobo Ferreira, J. P. (2001). “Seawater intrusion vulnerability mapping of aquifers using the GALDIT method”, A Coastal Policy Research Newsletter, 4, 7-11.

6. Chachadi, A. G., Lobo Ferreira J. P, Noronha, L. and Choudhuri B. S. (2002). "Assessing the impact of the sea level rise on saltwater intrusion in coastal aquifers using GALDIT model", A Coastal Policy Res. Newsletter, National Institute of Hydrology, Roorkee, India 7, 27-31.
7. Chachadi, A. G., Lobo Ferreira, J. P., Noronha, L. and Choudhuri, B. S. (2003). "Assessing the impact of sea-level rise on saltwater intrusion in coastal aquifers using GALDIT model", http://www.dha.Inec.pt/nas/estudos/COASTIN.htm. (Dec. 12. 2012).
8. Chachadi, A. G. (2005). "Seawater intrusion mapping using modified GALDIT indicator model-case study in Goa." Jalavigyan Sameeksha, 20, 29-45.
9. Chen, C. S. (1999). "TEM investigations of aquifers in the southwest coast of Taiwan", Ground Water, 37,890-896.
10. Cimino, A, Cosentino, C., Oieni, A. and Tranchina, L. (2007). "A geophysical and geochemical approach for seawater intrusion assessment in the Acquedolci coastal aquifer (Northern Sicily)", Env. Geol., 55, 1473–1482.
11. Demirel, Z. (2004). "The history and evolution of saltwater intrusion into a coastal aquifer in Mersin, Turkey", J. Environ Mgmt, 70, 275-282.
12. Georgescu, P., Ioane D., Niculescu, B. M. and Chite, A. F. (2010). "Geo-electrical investigations of marine intrusions on the Romanian black sea shore", Geo-Eco-Marina, Bucharest. 16, 85-92.
13. Khalil, M. A., Metwaly, M., El-Said Al-Sayed and El-Kenawy, A. (2012). "Tracing subsurface oil pollution leakage using 2D electrical resistivity tomography",Arab J. Geosci. DOI 10.1007/s12517-012-0600-z, online 30 May 2012.
14. Koukadaki, M. A., Karatzas, G. P., Papadopoulou, M. P. and Vafidis, A. (2007). "Identification of the saline zone in a coastal aquifer using electrical tomography data and simulation", Water Resour. Mgmt., 21(11), 1881–1898.
15. Lee, J. Y. and Song, S. H. (2007). "Evolution of groundwater quality in coastal areas: Implications for sustainable agriculture", Envi. Geo., 52, 1231-1242.
16. Natashekar, D. (2012). "Saltwater intrusion in to the coastal aquifers in and around Mangalore, Dakshina Kannada, Karnataka, using the geotechniques", Thesis, Dept. of Marine Geology, Mangalore, India.
17. Neuman, S. P. (1975). "Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response", Water Resour. Res., 11(2), 329-342.
18. Neuman, S.P. (1979). Perspective on 'delayed yield', Water Resour. Res.,15(4), 99-908.
19. Niwas, S. and Singhal, D. C. (1981). "Estimation of aquifer transmissivity from dar zarrouk parameters in porous media", J. Hydrol., 50, 393-399.
20. Nur Islami. (2011). "Geoelectrical resistivity method for salt/brackish water mapping", J. Coas. Devpt, 14,104-114.
21. Polemio, M., Dragone, V., Limoni, P. P. (2006), "Salt contamination in Apulian aquifer: spatial and time trend", Proc. 1st SWIM-SWICA Joint Saltwater Intrusion Conf, Cagliari, Chia Laguna, Italy, 115-122.
22. Raghunath, R., Murthy, S. T. R., and Raghavan, B. R. (2002). "The utility of multivariate statistical techniques in hydro-geochemical studies: an example from Karnataka. India", Water Res., 36, 2437–2442.
23. Rajgopalan, S. P., Prabhashankar, P. N. and Balakrishnan, V. (1983). "Pumping test and analysis data of open wells in the coastal tract of Kozikode district", GW/R-56/83. Centre for Water Resour. Develop. Mgmt. Kozikode, Kerala, 43.
24. Saha, D. K., Choudhury, K. and Murthy, B. S. R. (2002). "Geophysical studies for subsurface saline water zones in the south eastern part of Calcutta Megacity", GSI Special Pub. 75, 262-271.
25. Saha, D. K. and Choudhury, K. (2005). "Saline water contamination of the aquifer zones of eastern Kolkata", J. Indian Geophys. Union, 9(4), 241-247.
26. Sherif, M. M., Mahmoudi, A., Garamoon, H., Kocimov, A., Akram, S., Ebraheem, A. and Shetty, A., (2006), "Geoelectrical and hydro-geochemical studies for delineating seawater intrusion in the outlet of wali ham", UAE Environ. Geol. 49, 536-551.
27. Singh, S. K. (2006). "Semi-analytical model for drawdown due to pumping a partially penetrating large diameter well", J. Irrig. Drain., ASCE, 133(2), 155-161.
28. Theiss, C. V. (1935). "Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage", Trans. Am. Geoph. Union Pt. 2, 519-524.
29. Tuma, J., Scot Smith and Zoltan S. (2011)."Dynamics of Land Use Change in the Florida Panhandle Using GIS Optimization Models: A Framework to Determine the Impact of Climate Change on the Florida Panhandle", J. World Applied Sci. 14 (10), 1428-1437.
30. WHO. (2004), "Guidelines for drinking water quality, Vol. 1, Recommendations, 3rd Edition", World Health Organization, Geneva, 540.
31. Werner, A. D. (2010). "A review of seawater intrusion and its management in Australia", Hydrogeol.J., 18, 281–285.
32. White, I, Falkland, T. (2010). "Management of freshwater lenses on small Pacific islands", J.Hydrogeo, 18, 227–246.