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Salinity Ingress in Phreatic Aquifer of Coastal Maharashtra State, India

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Abstract: Maharashtra a coastal state of the western India where six out of thirty five districts, namely Palghar, Thane, Raigad, Ratnagiri, Sindhudurg and Greater Mumbai are maritime. Being coastal area, the immediate effect of high groundwater development is sea water intrusion. Hence, analytical study was carried out to decipher the level of salinity intrusion of the shallow coastal aquifer in the coastal Maharashtra.

The present research work was carried out for the assessment of groundwater contamination in the phreatic aquifers in the tidal backwater limits and adjacent to coast and estuaries. Geochemical characteristics, extent of salinity intrusion, drinking and irrigation suitability of the groundwater of the area were also assessed. Total 162 ground water samples from coastal part of Maharashtra were subjected to chemical analysis for 15 basic parameters in the month of May 2017. For the assessment of the sea water intrusion levels, different ionic ratios like Ca:Mg, Na:Cl, Cl:CO_3 + HCO_3, were computed. Wilcox Diagram, EC vs. Cl plots, Pipers Trilinear diagram etc. were also plotted for the interpretation of the results. Groundwater of the area selected for this study is slightly alkaline with pH range of 6.9 to 9.0 and electrical conductivity range from 61 to 29370 µS/cm. In general, water quality is good and fit for various domestic and irrigation purposes. Though salinity can be imparted to groundwater in many ways, it is mainly due to sea water ingress and waste water including industrial effluents in the area selected for the study. From the analysis it is found that about 2 to 10 km area from the coast and the inland tidal backwaters are affected from salinity intrusion.

Over-exploitation of groundwater, low seaward freshwater flow in rivers etc are the major reasons for sea water ingression. Regulation of groundwater development in the coastal area and adjacent to estuaries, maintaining adequate stream flow and stopping of river bed sand mining, construction of tidal regulators at suitable places and creating fresh water barrier through rainwater harvesting and groundwater recharge are essential to control further sea water intrusion in the area.

***Keywords*:Phreatic aquifer, Over-exploitation, Sea water intrusion, Ionic ratio**

I. Introduction

A huge percentage of the world's inhabitants (about 70%) resides in the coastal areas (Webb and Howard, 2011). According to reports of UN Atlas of the Oceans, eight out of the ten largest cities worldwide are situated along the coastal areas, as a consequence more than 2 billion people all over the world living 100 km from the coast (United Nations, 2013a, 2013b). The coastal areas have a threefold population density than the worldwide average (Small and Nicholls, 2003). Therefore the demand of freshwater has increased manifold in the coastal areas which ultimately creates stress on natural environmental system (Post, 2005). Under the future projected climate change conditions, the population growth and the warmer temperatures will surely increase the demand for fresh water (Post, 2005). Some more stresses associated with the climate change activities such as rising of sea level, changing in recharge, groundwater withdrawal and land use change etc moreover encompass the sufficient potential to impact the delicate hydrologic stability/cycle in the coastal aquifers (Turner et al., 1996). These stressors cumulatively be able to characterize an important groundwater concern in the coastal aquifers on the major source of water in coastal areas i.e. ground water.

Sea water Intrusion

The freshwater aquifers in the coastal area are in direct making contact with the oceans. The dense saltwater naturally circulates in inland, making a saline zone under the less dense overlying fresh water aquifer as shown in Figure-1 (Bear et al. 1999). The sharp boundary of fresh water and salt water and especially distinguished by unexpected transition from fresh water to salt water, but due to mixing and diffusion process, it is more commonly transitional (Barlow, 2013). Fresh water flow from the land to the ocean naturally and this flow is governed by the topography and is affected by aquifer hydraulic conductivity. The change in the hydraulic gradient makes the equilibrium among the fresh water and salt water. The magnitude of fresh water discharge decides the location of the fresh water – salt water interface. If increases in hydraulic gradient, fresh water discharge moves seawards and if the hydraulic gradient decreases, it moves landwards (Lyles, 2020).

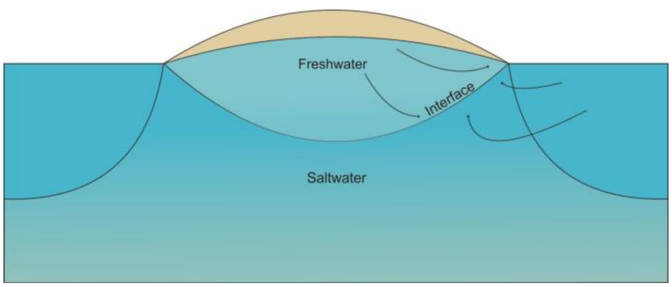

Figure 1: Graphic of the freshwater and saltwater boundary. On islands, the freshwater lens is encircled by saltwater

If salt water moves into the fresh water aquifer, it is called the salt water intrusion (SWI), which can be reduced through two different ways, one by pumping at higher rate or second by pumping few more wells together in the area affected. If pumping is done in the affected area, the natural gradient reduces and the crossing point of fresh water and salt water can shift to inland (Lyles, 2000). The salinization also affected due to pumping up coning from depth (Reilly and Goodman, 1985; Washington State Department of Ecology, 2005) and restricted sea water interference as a result of reversal of hydraulic gradient near the well (Fetter, 2001). Through discrete fractures salt water in fractured rocks enters into the wells (Allen et al., 2002).

Common Indicators of SWI

According to WHO report, 2% mixing of salt water in the fresh water aquifer exceeds the upper level of chloride and water start on to taste salty (Custodio, 2005; Nova Scotia Environment, 2008) and combination above 4% makes the water unfit for many other application. The combination of saline water into fresh water beyond 6% makes the water unfit apart from cooling and flushing uses (Custodio, 2005; Darnault and Godinez, 2008). A number of water quality parameter is good indicator of sea water intrusion which acts as important tool for the best water management practices and also enables ground water quality monitoring of coastal aquifers. The monitoring of Ground Water engaged the measurement of fundamental water quality parameter like most important cations, anions, Electrical Conductivity and Total Dissolved Solids (Barlow and Reichard, 2010). Approximately 35,000 mg/l concentration of dissolved solids found in the sea water of which roughly 19,000 mg/l is chloride (Lyles, 2000). Most likely contributor to the Sea Water Intrusion is the higher chloride contents (Scheidleder, 2003). Research studies conducted by Lyles (2000) also concluded that chloride content above 100 mg/l is an indicator of SWI.

II. Materials & Method

Objective of the Study

The aim of study was to appraisal the extent of contamination of groundwater in the phreatic aquifers in the tidal backwater limits and adjacent to coast and estuaries with respect to the selected study area. It was also planned to assess the drinking and irrigation suitability of the groundwater of the vicinity.

Details of the Study Area

The Palghar, Thane, Raigad, Ratnagiri and Sindhudurg districts and Greater Mumbai were selected for the study as shown in Figure-2. These districts are parts of Konkan Coast of Maharashtra State, India. Being coastal area, the immediate effect of high groundwater development is sea water intrusion (CGWB 2014).

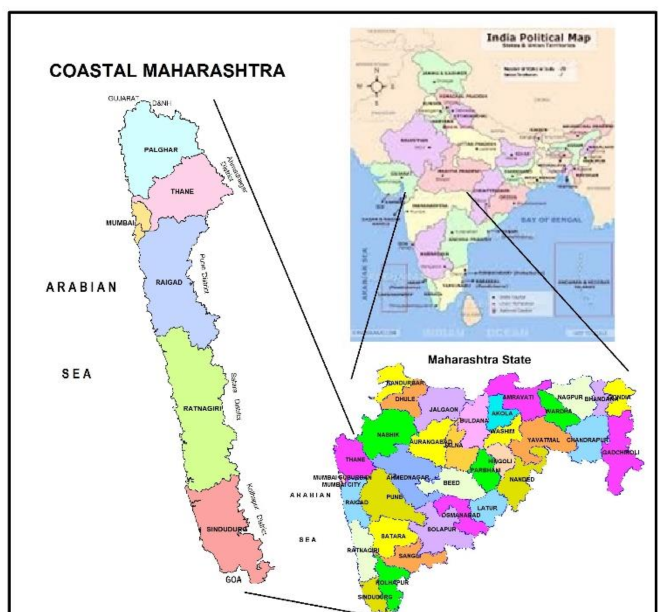

Figure 2: The map of Maharashtra (India) and location of study area

Maharashtra is the third largest state of India, situated in the western peninsular region, inhabiting a large portion of the Deccan plateau. Maharashtra is the second most populated state of the country, spread over 307,713 km^2. The three physiographic regions from west to east in Maharashtra such as Konkan Coastal Belt, Western Ghats and Maharashtra plateau. The Konkan Coastal Belt (KCB) is average width is about 40 km which have narrow and extended strip of land. The most of KCB region is enveloped through basaltic lava flows of the Deccan Trap of upper cretaceous to Eocene age (CGWB 2014).

Sampling

The pre-rinsed one liter polypropylene bottles were used for collection of groundwater samples during the month of May 2017. The collected samples were transported to departmental Chemical Laboratory at Nagpur, India for analysis of water quality parameters. The total 162 samples were collected from the study area, Thane &Palghar (46), Raigad (30), Ratnagiri (39) and Sindhudurg districts (44) and Greater Mumbai (3).

Chemical Analysis

All the collected groundwater samples were analyzed for basic parameters viz. pH, Electrical Conductivity(EC), Total Dissolved Solid (TDS), Sodium (Na^+), Potassium (K^+),Total Hardness (TH), Calcium (Ca^{++}), Magnesium (Mg^{++}), Carbonate (CO_3^{--}), Bicarbonate (HCO_3^-), Total Alkalinity (TA), Chloride (Cl^-), Sulphate (SO_4^{--}), Nitrate (NO_3^-) and Fluoride (F^-) by standard methods of chemical analysis (APHA 2017). The results of chemical analysis are presented in Table-3.1, as minimum, maximum and average values for all the 15 parameters.

Data Analysis and Interpretation

Different scientists worldwide have proposed different water quality indicators to identify the impact of SWI on groundwater (Panno et al., 2006; Kennedy, 2012; Allen and Liteanu, 2008; Bear, 1999; Washington State Department of Ecology, 2005). However, the natural chemical evolution of the groundwater system can make it challenging to apply these indicators in some area because cation exchange processes that increase the relative concentration of sodium compared to calcium (Allen and Suchy, 2001; Fetter, 2001).

In the present study, to differentiate and confirm the sea water intrusion, ionic ratios like Na^+:Cl^-, Ca^{++}:Mg^{++}, Base Exchange ratio, Cl^-:CO_3^{--} + HCO_3^-, Sodium Absorption Ratios were computed. Wilcox Diagram, Piper's Trilinear plot, EC vs. Cl^- plot etc were also plotted through the AquaChem (Ver. 4) software and MS Excel.

III. Result And Discussion

Hydrochemistry

The results of study area shows that groundwater is slightly alkaline in nature, with average pH of 7.4. The EC and TDS values that range from 27 to 8442 µS/cm at 25^0 C and from 18 to 5487 mg/l groundwater is moderately mineralized.

The ranges of Total alkalinity from 10 to 1083 mg/l as $CaCO_3$, with average value more than 160 mg/l. This may have an effect on the use of water for different applications. The maximum pH of groundwater is observed 8.4, which show bicarbonate as the governing species in groundwater and largely contributes in alkalinity. The Total hardness ranges from 10 to 1773 mg/l, with average value of 188 mg/l. The high value of hardness is mainly due to the bicarbonate salts of Ca^{++} and Mg^{++}.

Drinking Suitability Assessment

The obtained water quality data were compared with drinking water standards prescribed by Bureau of Indian Standards (BIS 2012) for assessment of groundwater quality. Various water quality parameters are summarized in Table-3-1.

TABLE III-1
The Chemical constituents reported in the ground water samples of study area, Maharashtra, India

Parameters		Minimum	Maximum	Average
1.	pH	6.4	8.4	7.6
2.	EC	27.0	8442.0	553.0
3.	TDS	17.6	5487.3	359.4
4.	Na^+	1.4	1241.8	37.5
5.	K^+	0.0	69.5	4.7
6.	TH	10.0	1772.9	187.9
7.	Ca^{++}	2.0	517.0	39.2
8.	Mg^{++}	1.9	305.2	36.1
9.	CO_3^{--}	0.0	24.0	1.2
10.	HCO_3^-	9.8	1083.4	159.1
11.	TA as $CaCO_3$	9.8	1083.4	160.2
12.	Cl^-	2.6	1395.6	70.2
13.	SO_4^{--}	0.0	986.0	26.1
14.	NO_3^-	1.0	44.0	8.5
15.	F^-	0.0	1.1	0.1

pH No unit, EC in µS/cm at 25^0C and all remaining parameters are in mg/l.

The results of chemical parameters of water samples and their suitability as per the BIS classification are summarized in Table-3-2.

Almost 20% of the samples are above the desirable limits of BIS making it unfit for drinking purpose. Total Hardness of 28 water samples out of 162, is above 300 mg/l making it unfit for drinking purpose. Total alkalinity of 53% of the total ground water samples is above the desirable limits. Other parameters namely chloride, sulphate, nitrate, fluoride etc. are well within desirable limits of BIS (2012) for all the water samples except at one or two locations. It is also evident that no ground water sample contains nitrate, fluoride, pH, sulphate concentrations beyond the BIS prescribed limits.

TABLE III-2
Percentage of groundwater samples exceeded the desirable limits as per the BIS Standards

Parameters	Desirable Limits	No. of samples exceeded limit	% of samples exceeded limit
pH	6.5-8.5	4	2.5
TDS	500	32	19.8
TH as CaCO3	300	28	17.3
Ca^{++}	75	13	8.0
Mg^{++}	30	72	44.4
TA as CaCO3	200	53	32.7
Cl^-	250	10	6.2
SO_4^{--}	200	4	2.5
NO_3^-	45	0	0.0
F^-	1.0	2	1.2

pH No unit, EC in µS/cm at 25^{0}C and all other parameters are in mg/l.

Irrigation Suitability Assessment

The sodium hazard is characterize by SAR, which is one of the important water quality parameters, that determines the suitability of groundwater for agricultural purpose (USSL 1954, 1973). Sodium and salinity hazards are the two important parameters, which can indicate suitability of water for irrigation usage. The salinity and sodium hazard analysis points out that most of the phreatic ground water samples and all the deeper groundwater samples are showing medium to high salinity and low sodium hazards. Wilcox Diagram plotted for the collected groundwater samples is presented in Fig. 3.

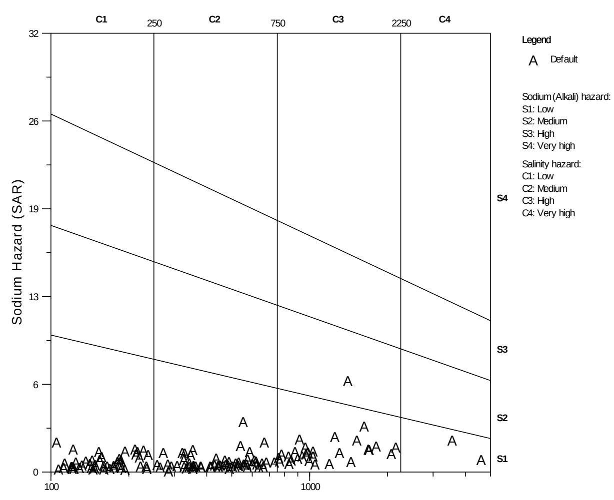

Figure 3: Wilcox illustration of the Sodium Hazard and

Salinity Hazard for the study area, Maharashtra, India

The SAR values of groundwater samples from all the dug wells are less than 10 hence possibility of sodium hazard to the soil is low (S1). The low values of SAR in the study area are due to the low concentration of Na^+ in groundwater as compared to the alkaline earth, i.e., Ca^{++} and Mg^{++} ions. However, EC values of nearly all of the samples fall under the class of low (C1) and medium (C2) salinity hazard zone and a small number of samples also fall in the C3 and C4 zone. Hence, it is indicating that specific type of crop and water management practices are required for utilizing such water for irrigation purpose.

Sea Water Intrusion Assessment

For sea water intrusion assessment various ionic ratios were computed viz. Na^+:Cl^-, Ca^{++}:Mg^{++}, Base Exchange ratio, Cl^- :CO_3^{--} + $HCO_3^-$and are presented in Table-3-3 along with the prescribed criteria and number of samples pertains to the criteria and percentage of total samples.

TABLE III-3
Different Ratios computed for deciphering sea water contamination

S. No.	Chemical Indices	Criteria	No. of samples*	%
1.	Ca^{++}/Mg^{++} ratio	Greater than 1 indicates SWI	22	13.5
		Less than 1 indicates no-SWI	140	86.5
2.	Base exchange indices (BEX) = Na^+ + K^+ + Mg^{++} – 1.0716 Cl^-	Positive BEX (represents freshening)	149	92
		Negative BEX (represents salinization)	13	8
		Value of zero (represents no base exchange)	Nil	0
3.	Higher Chloride levels	>100 mg/l (SWI)	28	17.3
		<100 mg/l (No-SWI)	134	82.7
4.	Na^+/Cl^- ratio	Less than 0.86 indicates SWI	86	53.1
		Greater than 0.86 indicates no-SWI	76	46.9
5.	Cl^-/ (CO_3^{--} +HCO_3^-)	Severely Contaminated :SWI	12	7.4
		Moderately contaminated: probably SWI	16	9.9
		Slightly contaminated: probably SWI	63	38.9
		Fresh and uncontaminated: No-SWI	71	43.8

* Number of samples pertains to the criteria.

Chloride vs. Electrical conductivity

An elevated chloride concentration represents saline water intrusion in ground water of study area. The figure 4 illustrates that groundwater samples with Cl concentration more than 200 mg/l and EC more than ~1000 μS/cm are most probably influenced salt Water Intrusion (SWI). The 17 samples that are characterized by Cl between 100-200 mg/l and EC between 600- 2000 μS/cm out of 162 ground water samples, which indicates mixing between the freshwater and the salt water.

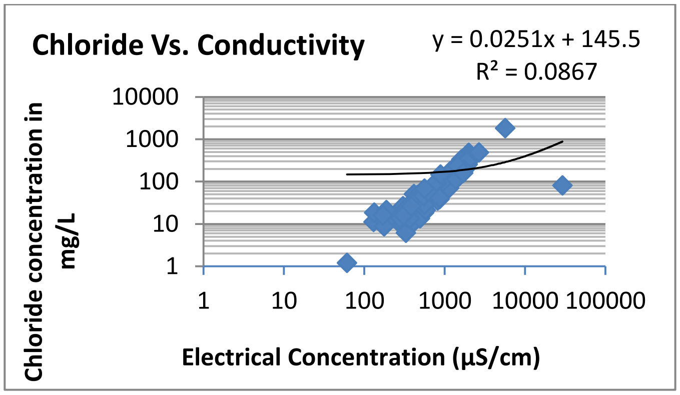

Figure 4: A plot of chloride vs. electrical conductivity showing normal groundwater conditions and saltwater intrusion

Ca^{++}/ Mg^{++} ratio, BEX and higher Chloride levels

The Ca/Mg ratio of 22 water samples is found to be beyond 1, which indicates the effect of sea water intrusion, rest of the 140 samples shows Ca/Mg ratio below 1 indicating the fresh water and is not affected with sea water intrusion. Classification of groundwater samples according to Ca and Mg ratio in the study area is presented in Figure-5. Chloride concentration of 28 samples was also found above 100 mg/l, indicating the chances of salt water intrusion in the area. Classification of groundwater samples according to higher chloride levels (>100 mg/l) in the study area is presented in Figure-6. Base Exchange indices (BEX) of only 13 water samples have found negative, indicating salinity. The study area groundwater samples are classified on BEX as shown in Figure-7.

Cl^-/ CO_3^{--}+ HCO_3^- and Na^+ / Cl^- ratios

Cl^-/ CO_3^{--}+ HCO_3^- is a significant major ionic ratio employ to detect the seawater intrusion. Sea water is rich in Chloride ion and poor in carbonate and bi-carbonate. Hence, this is generally considered as an indicator of seawater intrusion (Raghunath, 1982). Waters having this ratio less than 0.5 are considered fresh and uncontaminated; those having between 0.5 and 2.80 are slightly contaminated and those with more than 2.80 are severely contaminated. Based on Cl^-/ CO_3^{--}+ HCO_3^- ratio, classifications of groundwater samples is presented in Figure-8.

Na^+ / Cl^- is another major ionic ratio used for detecting sea water contamination. Sea water has an ionic ratio of 0.85 and the ionic concentrations are expressed in epm/l. According to the Na:Cl ratio, samples with a value of more than 1.0 are good and uncontaminated by sea water. Almost 53% of the water samples indicate the chances of SWI. Based on Na^+ / Cl^- ratio, classifications of groundwater samples is presented in Figure-9.

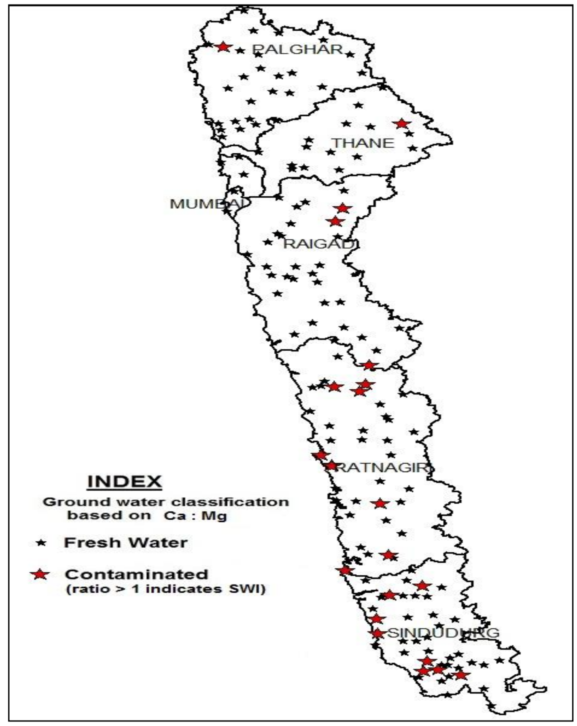

Figure 5: Classification of groundwater according to Ca and Mg ratio

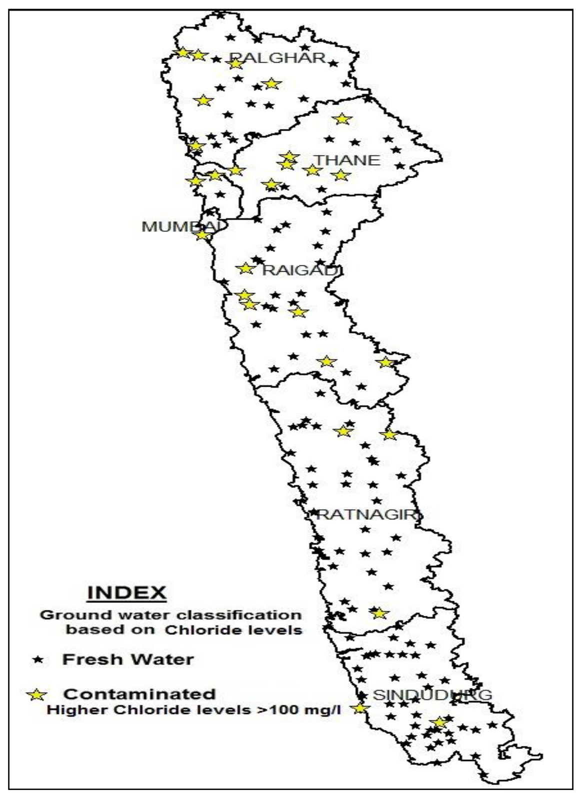

Figure 6: Classification of groundwater according to Chloride levels

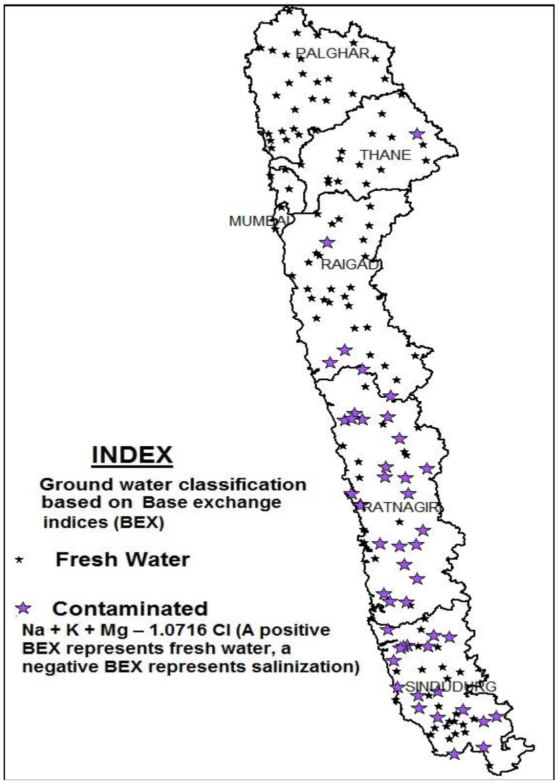

Figure 7: Classification of groundwater according to Base Exchange Indices

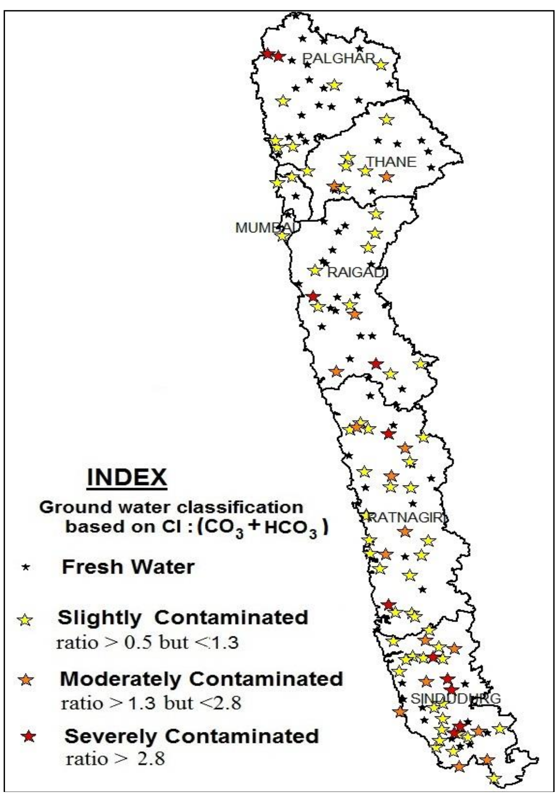

Figure 8: Classification of Ground water based on Cl : (CO3+HCO3) ratio

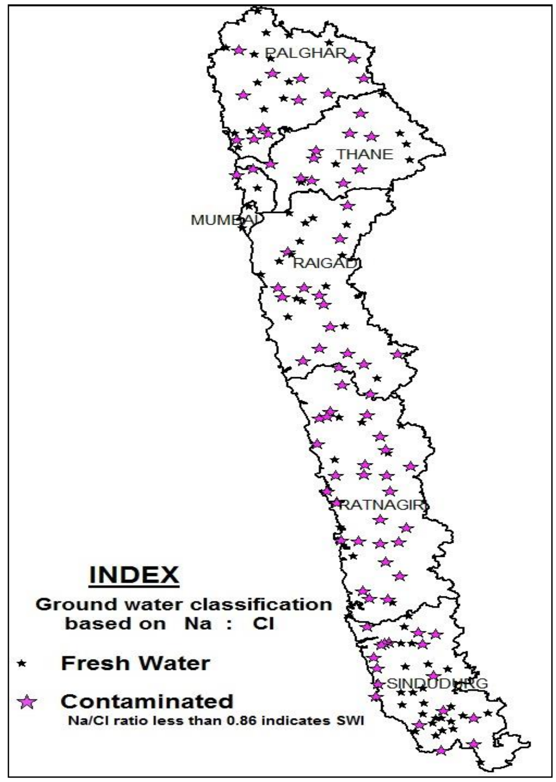

Figure 9: Classification of Ground water based on Na: Cl ratio

From the above two ratios (Na:Cl& Cl:CO3+HCO3) , it is obvious that the shallow groundwater in a stretch of 150 to 200 m from the coast, estuaries and backwater limits of river course, is subjected to sea water contamination to various degrees depending upon the distance from sea/estuary and the local developmental conditions.

Geochemical character of groundwater

Based on the type of mineralization, the geochemical evolution of ground water is deciphered in the coastal and estuarine environment. The plotting of relative concentrations of most important cations and anions in Pipers's Trilinear diagram, the overall characteristics of the water are represented in diamond field (Figure 10). Percent reactive values in epm/l of most important cations and anions are plotted in the modified Piper diagram as suggested by Chadha (1999). Piper's diagram is very functional tools in bringing out chemical relationships among ground water in more distinct terms. The study area groundwater are also classified on geochemical basis and carried out by subjecting the samples to graphical treatment as well as plotting them on Piper's trilinear diagram. It depicted that groundwater of the study area is predominately of Ca–HCO3 type and shows the characteristics of groundwater from basaltic aquifers. A small number of samples within the category of mixed type of water. In most of the samples, alkaline earths elements exceed the alkalis elements and weak acids exceed strong acids. However, alkalis (Na+K) exceed alkaline earths (Ca+Mg) in few water sample, while strong acid (Cl+SO4+NO3) exceeds weak acid (CO3+HCO3) in some groundwater samples.

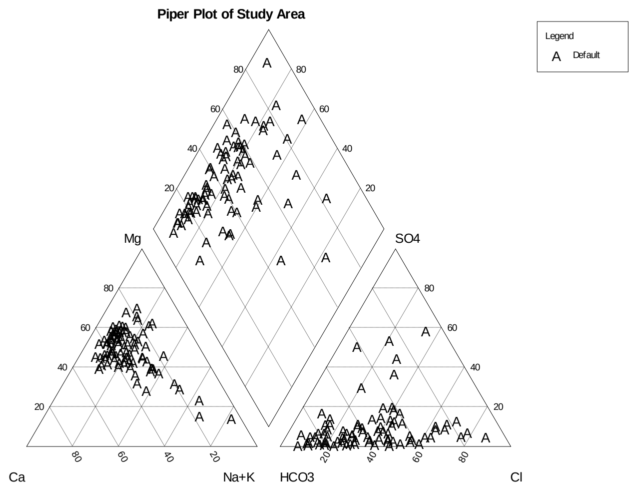

Figure 10: Piper's Modified Trilinear diagram for the groundwater samples of the study area

IV. CONCLUSION

The groundwater of the study area is predominately of Ca–HCO3 type and represents characteristics of groundwater from basaltic aquifers which show on the basis of Piper's diagram. A small number of samples are within the category of mixed type of water and almost 20% of the samples are beyond the desirable limits of BIS making it unfit for drinking purpose and almost 53% of the water samples indicate the chances of SWI. 18% of samples have Chloride concentration above 100 mg/l and negative Base Exchange indices (BEX) of 8% samples indicate the chances of SWI. Possibility of sodium hazard to the soil is low and most EC values fall under the category of low and medium salinity hazard zone.

V. RECOMMENDATIONS

Over-exploitation of groundwater, low seaward freshwater flow in rivers etc are the major reasons for sea water ingression. Regulation of groundwater development in the coastal area and adjacent to estuaries, maintaining adequate stream flow and stopping of river bed sand mining, construction of tidal regulators at suitable places and creating fresh water barrier through rainwater harvesting and groundwater recharge are essential to control further sea water intrusion in Palghar, Thane, Raigad, Ratnagiri and Sindhudurg districts and Greater Mumbai.

VI. ACKNOWLEDGEMENT

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