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Assessment of Seawater Intrusion in Coastal Aquifer of Bhavnagar District using MODFLOW and Hydro-Chemical Analysis

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Abstract: The Groundwater is major source for the people who works in different parts of works like irrigation, Domestic & Industrial parts, etc. So specially in coastal regions, there are some effects on the Groundwater due to sea water intrusion. Now a days, SWI is major environmental issue all over the world. These salinity concentration in groundwater may harmful for plants and animal that use it. Present study aims to analyses that how much effects should be done on the ground water by the nearer Sea water course. There are many reasons of SWI, but major factor is increasing the rate of pumping water from groundwater and decreasing rate of groundwater recharge. The aquifer zone in the study region are essential contributor sources of drinking water and irrigation water for agriculture needs. Present study uses the MODFLOW tool and Hydro-chemical method for the study of Sea water impact detailing in Groundwater in Bhavnagar district of Gujarat. From the literature study it is sensible that MODFLOW is best to study Seawater Intrusion because it is easy of applicate with effective inputs and accurate outputs. The MODFLOW is used for the creating, running and processing of Seawater Intrusion based model. The ground water samples are collected from 42 wells from different villages of Bhavnagar coastal area. Based on the well location and water sample, the study is carried out by making numerical model in MODFLOW and chemical analysis. Numerical model is generated in MODFLOW tool by putting Recharge, Drainage, Evapotranspiration value as an input parameter. From the model, it can be seen that SWI occurs in the coastal region at the rate of 3400-4500 cm^2/day varies in village to village. In Hydro-chemical analysis EC, TDS, pH parameters have been checked for study. In more than 54% of well, EC value is exceeding 2250 µmhos/cm and TDS concentration in more than 60% of wells is greater than 2000 mg/l and pH value of all the sample is lies between 7.1 to 8.5. So, these result shows that due to Sea water Intrusion, nearer groundwater is contaminated, its quality reduced and it is not suitable for any use.

Index Terms **- MODFLOW, Groundwater Modelling, Seawater Intrusion, Geo-Chemical, Coastal Aquifer, Bhavnagar coast**

I. INTRODUCTION

In last few years, the use of surface water is increased in different purposes like domestic, industrial, agricultural sectors as an agreeable source of water as well as its lower cost and ease of accessibility [Mohammad and Akbar, 2015]. The rapid pace of development in the country of India in line with the high population growth, land use change and heavy urbanization, is expected to require clean water to rise sharply [Mohammad, 2015; Purwanto, 2014]. Due to these factors, pressure is increased on the surface water source to the extent that it has led to use of alternative sources like ground water to satisfy the need. Also, the ground water is a major source of fresh water [Mohammad and Akbar, 2015].

But the problems arise in the ground water which is nearer to coastal line. Because, coastal zones are highly sensitive and it is influenced by human activities, some activities which requires large quantity of water, climate change and corresponding rise of sea level [Nerantzis, 2019]. So, because of such factors coastal aquifers are currently in critical situation throughout the world. These aquifers are important source of freshwater for more than 40% of world's population, which is living in the coastal areas. [Beshad and Marwan, 2019]. So, from these factors, the salinization of coastal aquifer, because of overexploitation, is a common and major phenomenon. So, seawater intrusion is a major environmental issue, which affects 80% of world's population lives in coastal areas. Also, seawater intrusion degrades the quality of coastal aquifer groundwater, which causes reduction in crop yield efficiency, reduce the sources of ground water and soil fertility. Also, the seawater intrusion has been considered a global issue. Any changes in coastal aquifer results in the movement of seawater from sea side towards the aquifer, which is known as seawater intrusion [Nerantzis, 2019; Ratnakar and Ratnalu, 2020; Mahdi and Hojjat, 2019; Rachid and El-Fadel, 2017].

From the previous study it concludes that the two major reasons of seawater intrusion are over-exploitation of coastal aquifer and sea level rise due to the climatic change. The India is not a land locked country, but the coastal areas are there at east, west and south part in India. So, the effective monitoring of groundwater is required to save the drinking water resources. Also, the preventive measures are requiring in the area which is saline affected [Ratnakar and Ratnalu, 2020]. The costal line length of the India is around 6031km which includes 9 coastal states and 2 union territories having 66 coastal districts [nccr.gov.in].

In various part of India, salinization of coastal aquifers has been studied by various authors: Digha, West Bengal (Choudhary et al., 2001), Godavari region (Surinaidu et al., 2014), Chennai (Nair et al., 2016), Gujarat (Desaai et al., 1979, Rina et al., 2013).

Also, various methods are used to study the problem such as Geophysical method, numerical method and hydro-chemistry approach. [Parul and Rina, 2018] Coastal length of the Gujarat state constituting 14 coastal districts and 2 union territories having 2542 villages is measured to be approximately 1701km from 2016 satellite imagery. [nccr.gov.in]

About 6632km long shoreline distributed among nine coastal state and two union territories. Coastal erosion has become one of the most serious problem in varying pockets along the Indian coast. The shoreline analysis shows that 34% of coast is eroding, 28% is accreting and 38% is in stable state. The state wise analysis suggests that in the West Bengal (63%) and Pondicherry (57%) coast erosion exceeds more than 50%, followed by Kerala (45%) and Tamil Nadu (41%). Odisha (51%) is the only coastal state which is having more than 50% of accretion, followed by Andhra Pradesh (42%). Considering the maximum and minimum values of the shoreline change rate, the shoreline is divided into seven categories as low erosion, moderate erosion, high erosion, stable, low accretion, moderate and high accretion which is shown in figure. (nccr.gov.in). It can be seen that the coastal states of Gujarat, Andhra Pradesh, Odisha and West Bengal have undergone drastic change in the past 26 years. Land gain of greater than 60 sq. km is observed along the states of Gujarat and Odisha. (nccr.gov.in)

The costal state of Gujarat is on the western end of Indian peninsula. It is longest coastline with geomorphic features, and based on the varied physiographic features, coastal processed and river discharge the coast can be broadly classified into five regions (1) The Rann of Kachchh (2) Gulf of Kachchh (3) The Saurashtra coast (4) Gulf of Khambhat and (5) The south Gujarat coast. The 1990-216 shoreline change assessment result shows that 43% of the coast is stable, 31% is eroding and remaining 26% is accreting which shown in figure. (nccr.gov.in)

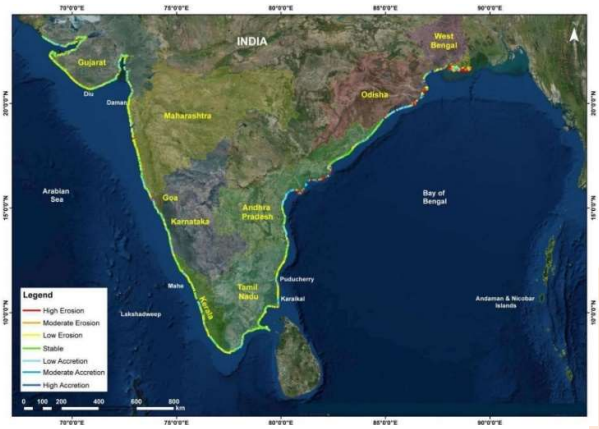

Figure 1 Coastal Boundary of India

Figure 2 Coastal Boundary of Gujarat

Sea water Intrusion measured by three methods, i.e., Geo-physical, numerical modelling and hydro-chemical analysis. Geo-physical method is very costly because it requires expensive instruments and skilled supervision. Hydro-chemical and numerical modelling methods is less costly compared to Geo-physical method. Hydro-chemical analysis done in Laboratory. There are many numerical modelling tools like MODFLOW, SUTRA, PHAST, SEAWAT, etc. Among that MODFLOW is vastly used tools for Seawater Intrusion study because its accuracy and having many input and output. Seawater intrusion occurs in the aquifer in which the water table level is very low. Electric conductivity parameter is used to study saline water study. EC shows the result in µmhos/cm. Above 2250 µmhos/cm value shows highly contaminated water sue to seawater intrusion. The mains cause of Sea water intrusion is high pumping rate from aquifer, Recharge is not available to rise ground water level.

II. STUDY AREA & DATA COLLECTION

The study area is the coastal aquifer of Bhavnagar district of Gujarat State. It is located in South-east direction of saurashtra and west side of Gulf of Khambhat. Bhavnagar lies between north latitude $21^0$18’ and $22^0$18’ and east longitudes $71^0$15’ and $72^0$18’. Bhavnagar district touches the boundary of Ahmedabad, Surendranagar, Rajkot, Amreli districts. The normal rainfall is 597mm Annually in Bhavnagar. The precipitation occurs due to southwest winds in June to September month. The average groundwater level depth in aquifer is lies in between 15-30 meter at pre-monsoon stage and in between 40-50 meter at post-monsoon stage.

The available ground water in the coastal region is the main source to people who stay in the villages which is located nearer to the coastal boundary. There are several variations in available soil strata in study area. Three types of soil are available, i.e., medium black soil, alluvial soil, and alkaline soil. In Bhavnagar district Black cotton soils are available in the soil strata. In geology formation, 79-81% of the total area having basalt formation and 19-21 % by alluvial formation.

The collection of water samples was done at 42 different wells. From which 5 wells monitored by GMDC (Gujarat Mineral Development Corporation) and 37 wells monitored by GWRDC (Gujarat Water Resources Development Corporation). From each wells the water samples of 250ml collected and also the details from farms like water level in the borewell, quality of water, quantity of water available in different season, water is portable or not, etc is collected. From this survey, some idea about seawater intrusion nearer the sea area or shore boundary has been collected. There are 37 villages available in present study area in Bhavnagar coastal area. Total 42 well samples were taken for ground water study for chemical analysis. The details of water sample collection are shown in the table 1. Due to paper length restriction only 5 well details are shown out of 42 wells.

Table 1 Well details

Village	Taluka	District	Geology	Latitude	Longitude	S.W.L. (mt)
Ghogha	Ghogha	Bhavnagar	MAR	21°40'57"	72°15'38"	7.30
Odarka	Ghogha	Bhavnagar	BAS	21°30'40"	72°10'05"	15.20
Rampara	Talaja	Bhavnagar	BAS	21°18'43"	72°00'48"	21.40
Bhatakda	Mahuva	Bhavnagar	MLS	21°09'45"	71°57'21"	20.00
Vadli	Mahuva	Bhavnagar	ALV	21°06'55"	71°46'41"	22.50

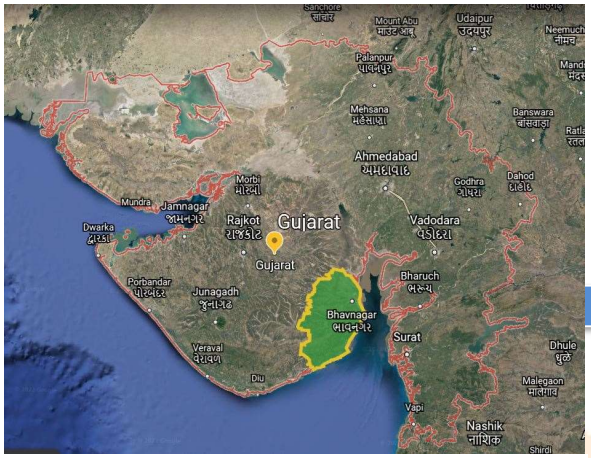

Figure 3 Bhavnagar District Boundary

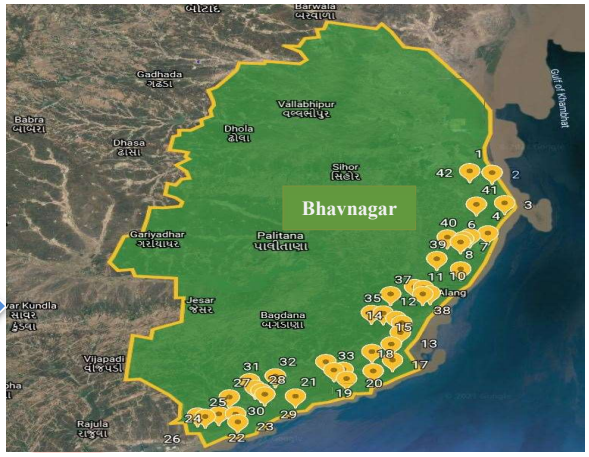

Figure 4 Well Location in Study area

III. METHODOLOGY

In the study, Numerical modelling and Hydro-Chemical method are used to know about ground water and saline water scenario in study area. Hydro chemical analysis is used to evaluate whether Seawater Intrusion is occurs or not and Numerical method is use to know about the rater at which sea water intrusion happens in coastal aquifer due to nearer seawater sources. Modular Finite-Difference Ground-Water Flow Modelling tool is the U.S. Geological Survey modular finite-difference flow model, which is a computer code that solves the groundwater flow equation. It is a computer program that can simulate one, two or three-dimensional groundwater flow using finite difference solution of the model. The program is used by researcher to simulate the flow of groundwater through aquifers. It's used to evaluate steady and unsteady flow in an aquifer in which its layer can be confined, unconfined and convertible. MODFLOW is designed to simulate groundwater systems where saturated-flow conditions exist, Darcy's Law is used by MODFLOW, and the density of groundwater is constant throughout. The modules are grouped into packages that deal with a single aspect of simulation. Depending on the problem individual packages may or may not be required, such as Well Package, Recharge Package and General Head Package. MODFLOW includes solver packages used to solve groundwater flow equations, such as Strongly Implicit Procedure (SIP), Successive over Relaxation (SOR), and Preconditioned Conjugate Gradient (PCG). Package and programs that is used for numerical model is shown in the table 2.

Table 2 MODFLOW Input packages

Sr. No.	Package	Name	Why to use?
1	DRN	Drain Package	cause the water leave the aquifer when head is rises above the elevation of drain boundary
2	ETS	Evapotranspiration segments Package	Use to define Evapotranspiration on top layers and for each stress periods
3	RCH	Recharge Package	Use to specify a recharge rater over an area. recharge data for different layers can specify using this tool
4	WEL	Well Package	Use to specify a volumetric rate of fluid withdrawal or discharge. Well pumping rates used in the tool
5	SWI	Sea Water Intrusion package	Simulating variable density flow. Two or more zones of density variation are analyses within each model cell

Governing equation used in MODFLOW:

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]+w=S_s\frac{\partial h}{\partial t}$$

Input parameter values that used in model preparation:

Table 3 MODFLOW Input Parameter values

Sr. No.	Parameters	Inputs	Remarks
1	Grid	cell size	200x200
2	Layers	5 layers	Upper two are confined and other 3 is convertible
3	Simulation Period	2	Each 100 days with 1st is steady state and 2nd is transient
4	Hydraulic conductivity		
	kx	0.004, $5x10^{-6}$, $1x10^{-6}$, $9x10^{-7}$, $5x10^{-7}$	top to bottom layer respectively
	ky	kx	-
	kz	kx/2	-
5	Evapotranspiration	0.8 meter top	Model top
6	Drainage	Conductance – 0.001 m	Model top
7	Recharge	300mm/year	Considering half of rainfall
8	SWI	Effective porosity – 0.1, Density – 1	From Model top

Procedure follow in the MODFLOW:
ModelMuse tool is used to develop MODFLOW numerical model. Also, ModelMuse compatible to use with different tools i.e. SUTRA, PHAST and WellFotprint project as per requirements. In present study MODFLOW used because its wide application in different parts of groundwater and accuracy in outputs. Now, the KML file is prepared of the study are and well location. Based on the KML file, shape file is prepared from QGIS with Geo-referencing. Without Geo-Referencing it is not possible to work on actual study area site. After that, import the Shape file in MODFLOW and generate the grid in study area with square cell size of 200m. Also define layer number and its properties. Five layers are considered to generate the mode with their depth from top to bottom is 40m, 35m, 30m, 25m and 20m respectively Then define stress period from MODFLOW stress period. In the study two consecutive stress periods are considered of 100 day each (8640000 seconds). Then select the Package and programs which is to be used in model. In the present study three Boundary conditions used i.e. Evapotranspiration, Recharge value, Drainage package and as a flow package, Sea Water Intrusion is taken to model generation in present study with their values shown in the Table 2 Now after successful inputting the input values save the model. Then use the run button and start run the model, that shows the whether the data used as input parameter is suitable or not and which is visualizable or not. Now, Output report is generated based on inputs which shows all the outputs and details seawater intrusion in the study area and wells that was considered.

Hydro Chemical analysis:
Groundwater sample were collected from the wells from study area. 42 wells sample collected in pos-monsoon period of Sept-Oct 2020. The sampling bottles were washed with distilled water before taking samples and brought to the laboratory the physical parameters pH, EC and TDS of water sample were determined by standard methods. pH was measured using digital pH meter and Electric conductivity was estimate with the HANNA EC analyser. Total Dissolved solids is estimated by TDS analyser. All result values of the sample are compared with BIS standards. As per Indian standard permissible limits is 2250 umhos/cm and 2000 mg/l for EC and TDS respectively. EC values above 2250 umhos/cm is considered as highly saline water more than 2000mg/l treated as contaminated water.

IV. RESULT AND DISCUSSION

In the model, there are three parameters considered, which is taken as input parameters or say boundary conditions as discussed in chapter 4. Based on this parameters seawater intrusion comes as output parameters. The input parameters discussed in previous chapter. So, in this chapter outputs or results of those inputs are discussed. In the model, there are three parameters considered, which is taken as input parameters or say boundary conditions as discussed in previous chapter. Based on this parameters seawater intrusion comes as output parameters MODFLOW. The input parameters discussed in previous chapter. So, in this chapter outputs or results of those inputs are discussed.

Evapotranspiration Package: MODFLOW gives the output parameters as contour data with output values. Evapotranspiration input value is 1200 mm/year. After the completion of the model run, some outputs are coming and it can be evaluating that for two stress periods the evapotranspiration values in varies from 0 to -0.0015 mm/sec.

Recharge Package: In the Recharge package, MODFLOW consider the total rainfall divided in to two equal parts. So, half the rainfall water going to aquifer as a infiltration, i.e., recharge, and half the rainfall portion is convert into direct runoff. Rainfall annual rainfall in Bhavnagar District is 597 mm/year. So, 300 mm/year is considered as recharge quantity. From the output, it can be seen that the result for two stress periods is varies from 0 to 0.00018 mm/second at location. The contour result is shown in figure.

Drainage Package: In Drainage parameter there are two different values are considered. Elevation is considered as top later i.e., top layer. Conductance is considering as 0.001m^2/day. From the outputs, it can be noted that the result value for two stress periods and for study area is varies from 0 to -0.04 m^2/day.

Seawater Intrusion Package: In the study area after analyzing all 3 parameters i.e., EVT, DRN, AND RCH, MODFLOW shows the actual scenario of seawater intrusion in the study area. This parameter shows the contour data for same concentration of seawater intrusion in affected area. From the figure, it can be noted that, the seawater intrusion value is varying from 3400-4500 cm^2/day with higher intrusion occurs in ghogha village say 4420 in cm^2/day. And lower intrusion occurs in Rampara and Methla Village say 3420 cm^2/day.

Report Discussion: At the end of model run processor, the model generates the report of some output parameters. On the basis of input data, output results are shown in this report. In the input data RCH – 1.2188 mm/sec with total IN is 1.2188. In the Output data DRN is 0.9848 m^2/day, EVT is 0.2328 mm/sec with total out is 1.2176. Also, Total IN-OUT is 1.1822 x 10^{-3} and Percentage Discrepancy is 0.10.

- **Hydro-chemical analysis:** From the graph shown EC parameter, it can be seen that, the well shown by red column has the EC values more than 2250 µmhos/cm. This well is highly polluted because of Seawater Intrusion. The well shown by green column shows the less contamination due to SWI. Because as per Bureau of Indian Standard (BOI) the permissible value of EC is 2250 µmhos/cm. Highest EC value in Vadli and Madhiya village say around 13520 µmhos/cm and 11230 µmhos/cm recpectivey. Lowest value is in Garibpura, Bhensavadi and Vaghnagar is 980 µmhos/cm, 910 µmhos/cm, 900 µmhos/cm respectively. From the graph shown TDS parameter it can be seen that the wells shown by blue colour has high concentration of TDS say more than 2000 mg/liter. All other wells has the TDS concentration in permissible limits. This concentration in more than permissible value. As per the Bureau of Indian Standard (BOI) the acceptable limit and permissible limits of TDS is 500 mg/liter and 2000 mg/liter respectively. Highest TDS concentration is in Padhiyarka and Dhudhala village say around 8560 mg/l and 8200 mg/l. Lowest value is in Garibpura and Trapaj village which is 550 mg/l and 590 mg/l. pH test was performed in the laboratory by using pH meter. Graph of pH results shows that in almost all the wells has the pH range from 7.1 to 8.5. So, it shows the alkaline concentration in ground water. It can be shown that, highest value of pH is in Khared village which is 8.5 and 7.1 is in Garibpura village which is the lowest one.

Graphs showing Numerical Modelling Analysis:

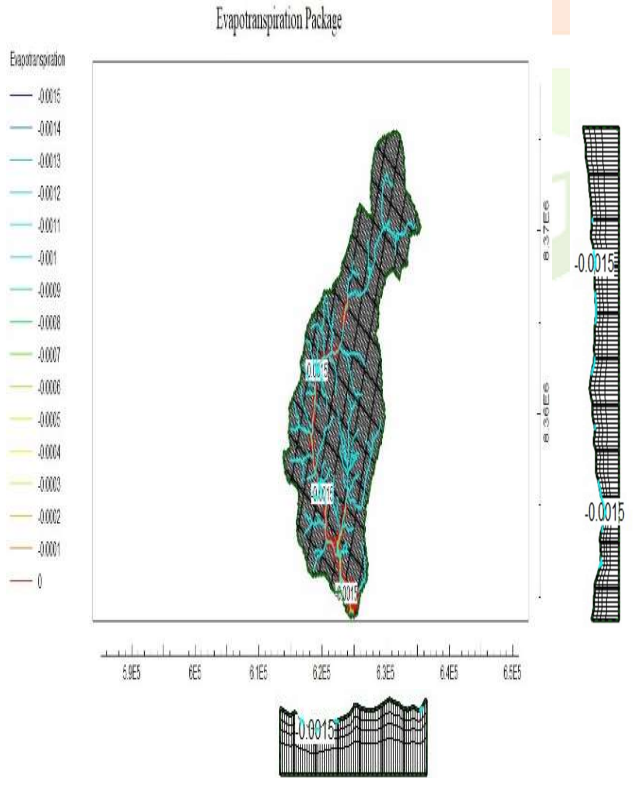

Figure 5 Evapotranspiration

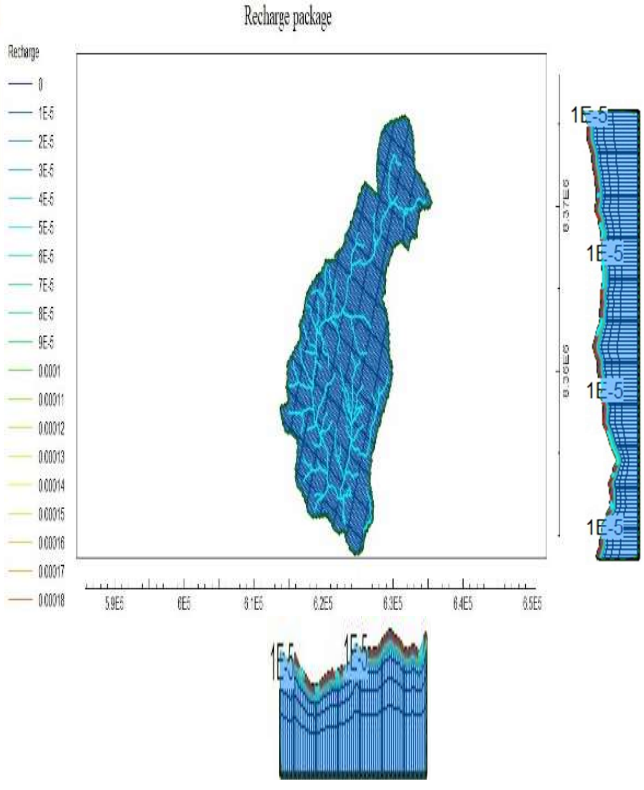

Figure 6 Recharge

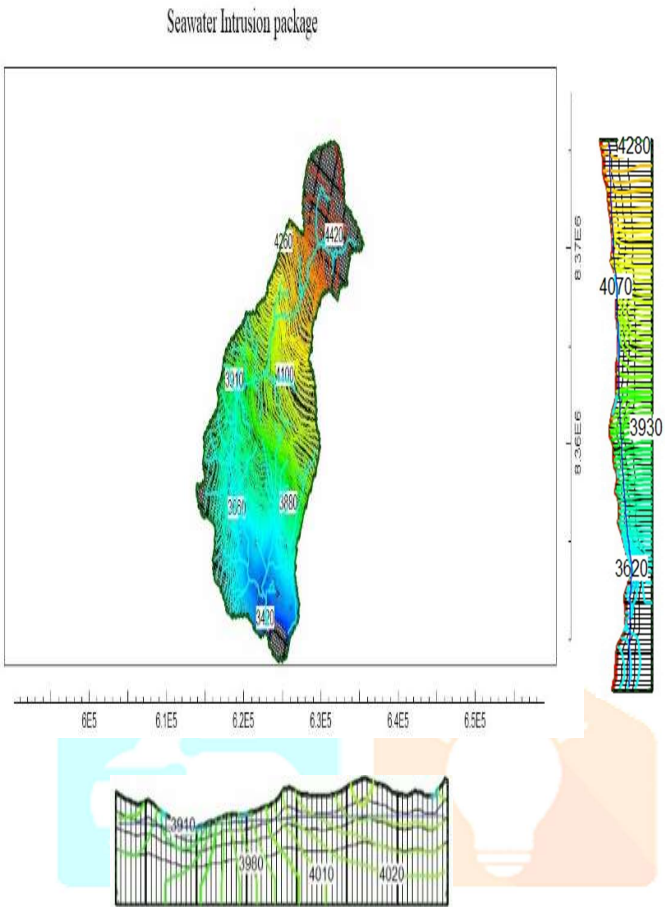

Figure 7 Seawater Intrusion contours

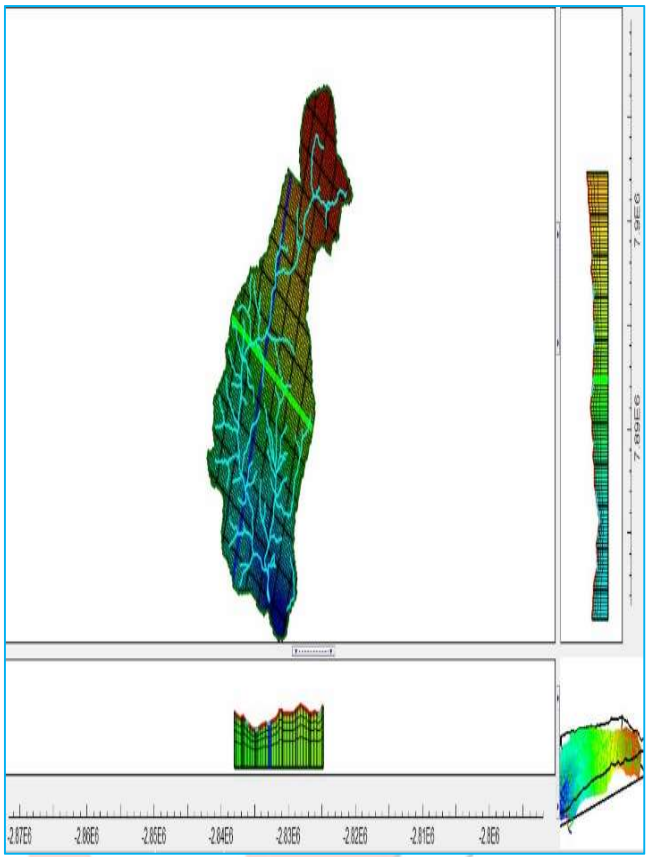

Figure 8 Seawater Intrusion in Bhavnagar

Graphs showing Chemical Analysis:

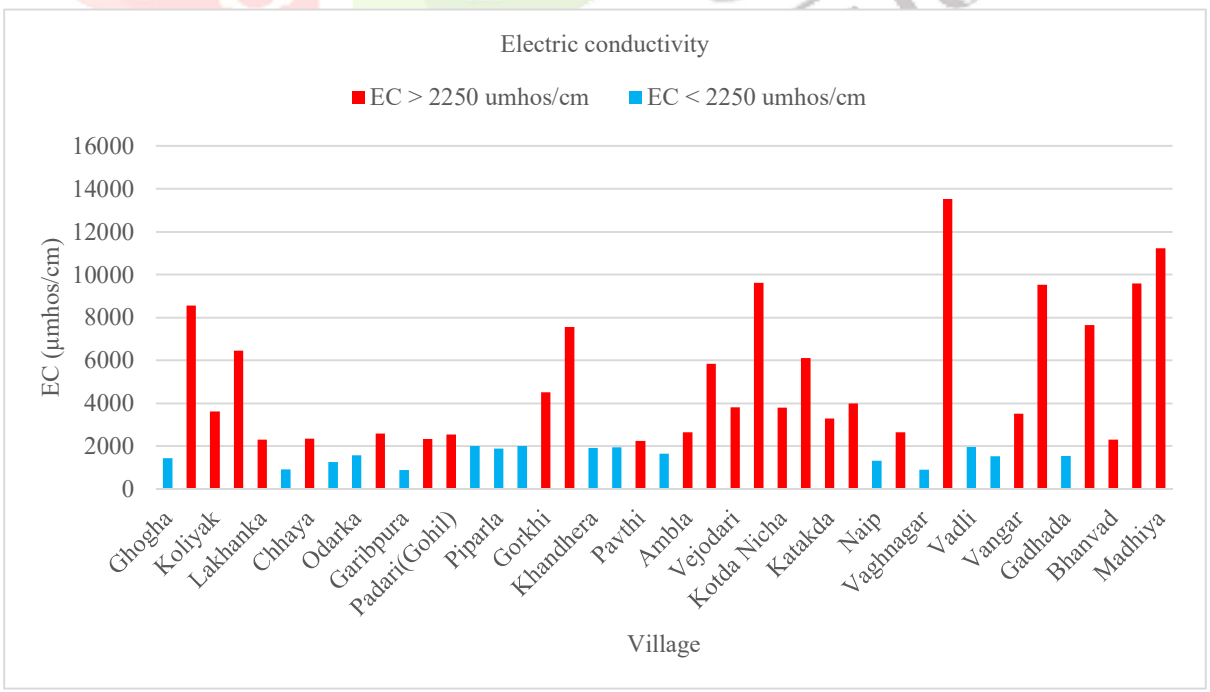

Figure 9 Electric Conductivity Results

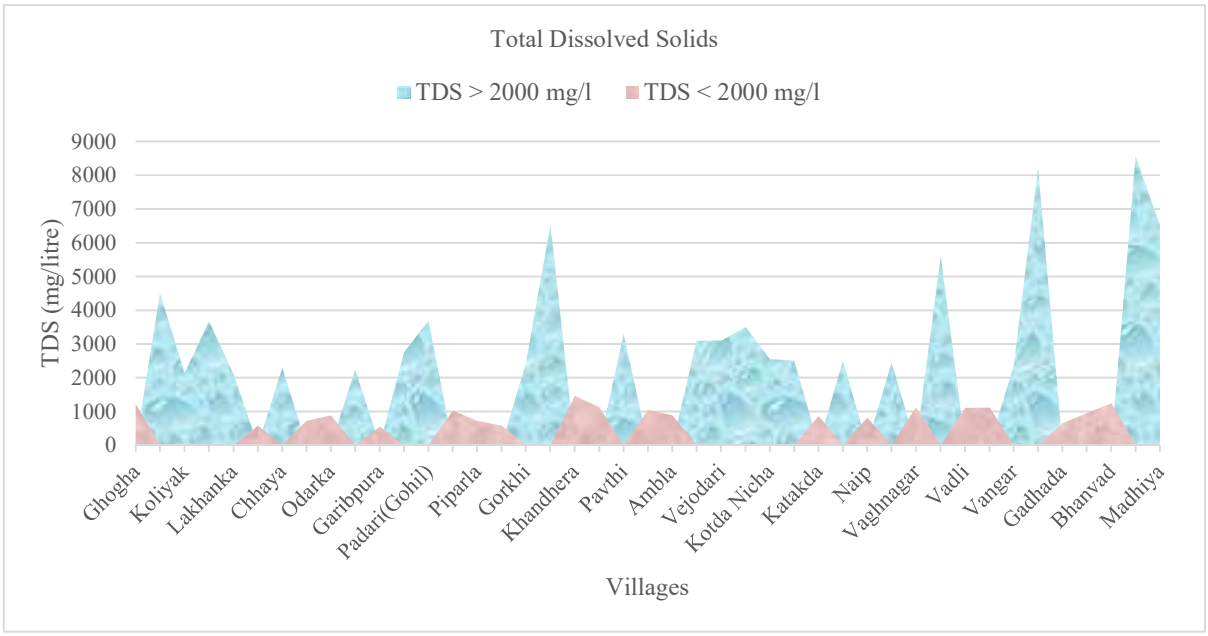

Figure 10 Total Dissolved Solids Results

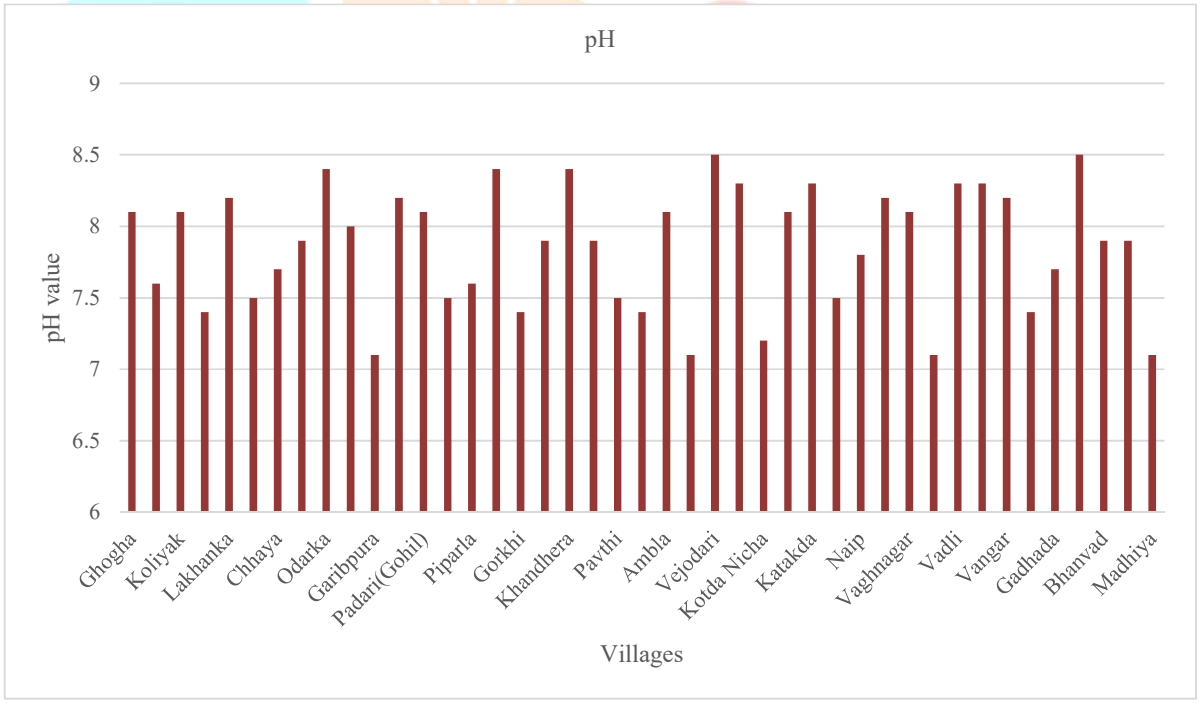

Figure 11 pH results

V. CONCLUSION

Numerical Model Analysis:

There are many numerical modelling tools are available, but for seawater intrusion study, MODFLOW is very effective tools having some important packages and programs. Also, this tool is freely available public domain tool. Result shows that in seawater affected area the parameters do not fall within the acceptable limits. The condition of seawater intrusion in Bhavnagar coastal region has increases day by day at the rate of 3400-3600 cm^2/day. At the end on the stress periods, the result value of Drainage in the Bhavnagar coastal area is 0.9848 m2/day. In the Study area, Evapotranspiration occurs at the rate of 0.2328 mm/sec from top layer of soil strata of depth 0.8 meter. The study area is recharge at the rate of 1.2188 mm/sec due to artificial activities, rainfall and agricultural process. The seawater Intrusion is more from the eastern side of the area or say more from the Gulf of Khambhat and less from other side.

Hydro-Chemical Analysis:

From the hydro chemical analysis Saline related parameters shows the results for different wells. In more than 70% area the EC concentration is more than 2250 µmhos/cm. It shows that, in more than 70% area ground water is contaminated due to seawater intrusion. From the TDS analysis it can be concluded that, more than 60% well has a high concentration of dissolved solids more than 2000 mg/l. From these results it can be clearly shows the ground water contamination because of saline concentration.

VI. ACKNOWLEDGEMENT

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