International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** IX **Month of publication:** September 2021

DOI: https://doi.org/10.22214/ijraset.2021.38062

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

Study of Groundwater quality, its impact on human health and Agriculture and Salt Water intrusion in and around Gandhidham, Kachchh, Gujarat

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Abstract: Hydrogeochemical studies were carried out in Gandhidham Taluka, Kachchh, Gujarat in post Monsoon season to assess the quality of groundwater and its suitability for drinking, irrigation, and industrial purpose. In this study, the groundwater contamination of Gandhidham which is mostly used as a potable source, for irrigation and industrial use along with Narmada water is carried out and compared with the recommended standards set by the Bureau of Intense Standards (BIS) and the WHO. The sample analyzed for the post-monsoon seasons reveals that some of the groundwater sources exceed the permissible limit of WHO and BIS. In this study the physiochemical parameters like electrical conductivity, pH, TDS, chlorides, fluorides Sulfate, Nitrate, and heavy metals like sodium, potassium, cobalt, iron, chromium, copper, Zinc are analyzed. Groundwater samples were collected and analyzed in post-monsoon seasons 2015, 2016, and 2020 which proves that most of the samples are not fit for drinking. Most of the samples are good for irrigation but not for the long run as a high evaporation rate leads to salinity and finally to degradation of soil quality. Analytical data studies in the study area reveal that there is a saltwater intrusion in the coastal areas of Gandhidham. The results of statistical analysis prove the elevated concentrations of some chemical elements leading to pollution with heavy metals are related to anthropogenic and industrial activities leading to contamination.

Keywords: Groundwater quality, Saltwater intrusion, Heavy metals, Kachchh, Gujarat

I. ABBREVIATIONS

BIS - Bureau of Intense Standards, WHO- World Health Organization, SWI - Seawater intrusion, DWAF - Department of Water Affairs and Forestry, Met. gen- meteoric genesis. KR- Kellies Ratio**,** MH% -Magnesium percentage, SAR- Specific Absorption Rate

II. INTRODUCTION

Groundwater is the major source of drinking water in rural and urban areas as well. In India, groundwater plays a very important role in fulfilling the demand for water for domestic, irrigation, and industrial use along with surface water. Moreover, Industrialization has become an important parameter to measure the development of a country's economy through the establishment of industrial sectors. However, the waste or by-products discharged from them are severely disastrous to the environment consists various kinds of a contaminant that contaminate the surface water, groundwater, and soil. There are many reasons the waste is not safely treated. One of the reasons is mainly due to the lack of highly efficient and economic treatment technology. The supply of good quality drinking and irrigation water will decrease in the future, as the development of new water supplies will not keep pace with the increasing water needs of industries and municipalities.

Kachchh has become an industrial hub after the severe earthquake on 26th January 2001, as it was declared a special economic zone for the industrial set up to lure various industrial units to establish and contribute to the development of Kachchh which shattered due to the devastations of the earthquake. Kachchh is having a source of Narmada canal but still, that is limited to certain regions and groundwater supplement source is fulfilling the increasing demand of water supply due to the population which has been increased in last 19 years after the earthquake. Groundwater in the study region is generally affected by certain geochemical processes and multiple contamination sources like industrial effluents, domestic sewage disposal as the population increased in the last decade at the rate of 32% (calculated based on population census 2011 and 2001 as index year (Source Panchayat Office, Gandhidham) because of industrial expansions (Rajmohan, N; et al)

In 20 years Ground Water level depleted to 38 meters that are 19 meters per decade. (Source – Gujarat Ground Water Supply Board, Bhuj) while the water depletion rate is 11.31 % per Decade.

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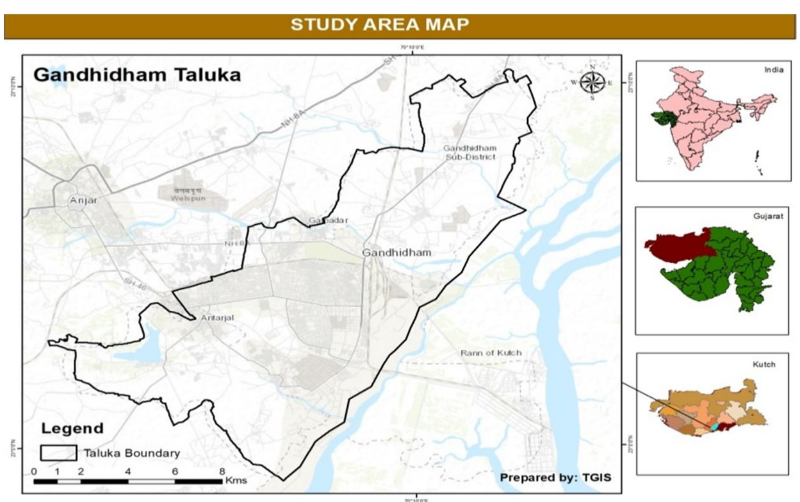
Intense irrigation activities, drainage patterns for industries, and Geochemical processes in the region are strongly related to geological formations, climatic conditions, groundwater flow, residence time, etc. (Ruiz, R.; et al). Gandhidham is having a semi-arid climatic condition, with a high evaporation rate without any surface water source of water, ion exchange reactions, oxidation-reduction processes, dissolution, and precipitation of minerals that affect groundwater chemistry. Surface contamination sources play a major role in water pollution due to shallow depth compared to natural processes. Intensive irrigation practices, domestic sewage, septic tank effluents, dumping sites, etc. are reported as major root causes for groundwater contamination worldwide. (Singh, C.K.: et al) Geochemistry and multivariate statistics are broadly used in groundwater contamination assessment and several researchers applied major ion chemistry and multivariate statistics to assess the geochemical processes and groundwater contamination in the aquifer (Machiwal, D.: et al) The present study was executed in Gandhidham and nearby areas of East Kachchh, which is semiarid Zone to evaluate the contamination sources and geochemical processes responsible for water chemistry and water suitability for drinking and irrigation uses and also for saltwater intrusion due to over-exploitation of groundwater sources. Groundwater recharge is too slow as the average rainfall of this region is 348 mm per annum. However, several developmental expansions have resulted because the Kachchh region is no tax zone after the severe Earthquake of 26th January 2001 to develop economic opportunities in this area which was completely devastated and shattered in this earthquake groundwater quality is affected due to intensified development of industries and increasing population. The purpose of this study is to evaluate the groundwater chemistry and its associated geochemical processes and to evaluate the contamination sources in this region. In addition, groundwater suitability for drinking and irrigation purposes is also assessed using major ion chemistry.

Seawater intrusion (SWI) is a universal concern, intensified and aggravated due to over-exploitation of groundwater, sea-level rise, and climate change in the coastal province. According to the Ghyben–Herzberg principle, the stability between freshwater and saltwater is caused by the density difference between the two, until the pressure equalizes. (Swayam Sidha .et. al) Suitability for Drinking Purposes the DWAF and WHO have recommended standards for drinking water suitability for the coastal aquifers and those standards were used to evaluate the suitability of groundwater. Anthropogenic activities add to the condition where it proves to be toxic to plants and animals and is highly oxidative, corrosive, and carcinogenic in nature. Lead is physiologically and neurologically toxic in nature. High concentrations of nickel may cause skin irritation. Lead is a known carcinogen and accumulates in bones as it replaces calcium in bones.

A. Study Area

Gandhidham is a city and a Municipality in the Kachchh District of Gujarat state in India. The town was created in the early 1950s for the refugees from Sindh (Pakistan) in the aftermath of the partition. Gandhidham is the economic capital of Kachchh and is a fast developing city in Gujarat State. It is the 8th most populated city in the state of Gujarat. It is located at latitude 23.080 N Longitude 70.1 Hydrogeochemical studies were carried out in Gandhidham Taluka, Kachchh, Gujarat in post Monsoon season to assess the quality of groundwater and its suitability for drinking, irrigation, and industrial purpose.3^0 E Summers are hot and touch 45^0 C (113^0 F) in winter, it falls to 3^0 C (37^0 F) It is a semi-arid region.

B. Study Area Map



C. Objectives

1) Study of key effluents of the industrial setups.
2) To find the various physicochemical parameters including heavy metals in groundwater.
3) Effect of physicochemical parameters and heavy metals present in groundwater on human health
4) Study of Saltwater intrusion.

III. METHODOLOGY

A. General Preparation of Sampling Containers

General Preparation of Sampling Container s Groundwater analysis was carried out post-monsoon (2015), post-monsoon (2016), and post-monsoon (2020) in the study area. Samples were collected in Polyethylene bottles Each sample bottle was washed with a brush and phosphate-free detergent, Rinsed three times with tap water, rinse three times with distilled water and while collecting water samples it is washed with sample water 2 to 3 times after free flow of bore well for five minutes and from open wells directly to the full capacity of the bottle without any air, to avoid oxidation. In the study, the samples were collected from the various villages from Gandhidham and were analyzed using standard chemicals. The special protocol was maintained for the collection of the samples from different sources. Somewhere it is found along with the tube well there are the open wells also. Standard methods were used for the analysis of pH, EC, fluorides, etc. suggested by the American Public Health Association APHA 2012.

Table 1- Methodology for analyses

Parameter	Method
pH	In situ
EC ,TDS	In situ
Nitrate, Sulphate, Silicate	UV Spectrophotometer (UV 800, SMAZDU)
Fluoride	In situ using Flouride kite
Total Alkalinity, Chloride	(Titrimetric)
Total Hardness as $CaCo_3$, Calcium, Magnesium	EDTA Titration Method
Heavy metals (Na, K, Pb, Cu, Cd, Ni, Fe, Mn, Ni, and Co.)	AAS (SMAZDU 7200)

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IV. RESULT AND DISCUSSION

Table 2 - Water quality - Groundwater, Gandhidham, Kachchh, Gujarat

POST Monsoon			
Parameters	2015	2016	2020
TDS	2158.60±265.43	1585.40±160.28	1870.73±232.93
Chloride	716.1±92.02	992.12±141.61	286.41±61.78
Alkalinity	401.11±34.27	493.62±42.706	229.411±31.31
Hardness	513.94±65.27	663.37±106.56	504±97.82
Calcium	281.05±43.74	307±41.47	240±19.12
Magnesium	232.89±40.38	356.37±74.54	145.83±11.62
Silicate	21.84±3.67	27.75±4.69	29.478±6.66
Sulfate	90.33±18.08	93.54±20.211	158.51±32.05
Nitrate	23.49±6.47	14.68±4.93	12.86±3.48
Fluoride	1.49±0.25	1.86±0.36	1.1±0.31
Sodium	400.47±60.21	541.3±111.7	707.77±154.81
Potassium	17.77±4.50	8.25±1.67	8.06±1.87
Iron	0.2±0.06	0.43±0.13	0.12±0.01
Nickel	0.06±0.01	0.02±0.005	0.13±0.029
Manganese	0.03±0.008	0.05±0.017	0.067±0.016
Cadmium	0.005±0.0003	0.008±0.0007	0.007±0.0008
Lead	0.03±0.003	0.04±0.004	0
Copper	0.005±0.0006	0.005±0.0006	0.0046±0.0003
Zinc	0.12±0.01	0.014±0.01	0
Chromium	0.035±0.01	0.032±0.002	0.03±0.0021
Cobalt	0.09±0.0032	0.076±0.005	0.06±0.0053

Analytical results of the chemical parameters and the statistical parameters such as a minimum, maximum, average mean, standard deviation, and standard error are calculated for the post-monsoon seasons 2015,16 and 2020. The water samples which are collected in the study area were generally colorless, odorless, and non-turbid. The pH of groundwater is mostly alkaline in 2015. In 2016 the pH of only one region which is used for the irrigation is 6.8 and the rest of them were alkaline in nature and in 2020 the pH of one sample is acidic in nature having a pH of 6.2 and the rest of the samples were alkaline in nature .pH of all the seasons ranges from 6.2 to 8.96 and mostly for all the three seasons pH remains consistent. The TDS of 2015 was 4034.58 but it decreased in 2016 to the maximum limit of 2662.82, and in 2020 it remained to the highest value of 2910.73 ppm. It depicts that all the samples

The chloride ions concentration in 2015 was a maximum of 1585.40 ppm, which increased to 2156 ppm in 2016. And again in 2020, the chloride concentration decreased to 779 ppm and the rest all the samples are showing almost variations from 19 ppm to 1810 ppm in all the three-season, the highest is in 2016. Since chloride is found in abundance in three seasons, it might have been deprived of the anthropogenic sources of the chloride including fertilizers and human and animal waste, and even industrial applications also.

The desired limit of Calcium is 75 ppm and the permitted limit is 200 ppm In 2016, the calcium concentration of only 10% of samples was under the desired limit and 57.89 % of samples were beyond the permitted limit and 2016 the calcium concentration is found to be beyond the permitted limit in 75% while under the desired limit were 12.5%. In 2020, 73% of samples were beyond the permitted limit and only 6% of samples were under the desired limit. The concentration of Calcium from 2015 to 16 is found to be almost the same while there is an increase of about 60% samples in 2020, post-monsoon season. (Table 2)

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The desired limit of Fluoride is 0.5 ppm and the permitted limit is 1.5 ppm, Fluoride concentration in 2015 was 4.12 ppm to the maximum in sample number five. The average concentration was 2.88 and the rest of the samples were under the desired limit. In 2016 the maximum concentration is found to be 2.37 ppm and in 2020 the concentration of fluoride is 3.2 ppm.

High concentrations were salts of sodium, calcium and magnesium are responsible for the high concentration of TDS. (Haritash et al). The total hardness in the groundwater is a major problem for water quality deterioration. The presence of the ions such as calcium and magnesium in the water causes hardness which makes it bitter in taste and unsuitable for drinking (Jain et al) 2005 In all the seasons, most of the water samples are found to be hard that is the concentration is more than 600 ppm, which is specified by the ISI that is the international standard for water quality. The hardness of the water leads to the incidence of urolithiasis. According to one of the reports by WHO in 1989 it causes prenatal mortality and some types of cancers also, the study was done by (Agrawal et al) 1996.

Cardiovascular disorders are also caused because of that, as the water in the study areas was found to have more concentration of sodium. The permitted concentration of Sodium is 200 ppm and there is no further limit for sodium because sodium is present in sources other than water. The sodium concentration in water leads to hypertension while most of the samples show less manganese concentration which is used for the medicines to reduce blood pressure. So as the sodium concentration is more, it aggravates the conditions of hypertension. In 2015, the sodium average concentration was 400.47 ppm; in 2016 it increased to 541.30 ppm while in 2020 further increases to 707.77 ppm. From 2015 to 2016 it shows a 26% increase while from 2016 to 2020 the increase in the concentration is about 43.41%. Potassium concentration in 2015 was 17.77 ppm on average, which decreased to 8.25 ppm in 2016 and remains consistent in 2020 that is 8.06 ppm on average.

Table 3 % of Groundwater samples suitability according to SAWQG and WHO standards

Parameter	SAWQG								WHO							
	DL	MAL	No. of Samples % under DL			No. of Samples % exceeding MAL			HDL	MAL	No. of Samples % under DL			No.of Samples % exceeding MAL		
			2015	2016	2020	2015	2016	2020			2015	2016	2020	2015	2016	2020
pH	6	9	0	0	0	0	0	0	6.5	8.5	0	0	6.6	5.27	99.4	0
EC	700	1500	0	0	20	15.78	25	80								
TDS	450	1000	0	0	20	94.73	6.25	80	500	1000	0	0	20	94.73	99.37	80
TH	50	100	0	0	0	94.73	93.75	53	100	500	5.7	6.25	0	42.1	62.5	46.6
Na	100	200	5.7	0	6.6	89.21	93.75	86.6		200				84.21	93	86.6
K		50				5.7	0	0		12				31.57	25	13.3
Ca	32	80	0	0	0	89.47	93	100	75	200	10.52	6.25		57.89	68.75	73.3
Mg	32	100	5.26	6.25	0	84.21	93.75	73.3	50	150	10.52	6.25		73.68	75	33.3
SO_4^{2-}	100	600	57.89	43.75	26.6	0	0	0	200	600	89.47	81.25	75	0	0	0

Table -3 shows most of the samples are not fit for consumption but can be used for irrigation. The permitted limit of TDS in Groundwater is 2000 ppm (according to WHO norms for the drinking water) the desired limit is 100. In 2015, 47%, in 2016, 25%, and 2020, 64% of samples were beyond the permitted limit of the TDS. In the post-monsoon season, the table shows the groundwater quality based on the TDS desired limit for total hardness is 300 ppm, while in the absence of any other source, the permitted limit is 600 ppm. In 2015, only 10% of samples were below the desired limit, and maximum samples were in 2015 15%, samples were beyond the permitted limit and only 10% were under the desired limit, while in 2016 12.5%, samples were under the desired limit and 37.5% samples were found to be above the permitted limit the absence of any other resource and in 2020 20% samples Davis and De Wiest were beyond the permitted limit while 13.3% samples were under the desired limit.

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Table - 4 Water classification Based on TDS ()

TDS(mg/L)	Classification	No of Samples %		
		2015	2016	2020
<500	Desirable for drinking	0	0	20
500 – 1000	Permissible for drinking	10.52	25	0
1000-3000	useful for irrigation	47.36	75	80
> 3000	Unfit for drinking and Irrigation	26.31	0	0

Water classification based on TDS given by (Davis et al). In 2015 and 2016, no sample was under the desirable limit that is under 500 ppm, but in 2020, 20% of the samples reached the desirable limit which means, its dilution in the 5 years. The 500 to 1000 ppm range that is permissible for drinking reach 0% in 2020 did while it increased from 15 to 16. In 2015 26%, samples were having more than 3000 ppm TDs but in 2016 and20 20, it is found to be 0%**.**

Table -5 Water Classification based on TDS (*Freez* RA*; et al*)

TDS(mg/L	Classification	No of Samples %		
		2015	2016	2020
<1000	Fresh Water	10.52	20	20
1000 – 10000	Brackish Water	89.47	80	80
10000-100000	Saline Water	0	0	0
> 100000	Brine type Water	0	0	0

Table-5 shows the groundwater quality based on the TDS, that is zero to 1000 ppm is freshwater, 1000 to 10,000 to the brackish water, and 10,000 to one lakh is salty water more than that is a brine (Freez R.A; et al). There is 10.52% in 2015 less than 1000 ppm which remained consistent in 2016 and 2020 as 20% of the samples were found in this range Almost about 80 to 90% of samples were found in the range of brackish water, while the saline water and the brine type water are found to be 0%

A. Groundwater Suitability for Irrigation

$$\text{Na\%} = \frac{(\boldsymbol{Na^+} + \boldsymbol{K^+}) \text{ x } 100}{(\boldsymbol{Ca^{2+}} + \boldsymbol{Mg^{2+}} + \boldsymbol{Na^+} + \boldsymbol{K^+})}$$

Table -6 Ground Water Suitability for Irrigation based on Na%

Na%	Suitability for Irrigation	Sample % 2015	Sample % 2016	Sample % 2020
< 20	Excellent	5.26	6.25	6.66
20-40	Good	31.57	43.75	13.33
40-60	Permissible	52.63	31.25	40
60-80	Doubtful	10.52	18.75	33.33
>80	unsuitable	0	0	6.66

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Analysing data for the irrigation suitability of groundwater based on the sodium percentage shows that the sodium percentage which is less than 20 ppm is excellent for irrigation. In 2015, 5.26% of samples were in excellent range while in 2016 it raised to 6.26 and again it increased to 6.66 % in 2020. From 20 to 40 ppm range of sodium % considered good, 31.57% samples were in this range in 2015 decreased to 2,031.25 in 2016, and again increased to 40% in 2020. Groundwater suitability for irrigation which is based on the sodium percentage, the table shows the sodium percentage less than 20 is considered as excellent for the irrigation in 2015 5% of 5.26% of the sample shows the excellent suitability while in 2016 it raised to 6.25% and further increase to 6.66% in 2020. The samples found to be good for irrigation that is the ranges range from 20 to 40%, in 2015, it was 31.57 which increased to 43.75 and then again decreased to 13.33 in 2020. That means, it is not consistently remained the same. For the range of 40 to 60 % sodium which is permissible, in 2015 were 52.63 and in 2016, it decreased to 31.25% of samples and again further increased to 40% in 2020, under the permissible limits. While the doubtful and unsuitable ranges show an increase in Na%. In 2015 and 2016. there was zero unsuitability in 2015 and 2016 increased to 6.66% in 2020, this concludes that the concentration of Sodium is increasing salinity of water making it unsuitable for irrigation in long run.

Table -7 Ground Water Suitability for Irrigation based on EC

EC	Salinity Class	Quality	Sample % 2015	Sample % 2016	Sample % 2020
< 250	C1	Excellent or Low	0	0	0
250-750	C2	Good or Medium	0	0	14.28
750-2250	C3	Permissible or High	31.57	43.75	0
2250-5000	C4	Unsuitable	68.42	56.25	85.71

If we consider the suitability for irrigation based on electrical conductivity which is categorized under the four categories less than 250- excellent, 250 to 750 is considered as a medium, 750 to 2250 is permissible or high and beyond that it is unsuitable. The trend is again the same that is excellent is 0% in all the three-season while the good or medium person level of EC increased from 00 in 2015 16 to 14.28% in 2020. The permissible limit shows increased from 2015 to 16. And then suddenly it shows 0% in 2020. The unsuitability of the water samples rose to 85.71% in 2020, which was 68.42% and 56.245% in 2015 and 16 respectively. (Table -7)

B. Ground Water Suitability for Irrigation based on SAR

$$\textbf{SAR} = \boldsymbol{Na^{+}}/\sqrt{(\boldsymbol{Ca^{2+}} + \boldsymbol{Mg^{2+}})}\ /2$$

Table – 8

Range	Quality	Irrigation Suitability	Sample % 2015	Sample % 2016	Sample % 2020
< 10	S1	Low	10.52	12.5	13.33
10 to 18	S2	Medium	52.63	25	13.33
18-26	S3	High	15.78	18.75	20
>26	S4	Very High	21.05	43.75	53.33

Table 8 shows the suitability based on the SAR, the range less than 10 is considered as low suitability. Samples in 2015 were 10.52% while it increased to 12.5% in 2016 and 2020 is 13.33% of samples. The range from 10 to 18 SAR is considered as a medium, 52% of samples are in this class in 2015 which shows a regular decrease from 2016 to 2020. The high range of irrigations suitability that is 18 to 26 was showing a consistent increase from 2015, 2016 to 2020. And the very high is again showing the consistent increase and reaches 5 3.33% samples in 2020 which was 21.05 and 43.75% in 2015 and 2016.

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C. *Ground Water Suitability for Irrigation based on Kellies Ratio*

$$KR = Na^{+} / (Ca^{2+} + Mg^{2+})$$

Kelly's index (KI) is an indicator to assess irrigation water suitability and it is free from the effect of the K^{+} parameter, which purely depends on Ca^{2+}, Mg^{2+} and Na^{+}.(Kishan S. R. et al)

Table -9

Range	Irrigation Suitability	Sample % 2015	Sample % 2016	Sample % 2020
< 1	Safe	73.68	68.75	46.66
>1	Unsafe	26.31	31.25	53.33

According to the Kellies ratio, the suitability for the irrigation if the ratio is less than one it is safe, and if it is more than one it is unsafe. In 2015 the safe sample percentage was 73.68% in 2016 it decreases to 68.75% while in 2020 it was 46.46%. The unsafe samples % was 26.31%, 31.25% and 53.33% in 2015, 2016 and 2020 respectively. (Table-9)

D. *Ground Water Suitability for Irrigation based on MH%*

$$MH\% = Mg^{2+} x100/ Ca^{2+} + Mg^{2+}$$

Table -10

Range	Irrigation Suitability	Sample % 2015	Sample % 2016	Sample % 2020
< 50	Suitable	57.89	56.25	100
>50	Unsuitable	42.1	43.75	0

For the groundwater suitability based on MH% (Magnesium percentage), less than 50 is considered suitable and more than 50 is considered unsuitable. The samples in 2015 were 57.89 while in 2016 it decreased to 56.25%. 100% of the samples were safe to be used for irrigation in 2020. In 2015, the unsuitable samples were 42.1% and in 2016, it is 43.7% which is 0% in 2020. (Table-100

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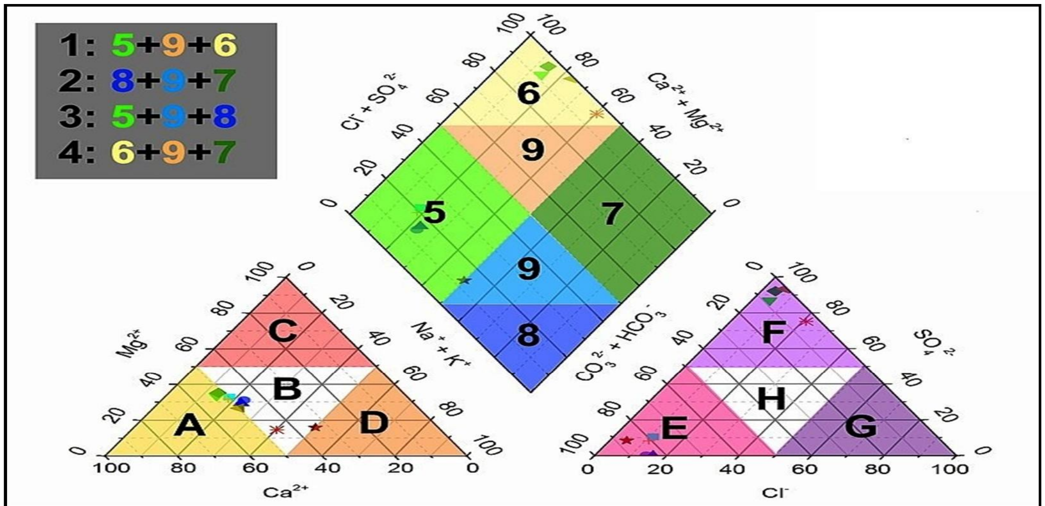
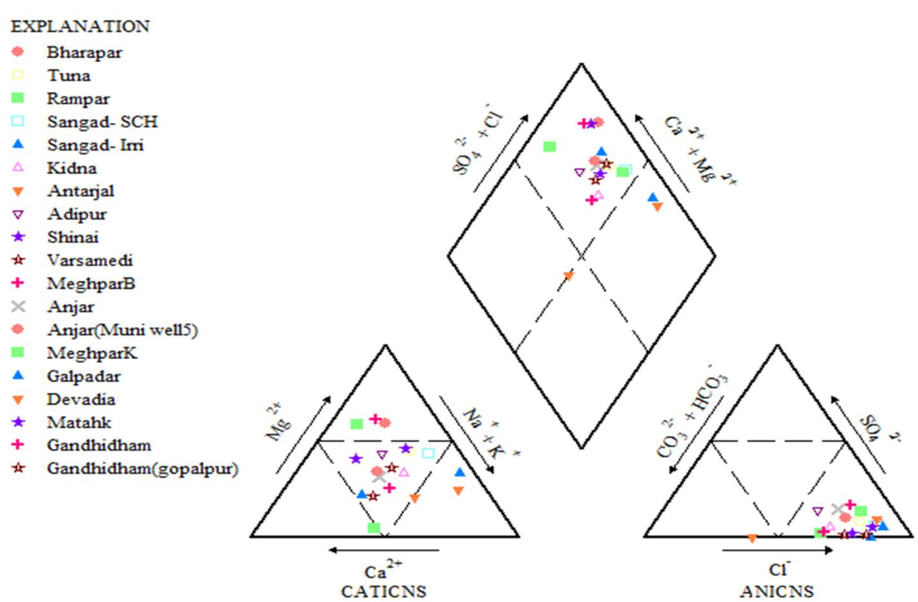
E. Interpretation through Piper Diagrams



The Piper diagram can be separated in hydrochemical facies. Legend: A: Calcium type; B: No dominant type; C: Magnesium type; D: Sodium and potassium type; E: Bicarbonate type; F: Sulphate type; G: Chloride type; 1: Alkaline earths exceed alkalies; 2: Alkalies exceed alkaline earths; 3: Weak acids exceed strong acids; 4: Strong acids exceed weak acids; 5: Magnesium bicarbonate type; 6: Calcium chloride type; 7: Sodium chloride type; 8: Sodium bicarbonate type; 9: Mixed type

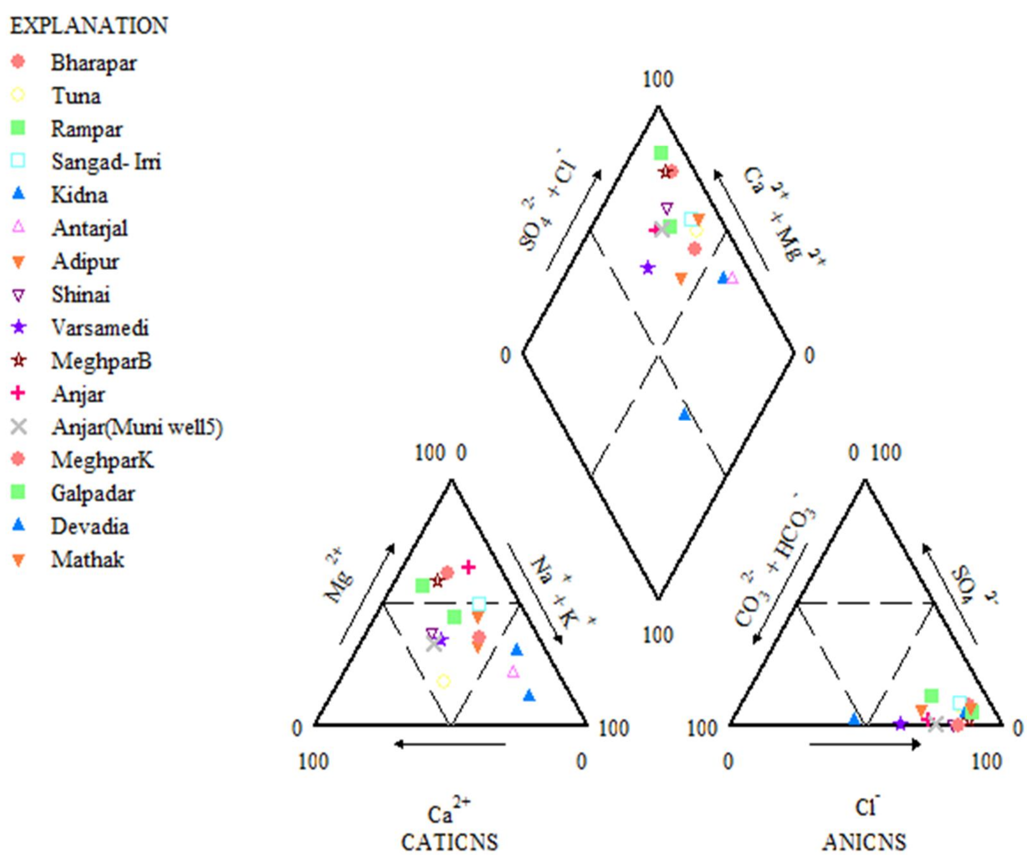
F. Piper Diagram 2015



International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

Interpreting analysis data for the year 2015 it was observed that most of the water samples belonged to or mixed Ca^{2+}–Mg^{2+}–Cl^{-} type further it was observed that alkaline earth (Ca + Mg) exceeds the alkaline (Na + K) and strong acid (Cl^{-} and SO_4^{2-}) exceed weak acids(HCO^{3-} and CO_3^{2-}) according to the classification of meteoric genesis groundwater is of two types deep meteoric water percolation type met gen 1 based on the values of base exchange values 1 represent NaCl type water based on the classification criteria of base exchange and meteoric genesis the groundwater with shallow meteoric percolation was found to be NaCl type and water with deep meteoric percolation was Na^{+} - SO_4^{2-} type

G. Piper Diagram 2016



Based on normalized percentages of different anions and cations, a piper trilinear diagram was plotted to arrive at the hydro-chemical faces of groundwater. It was observed that most of the water samples belonged to Na–Cl or mixed Ca–Mg–Cl type. Further, it was observed that alkaline earth (Ca + Mg) exceeds the alkaline (Na + K); and strong acids (Cl^{-} and SO_4^{2-}) exceed weak acids (HCO^{3-} and CO_3^{2-}). According to the classification of meteoric genesis, groundwater is of two types—deep meteoric water percolation type (Met. gen. < 1) and shallow meteoric water percolation type (Met. gen. > 1). Based on the values of base exchange, values < 1 represent sodium sulfate type water, and values > 1 represent Na–Cl type water. Based on the classification criteria of base exchange and meteoric genesis, the groundwater with shallow meteoric percolation was found to be Na–Cl type, and water with deep meteoric percolation was Na+ SO4 $^{2-}$ type.

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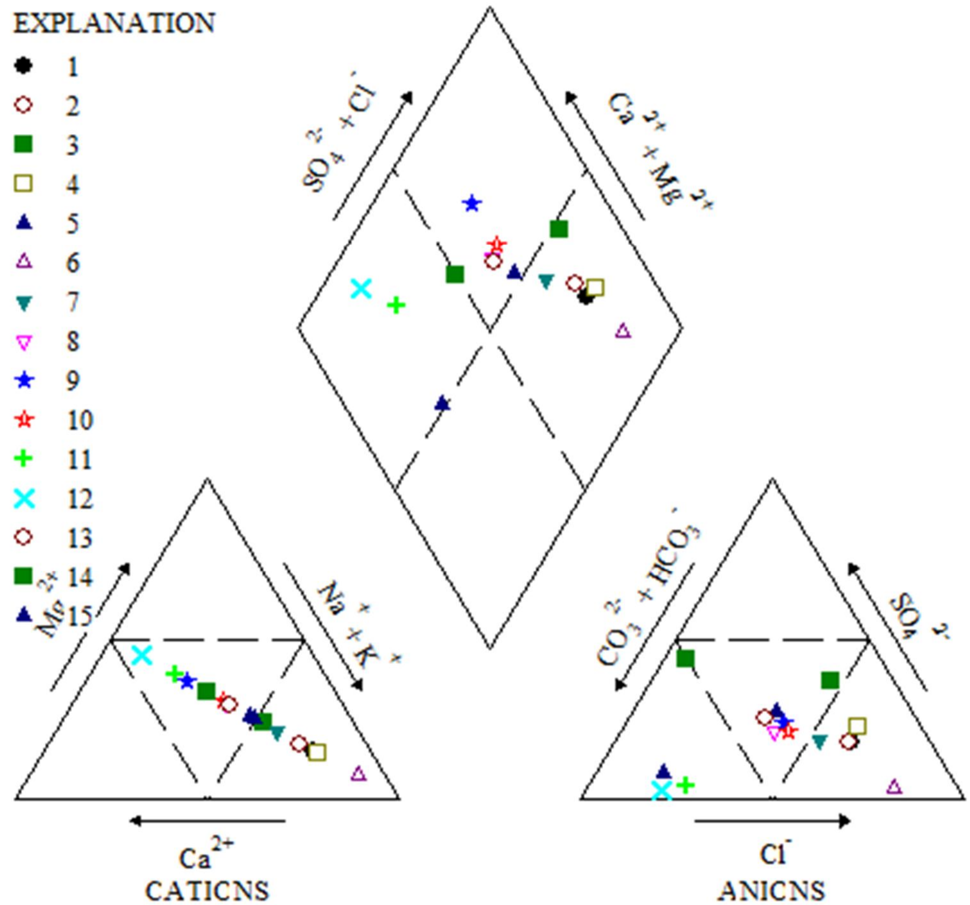
International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

H. Piper Diagram 2020



Based on normalized percentages of different anions and cations, a piper trilinear diagram was plotted to arrive at the hydro-chemical faces of groundwater. It was observed that most of the water samples belonged to Na–Cl or mixed Ca–Mg–Cl type but one or two samples are falling under magnesium bicarbonate $CaHCO_3$ type. Further, it was observed that alkaline earth (Ca + Mg) exceeds the alkaline (Na + K); and strong acids (Cl^- and SO_4^{2-}) exceed weak acids (HCO^{3-} and CO_3^{2-}). According to the classification of meteoric genesis, groundwater is of two types—deep meteoric water percolation type (Met. gen. < 1) and shallow meteoric water percolation type (Met. gen. > 1). Based on the values of Base Exchange, values < 1 represent sodium sulfate type water, and values > 1 represent Na–Cl type water. Based on the classification criteria of Base Exchange and meteoric genesis, the groundwater with shallow meteoric percolation was found to be Na–Cl type and water with deep meteoric percolation was Na^+ - $SO4^{2-}$ type.

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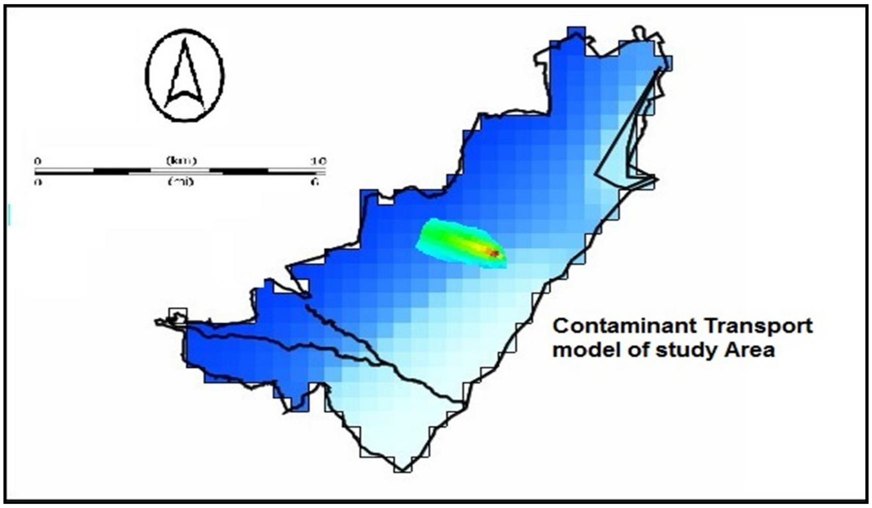
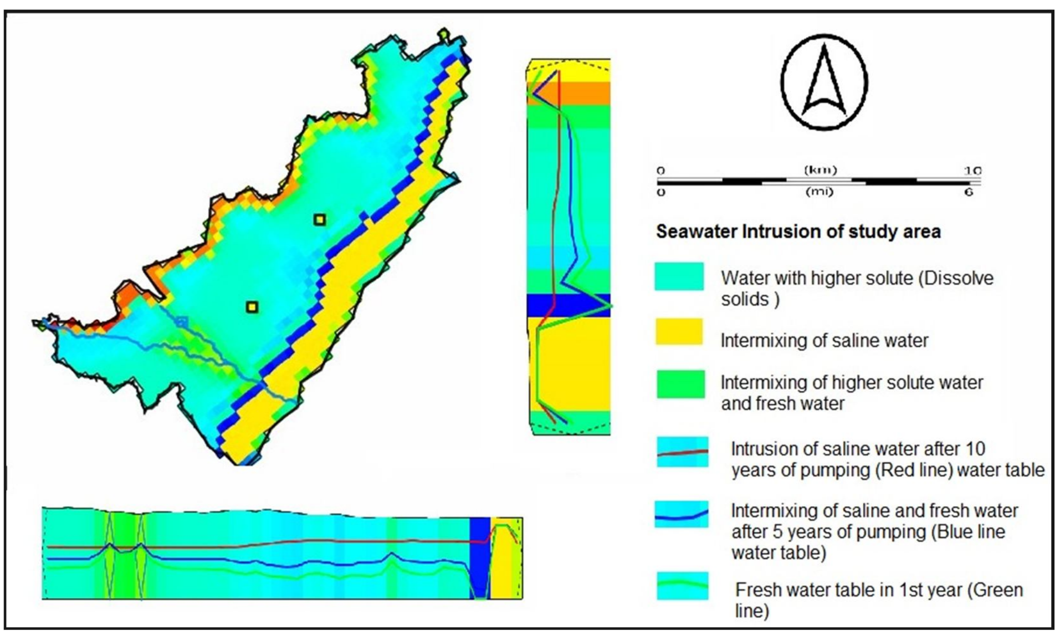
Study of contaminant Transport in Study area



A steady-state groundwater flow model of coastal area aquifer was developed for the Gandhidham area of Gujarat by MODFLOW-2005. In this steady-state flow model for the northern, southern, and western edges. The northern edge is a no-flow boundary, as the drainage network indicates a groundwater divide. The southern boundary is treated as a general head boundary due to the continuation of the study area aquifers beyond the modeled domain here and the absence of a groundwater divide. The western edge of the steady-state groundwater flow model is also considered a general head boundary to account for cross-boundary flow.

The red colour point is well and where the contamination is higher than with dispersion the colour is getting changing from orange, yellow, and green. The concentration of sulfate is taken 202 mg/l from a location of 1 with latitude 23.02537^0 N and longitude 70.10103^0 E.

Due to pressure from the sea area and due to higher extraction rate from the well on inner land places the groundwater is moving towards the north-west direction. The concentration of contaminates of sulphates can be seen moving in the direction of groundwater movement. The map shows the dispersion of sulfates with time. The red zone is the point where the concentration of sulfates is higher and with distance, its spreading and colour is also changing. The green colour represents contamination but the concentration is less or spreading mixing with water .yellow colour represents the contamination concentration at moderate. Red and orange colour where the concentration is high. The light blue colour is that water where the concentration of saltwater is higher and the dark blue colour water represents the freshwater.



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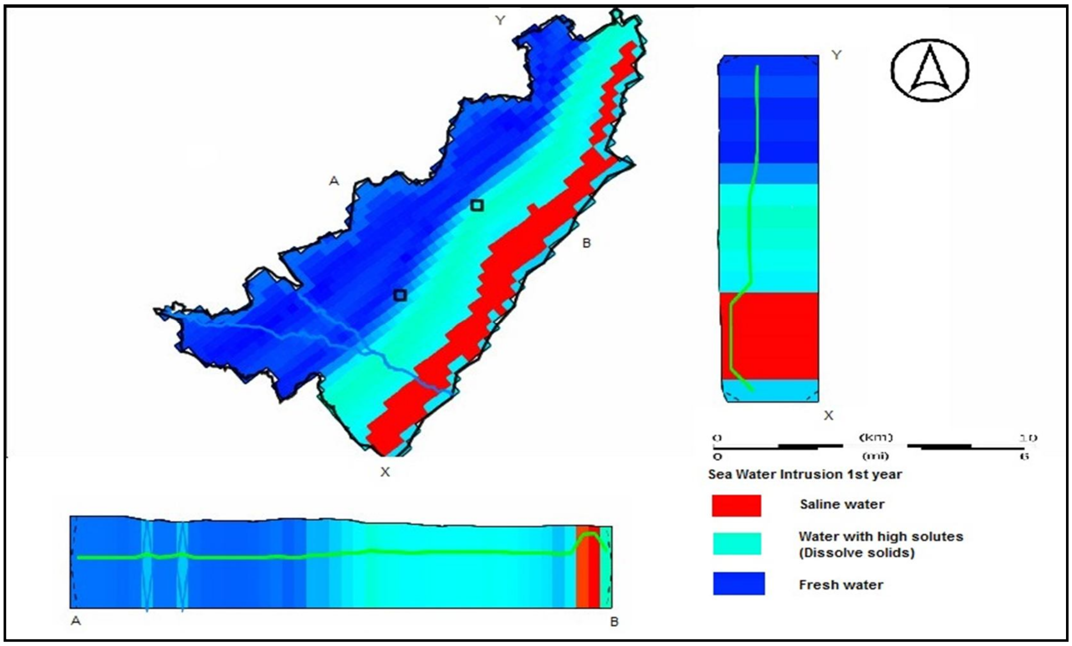
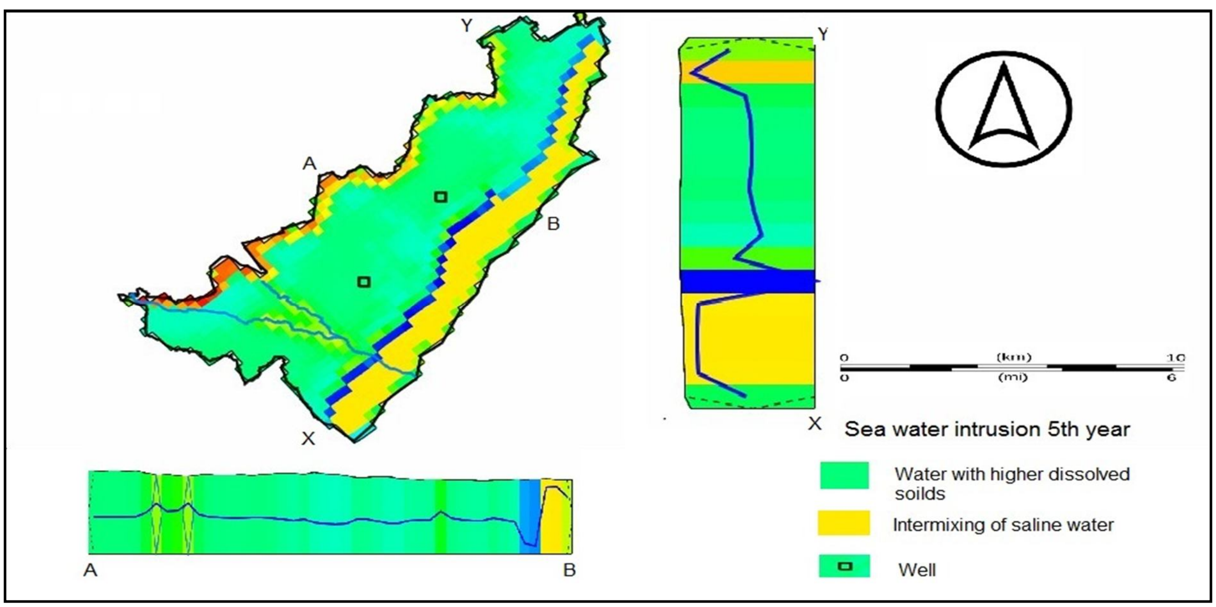
International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue IX Sep 2021- Available at www.ijraset.com

Seawater incursion and weathering of salt deposits are the prime factors of the presence of Cl^- in sub-surface water. The higher amount of SO_4^{2-} in sub-surface water might be derived from the leaching of domestic wastes and marine sources. The presence of a high amount of SO_4^{2-} in the coastal part of the study area may be from the marine sources (Krishna Kumar et al. 2014). Among all the ions, the concentrations of Mg^{2+} and Cl^- surpass the permissible values and Na^+ and Ca^{2+} succeed them. This is an indication that the saline water ingression is a principal mechanism of higher salinity along with the involvement of anthropogenic activities like salt panning as suggested by Singaraja et al. (2014). Nitrate and phosphate ions are within the permissible limits



In this section, the scenario is set up in a way where the availability of freshwater can be seen whereas the extraction from the well was normal where no intrusion of saline or intermixing of saline water can be seen. The green line in AB section represents the water table.



In this section, simulation has been done to predict the future scenario of the study area **after 5 years** and it shows the water intermixing has been started with saline water because of extraction from a well and higher presence of solute in the water which is coming out from the system because of higher density of the saline water.

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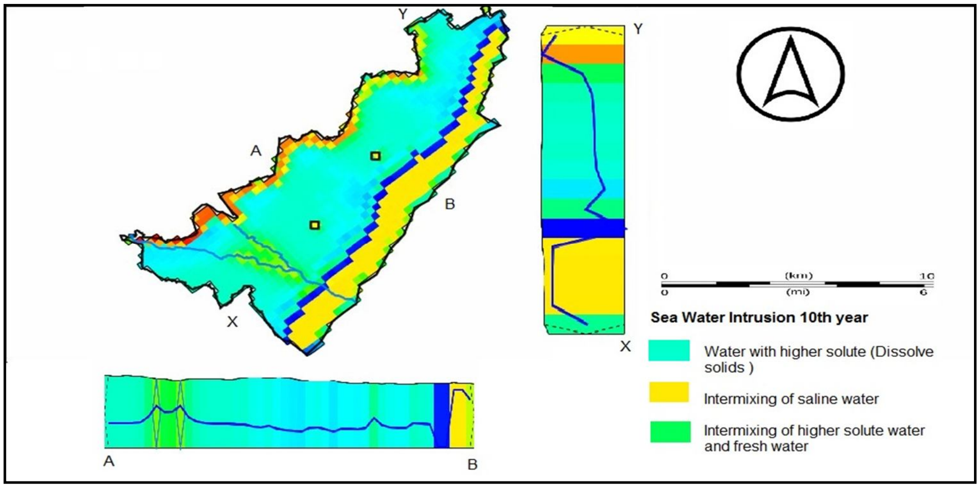

In this section, simulation has been done to predict the future scenario of the study area after 10 years and it shows the water intermixing is at peak with saline water because of higher extraction from a well and the colour composition is changed in comparison from 1st year and a study area has started yielding saline water.

V. CONCLUSION

The groundwater of the study zone is generally alkaline in nature. and most of the samples are not fit for the drinking purpose but 60- 80 % of samples can be used for irrigation, but because of the higher salinity rate and evaporation factors, it may lead to the increase in salinity of the soil. Groundwater studies are done in the Gandhidham area of the Kachchh region of Gujarat, India. The suitability of the groundwater for the drinking and irrigation activities was assessed and the geochemical processes are found to be controlled or identified. The groundwater chemical composition is mainly predominantly controlled by the evaporation and the ion exchange processes. Seawater intrusion and weathering of the salt deposits are the prime factors for the presence of chloride ions in subsurface water. A higher amount of sulfate ions in the subsurface leaching is because of domestic waste and marine sources. In the study area near the coastal part among all the ions, the concentration of magnesium and chloride surpasses the permissible values, and sodium and calcium succeed them. This is indicating that the sale in water integration is a principal mechanism of higher salinity along with the involvement of anthropogenic activities like the salt pans. The study of the groundwater intrusion that is a saline water intrusion has been predicted by the plume diagram shows a future scenario after five years and even the 10 years. The water intermixing has been started with the saline water because of the excessive extraction of the well. The higher presence of the solids in the water is coming out from the system because of the higher density of the saline water.

VI. ACKNOWLEDGMENT

Authors express gratitude to DST (Department of Science and Technology, Ministry of Science and Technology for providing funds for the research in 2020. The author further extends gratitude to IFFCO, Kandla for providing laboratory facilities (2015, 2016) and to the Chemistry Department, KSKV Kachchh University for the analysis in 2020, and to the Vice-Chancellor of KSKV Kachchh University motivating for the research work.

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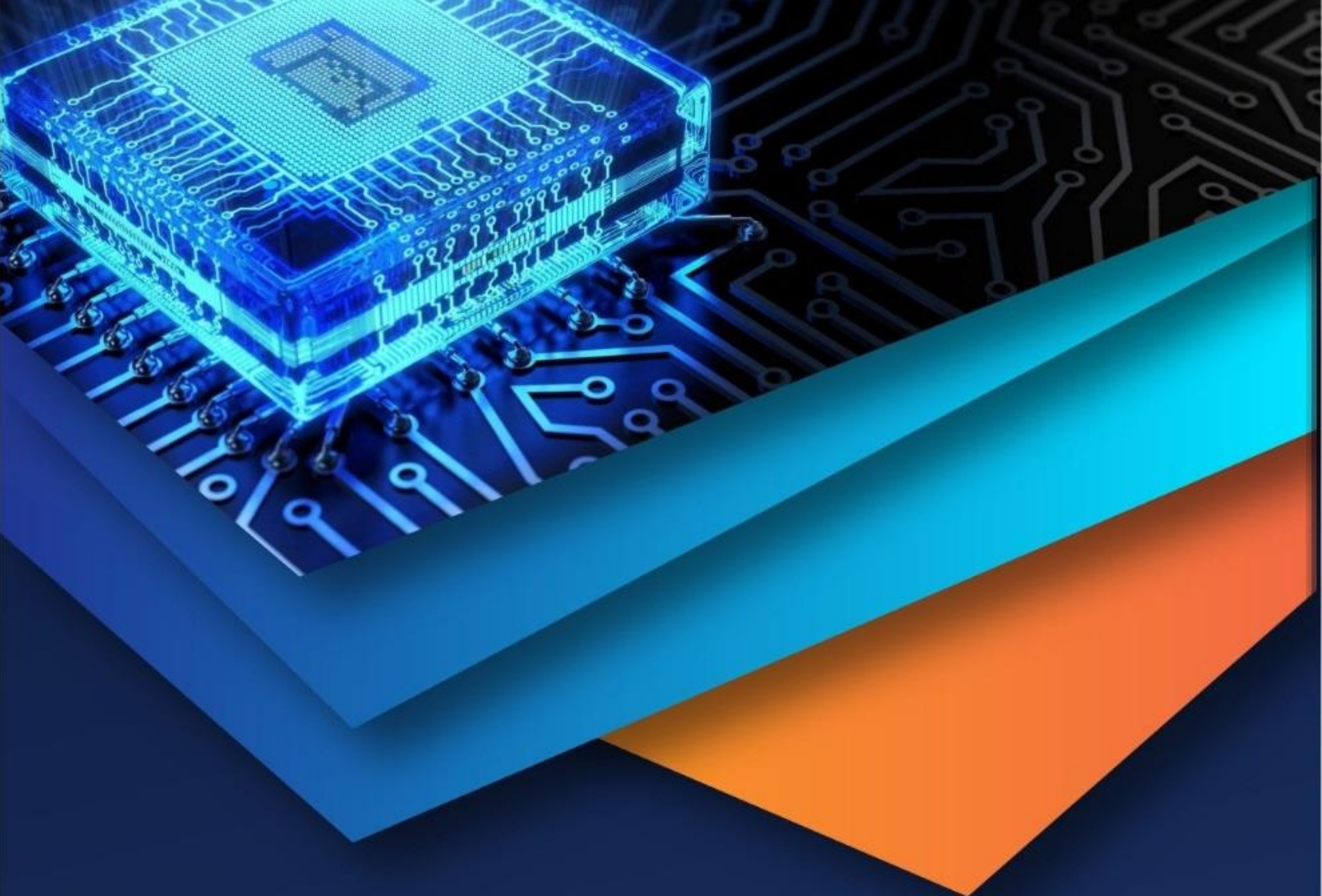

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