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Hydrogeochemical investigation of Groundwater Quality in the coastal stretch from Bhavnagar to Una

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Abstract: The minerals in the geological system tend to dissolve due to water's great solvent properties. Given that the chemistry of groundwater can be directly correlated with the source of water, the local climate, and the region's geology, hydrogeochemical analysis is crucial. In the context of contemporary water management, groundwater quantity and quality are equally significant issues. The coastal region from Bhavnagar to Una is subjected to a hydrogeochemical investigation of the groundwater in the current study. pH, Ca, Mg, Na, K, CO3, HCO3, Cl, SO4, EC, TDS, TH, and F have been chosen as the hydrogeochemical parameters for this analysis. From the Geohydrologist Groundwater Investigation Unit-3 in Rajkot, the hydrogeochemical parameters were gathered. The collected data has been examined using GW_Chart and QGIS version 3.28.1 water quality modeling software. For the purpose of working with hydrogeochemical facies, the primary hydrogeochemical parameter data were displayed on Piper's diagram. The Weighted Arithmetic Water Quality Index (WAWQI) approach proposed by Brown et. al., 1972 was used to construct the WQI using MS-Excel software. QGIS software has been used to do spatial inverse distance weighted (IDW) interpolation of WQI for well points. The hydrogeochemical study's findings indicate that the water quality is suitable for drinking, farming, and industrial uses. Also, it will be feasible to comprehend how anthropogenic influences such as salinity intrusion, seawater intrusion, and rock-water interaction affect the quality of groundwater.

Index Terms **– Hydrogeochemical parameters, WQI, WAWQI, GW Chart, QGIS, Piper diagram.**

I. INTRODUCTION:

In the context of contemporary water management, both the amount and quality of groundwater are crucial elements. Pollution from a variety of sources is the key factor affecting water quality. Sectoral techniques split the total accessible water, leading to scarcity. Seawater intrusion is the main cause of groundwater pollution in coastal areas. A serious issue that impacts the potability of water is overexploitation. Water chemistry is governed by hydrogeochemical processes. Groundwater appears to be the only source of freshwater for household, agricultural, and industrial needs in many coastal towns and cities. The underground water that is present in the saturated zone below the earth's surface, which has a variable thickness and depth, is known as groundwater.

There is a possibility of contamination with harmful compounds because many substances can dissolve in water and others might float there. They include petroleum, hydrocarbons (oil), insecticides, minerals, and disease-producing (pathogenic) microbes. Due to the fact that toxins must travel through the ground in order to reach the water, groundwater is typically less likely to get contaminated than the surface waterways like streams, rivers, and lakes. Nonetheless, contamination is still possible, particularly if the rocks and soil above have gaps that allow harmful substances to move more freely. Analysis of the chemical, physical, and biological nature are typically necessary to determine the quality features of groundwater.

The purpose of this research is to determine the Water Quality Index and draw Hill-Piper Trilinear diagrams to comprehend the hydrogeochemical aspects of the study area. The present study will be done for the hydrogeochemical analysis and calculation of hydrogeochemical parameters in the coastal region from Bhavnagar to Una. The Water Quality Index will be calculated using the Weighted Arithmetic Index Method described by Brown et. al., 1972 utilizing MS-Excel software. To determine the primary hydrogeochemical input parameters and assess the groundwater type of the study area.

II. STUDY AREA:

In the present paper, study area is taken as the coastline stretch from Bhavnagar to Una, which is a part of the Saurashtra region. Bhavnagar, also known as Kathiawar, is a seashore city on the eastern coast of Saurashtra that is situated at 21.76°N latitude and 72.15°E longitude. It stands 24 meters tall on average (78 feet). The total area of the Bhavnagar district is 108.27km2. Una may be found at 21.76°N latitude and 72.15°E longitude on the bank of the Machchundri River in the Gir Somnath region of Saurashtra. It is typically 14 meters above sea level 946 feet). Kodinar is situated to the west of Una, and Diu to the south of it. Like to the rest of Gujarat, Bhavnagar gets warm winters from November to February, hot, dry summers from March to mid-June, and the wet monsoon season from mid-June to October. During the monsoon season, Bhavnagar receives 655mm, or 26 inches, of rain. Bhavnagar's average yearly temperature is 27.7°C (81.8°F). Una has a tropical, wet, and dry climate. The district's average annual temperature is 28.79°C (83.82°F), which is 2.82% warmer than the country's average. Una typically experiences precipitation of roughly 25.68 millimeters (1.01 inches).

The Bhavnagar district has a lot of medium-black soil. Alluvial soil may be seen along the Shetrunji River, which traverses parts of the Gariyadhar and Palitana talukas. The saline soil in this area makes it less productive. The Gariyadhar taluka contains some locations with alkaline soil. Both productive and unproductive soils make up their composition. In comparison to the extraordinarily fruitful soils in Kodinar taluka, the soils in Rajula and Jafrabad talukas are saltier and less productive. The bulk of the villages in the Bhesan, Una, Kodinar, Talala, Malia, and Visavadar talukas of Junagadh have medium black soil, according to the Central Ground Water Board Report 2014.

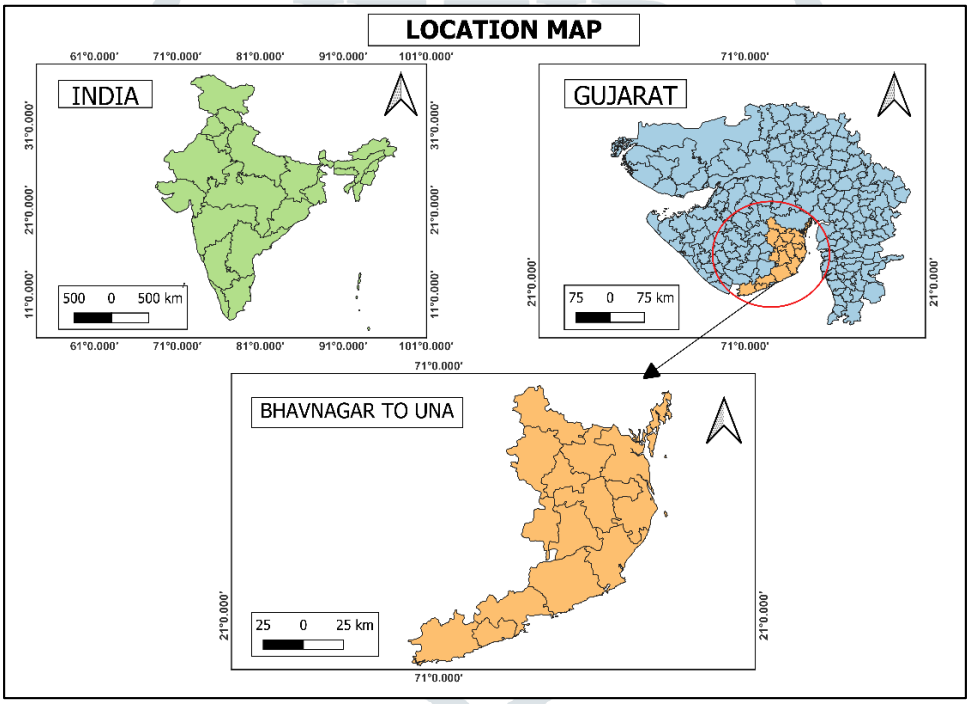

Figure 1.1 Study Area Map

III. DATA COLLECTION:

For the present study, data were gathered from the Geo-hydrologist, Groundwater Investigation Unit-3, for the period of 2017 to 2021. For this study, groundwater quality data was collected from 40 well points near and far from the coastal stretch of Bhavnagar to Una. These data include latitude, longitude, geology, and major cations and anions like sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), sulphate (SO4), carbonate (CO3), and bicarbonate (HCO3). Total Dissolved Solids (TDS), Total Hardness (TH), fluoride (F), pH, and electrical conductivity (EC). Data were gathered for the premonsoon and postmonsoon seasons over a five-year period for the present study. According to the data, every well that was found in the study region was assumed to be a dug well.

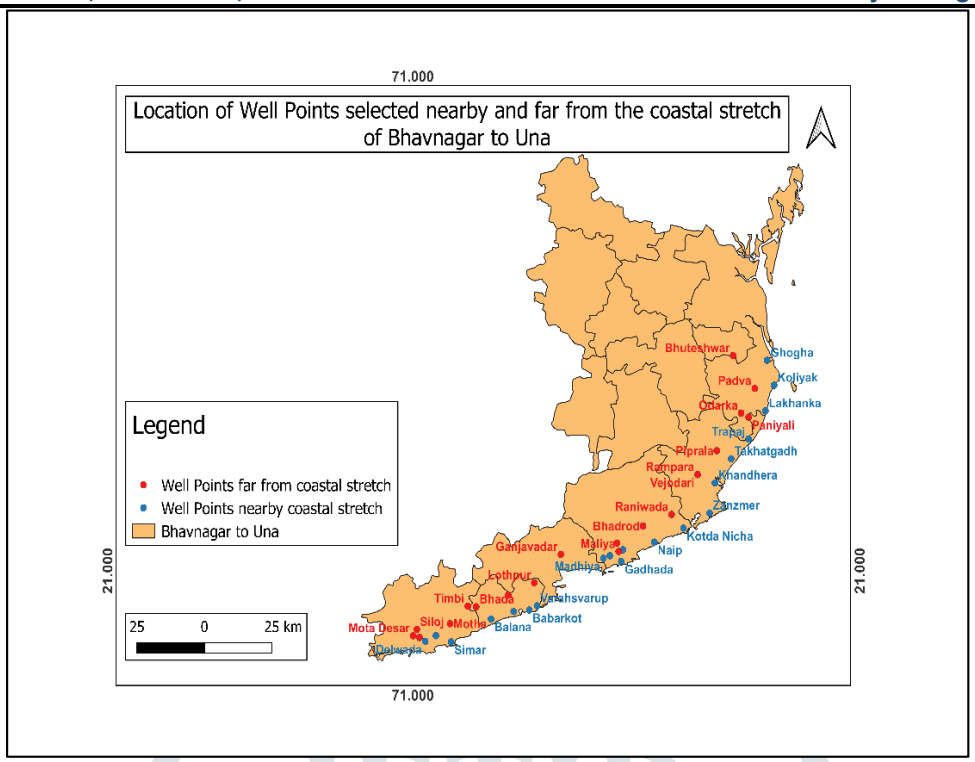

Figure 1.2 Location of Well Points selected nearby and far from the coastal stretch of Bhavnagar to Una.

IV. RESEARCH METHODOLOGY

A. Weighted Arithmetic Index Method calculation with MS-Excel software (by Brown et. al., 1972).

Step 1: Using the formula, determine the unit weight (Wn0 factors for each parameter

$$Wn = \frac{K}{Sn}$$

Where,

$$K = \frac{1}{1/S1 + 1/S2 + 1/S3 + \ldots + 1/Sn} = \frac{1}{\sum \frac{1}{Sn}}$$

Sn = Standard desirable value of the nth parameters

Wn = 1(unity) when all the chosen parameters unit weight factors are added together.

Step 2: Using the formula, determine the Sub-Index (Qn) value

$$Qn = \frac{[(Vn - Vo)] * 100}{[(Sn - So)]}$$

Where,

Vn = Mean concentration of nth parameters.

Sn = Standard desirable value of the nth parameters.

Vo = Actual values of the parameters in pure water (generally Vo = 0, for most parameters except for pH)

$$QpH = \frac{[(VpH - 7)] * 100}{[(8.5 - 7)]}$$

Step 3: Adding Step 1 & Step2, WQI is determined as follows

$$\text{Overall WQI} = \frac{\sum WnQn}{\sum Wn}$$

B. Using QGIS 3.28.1 software version, perform Spatial IDW Interpolation

Step 1: Preparing a Shapefile.

As QGIS software is public domain, it is necessary to be familiar with it in order to readily get shape files for any type of research topic. Shape files can be acquired from their official websites because QGIS is free software. You must first browse DIVA GIS website and download a free shapefile in order to access the Indian spatial data. The next step is to launch QGIS, create a new project, then select Add Layer and Add Vector Layer. By right clicking on a vector layer that you've added to layer groups, you may use the

layer properties option to adjust the style, font, label, symbology, and other things. Click on OK, and your file will now be saved as an ESRI Shapefile with the CRS taken as (Project CRS: EPSG: 4326; WGS 84).

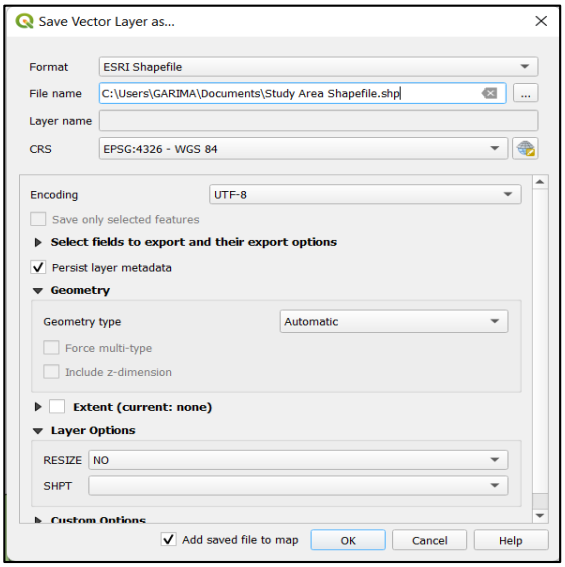

Figure 1.3 Save Vector Layer as Shapefile

Step 2: Creating an Inverse Distance Weighted (IDW) Interpolation File.

Go to Layer and select Add delimited text layer to create an Interpolated (IDW) Inverse Distance Weighted file. Save the text layer file with delimited in CSV (comma-separated values) format. Now navigate to the raster option in the QGIS software's menu bar and select the Grid (Inverse Distance to a Power) option under Analysis. Run the software after choosing the necessary ESRI Shapefile to be interpolated and the Water Quality Index (WQI) option in the advance parameters field option.

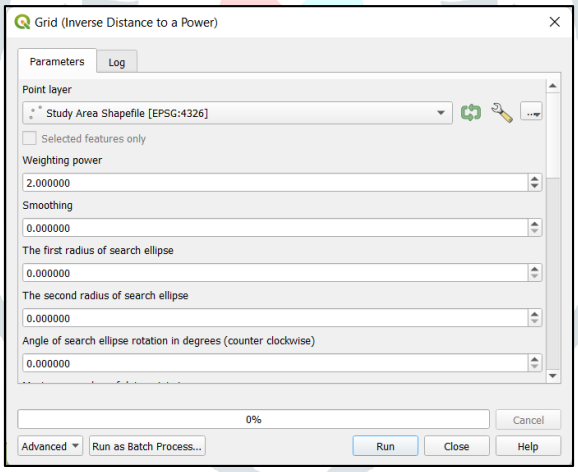

Figure 1.4 Creating an Inverse Distance Weighted (IDW) image using Grid (Inverse Distance to a Power)

Once more, select the Raster option from the menu bar of the QGIS software, and then select the Clip Raster by Mask Layer option under Extraction. Run the software after entering the necessary Mask Layer name in the Mask Layer field in [EPSG:4326] format.

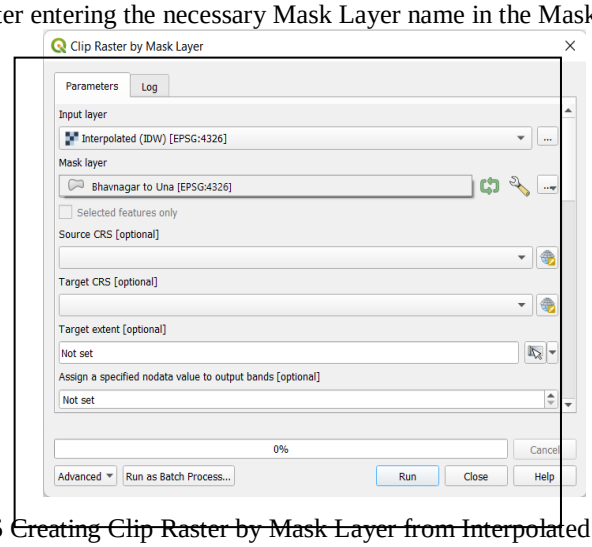

Figure 1.5 Creating Clip Raster by Mask Layer from Interpolated (IDW) image

C. Piper Diagram Data Analysis of Hydrogeochemical Facies

Arthur M. Piper originally suggested the use of a Piper diagram as a visual representation of water chemistry data in 1944. It can be utilized to comprehend where the dissolved salts in water come from. A Piper diagram illustrates the chemistry of a water sample or samples in a visual way. The cations and anions are shown on separate ternary graphs. The apex cations of the cation plot are sodium, potassium, calcium, and magnesium. The hydrogen carbonate anions, sulphate, chloride, and carbonate anions are located at the peak of the anion plot.

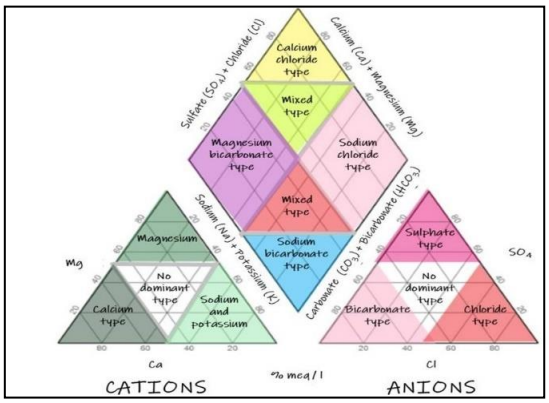

Figure 1.6 Piper Trilinear Diagram

The water samples shown on the Piper diagram can be classified using hydrogeochemical facies. The cation and anion triangles can be separated into regions based on the dominant cation(s) or anion(s), and their combination results in the diamond-shaped portion of the diagram.

D. Piper Diagram Plotting and Data Input with GW_Chart Software

The United States Geological Survey (USGS) developed GW Chart. For use in groundwater investigations, this application creates particular graphs. A Piper diagram, which is a graphical representation of the chemistry of a water sample, is used in the GW Chart Piper Graph to visualize chemical composition. Ratios, percentages, milliequivalents per liter, and milligrams per liter are all acceptable ways to provide data for the Piper diagram. Hydrogeochemical parameters such as calcium (Ca0, magnesium (Mg), Sodium (Na), Potassium (K), carbonate (CO30, bicarbonate (HCO3), chlorine (Cl), sulphate (SO4), and total dissolved salts (TDS) are the main input parameters for the GW Chart-Piper Graph.

V. Result and Discussion:

IDW Interpolation of WQI for Well Points nearby to the coastal stretch of Bhavnagar to Una for Premonsoon (May 2017) and Postmonsoon (Oct 2017)

The acceptable limit and the permissible limits of the Water Quality Index value are 25 and 100, respectively, according to the Weighted Arithmetic Water Quality Index method (WAWQI) by Brown et. al., 1972 water quality evaluation. It can be seen from the Premonsoon and Postmonsoon Inverse Distance Weighted (IDW) Interpolation of WQI for Well Points close to the coastal stretch of Bhavnagar to Una that the wells area represented for the Premonsoon period by light orange color has a lower concentration of WQI value, say less than 67.25, and dark maroon color has a greater concentration of WQI value, say greater than 142.84. Similarly, it is clear that wells area represented for the Postmonsoon period by white color has lower WQI value concentration, say less than 50.33, and dark blue has more concentration, say greater than 151.60. This concentration exceeds the permitted level.

According to the color-coded WQI value intervals in the figure, the areas with the highest concentrations of WQI values for Premonsoon are in Dudhala, Gadhada villages in the Mahuva taluka and Ghogha village in the Ghogha taluka of Bhavnagar, respectively. These areas have WQI values of around 168.73, 164.59, and 160.59. The Premonsoon WQI concentration is lowest in the villages of Bhadrod, Naip at Mahuva taluka in Bhavnagar and in Khan village at Una taluka in Gir-Somnath approximately 41.05, 53.96, and 46.56, respectively.

As indicated by the color-coded WQI value intervals in the figure, the Postmonsoon areas with the highest concentrations of WQI values are in Madhiya village in the Mahuva taluka, Ghogha village in the Ghogha taluka in Bhavnagar, as well as Balana village in the Jafrabad taluka of Amreli, where the respective values are 185.94, 171.37, and 147. The two villages of Trapaj and Takhatgadh, which are situated in Talaja taluka of Bhavnagar and Khan village in Una taluka of Gir-Somnath, respectively, had the lowest Postmonsoon WQI value concentration, measuring 16.55, 37.56, and 43.56.

IDW Interpolation of WQI for Well Points far from the coastal stretch of Bhavnagar to Una for Premonsoon (May 2017) and Postmonsoon (Oct 2017)

Premonsoon's highest WQI value concentration is in Bhadrod village at Mahuva taluka in Bhavnagar, Siloj at Una taluka in Gir-Somnath, and Ganjavadar village at Rajula taluka in Amreli, respectively, with values of 166.81, 159.54, and 144.35. This is as

indicated in the color legend for the WQI value intervals in the figure. Premonsoon WQI values are lowest in Rampara village in Talaja taluka, Paniyali village in Ghogha taluka in Bhavnagar, and Motha village in Una taluka in Gir-Somnath, with respective values of 29.74, 36.66, and 44.82.

According to the color legend for the WQI value intervals in the figure, the Postmonsoon areas with the highest concentration of WQI values are Bhuteshwar village in Bhavnagar and Bhada, Lothpur villages in Jafrabad taluka in Amreli, which are respectively about 170.44, 161.68, and 161.42. The villages of Piprala in Talaja taluka, Odarka in Ghogha taluka in Bhavnagar, and Nageshri in Jafrabad taluka in Amreli have the lowest Postmonsoon WQI value concentrations; these values are, respectively, 31.25, 44.8, and 44.54.

Tabel 1.1 Premonsoon and postmonsoon WQI values for Well Points nearby coastline stretch for the year 2017

Well No.	Village	Latitude	Longitude	Pre-monsoon WQI	Post-monsoon WQI
1	Ghogha	21.68	72.26	160.59	171.37
2	Koliyak	21.6	72.28	99.43	68.47
3	Lakhanka	21.51	72.25	94.05	68.31
4	Trapaj	21.42	72.19	56.64	16.55
5	Takhatgadh	21.36	72.13	80.19	37.56
6	Khandhera	21.28	72.07	160.06	44.94
7	Zanzmer	21.18	72.05	79.4	76.28
8	Kotda Nicha	21.13	71.96	113.41	81.72
9	Naip	21.09	71.85	53.96	83.98
10	Mahuva	21.06	71.74	41.05	90.35
11	Gadhada	21.03	71.74	164.59	116.14
12	Madhiya	21.04	71.67	162.73	185.94
13	Varahsvarup	20.88	71.44	69.01	100.84
14	Babarkot	20.87	71.41	78.66	96.82
15	Jafrabad	20.86	71.35	104.8	73.28
16	Balana	20.84	71.27	156.34	147.69
17	Dudhala	21.04	71.7	168.73	124.29
18	Simar	20.76	71.13	134.56	70.47
19	Khan	20.78	71.08	46.56	43.06
20	Delwada	20.77	71.04	161.67	140.31

Tabel 1.2 Premonsoon and postmonsoon WQI values for Well Points far from coastline stretch for the year 2017

Well No.	Village	Latitude	Longitude	Pre-monsoon WQI	Post-monsoon WQI
1	Bhuteshwar	21.69	72.14	138.44	170.44
2	Padva	21.59	72.21	131.01	79.83
3	Odarka	21.51	72.16	70.82	44.8
4	Paniyali	21.49	72.19	36.66	46.97
5	Piprala	21.38	72.08	78.7	31.25
6	Rampara	21.31	72.01	29.74	60.64
7	Vejodari	21.31	72.01	125.77	78.1
8	Raniwada	21.18	71.92	140.13	159.9
9	Bhadrod	21.14	71.81	166.81	90.35
10	Bhanvad	21.09	71.72	141.98	144.14
11	Maliya	21.06	71.73	121.05	91.01
12	Ganjavadar	21.05	71.52	144.35	131.73
13	Lothpur	20.96	71.43	108.4	161.42
14	Nageshri	20.92	71.33	93.97	44.54

15	Bhada	20.88	71.22	120.42	161.68
16	Timbi	20.88	71.19	137.86	77.43
17	Motha	20.82	71.13	44.82	51.22
18	Una	20.78	71.02	135.39	104.2
19	Siloj	20.81	71.01	159.54	160.09
20	Mota Desar	20.78	71	109.74	72.94

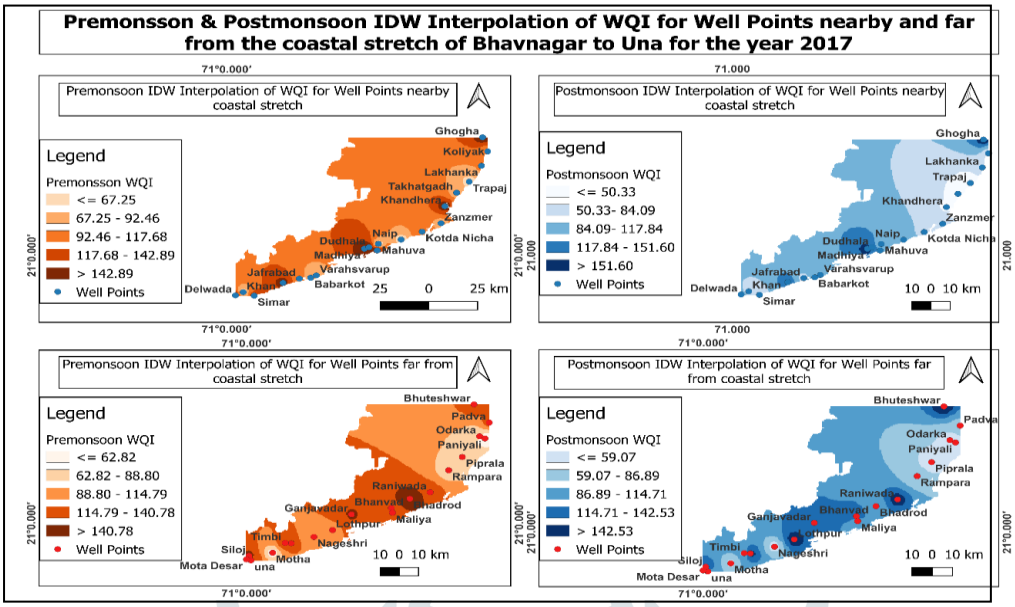

Figure 1.7 Premonsoon & Postmonsoon IDW Interpolation of WQI for Well Points nearby and far from the coastal stretch of Bhavnagar to Una for the year 2017

IDW Interpolation of WQI for Well Points nearby to the coastal stretch of Bhavnagar to Una for Premonsoon (May 2021) and Postmonsoon (Oct 2021)

It is evident that the wells region depicted by the light orange color for the Premonsoon period has a lower concentration of WQI value, say less than 83.40, and the dark maroon color has a greater concentration of WQI value, say greater than 171.07. Similarly, it can be seen that the wells region indicated for the Postmonsoon period by the white color has a lower concentration of WQI value, say less than 87.09, and the dark blue color has a greater concentration of WQI value, say greater than 160.28. This concentration exceeds the permitted level.

Premonsoon WQI value concentration is highest in Ghogha village in Ghogha taluka, Dudhala, and Gadhada village in Mahuva taluka in Bhavnagar, respectively, at 201.05, 181.59, and 160.33, as indicated in the color legend for the WQI value intervals in the figure. At Bhadrod and Naip villages in the Mahuva taluka, as well as Takhatgadh village in the Talaja taluka in Bhavnagar, the Premonsoon lowest WQI value concentration is 53.3, 67.18, and 76.71, respectively.

The villages of Madhiya and Dudhala in the Mahuva taluka and Khandhera village in the Talaja taluka in Bhavnagar had the highest Postmonsoon WQI value concentrations, respectively, of 184.96, 162.37, and 154.76. In Trapaj and Takhatgadh villages in Talaja taluka, as well as in Naip village in Mahuva taluka in Bhavnagar, the Postmonsoon lowest WQI value concentration is around 62.67, 74.94, and 73.62, respectively.

IDW Interpolation of WQI for Well Points far from the coastal stretch of Bhavnagar to Una for Premonsoon (May 2021) and Postmonsoon (Oct 2021)

The wells region represented by the white color for the Premonsoon period has a lower concentration of WQI value, say less than 84.28, while the dark maroon color has a higher concentration of WQI value, say more than 162.78. Similarly, the wells region indicated for the Postmonsoon period by the white color has a lower concentration of WQI value, say less than 76.27, and the dark blue color has a higher concentration of WQI value, say greater than 151.65.

Premonsoon's greatest WQI value concentration is in Bhuteshwar, Raniwada village at Mahuva taluka in Bhavnagar, and also in Lothpur village at Jafrabad taluka in Amreli, with values of approximately 189.02, 175.24, and 152.27, respectively, as shown in the color legend WQI value intervals in the figure. Motha village in Una taluka in Gir-Somnath, Rampara village in Talaja taluka in Bhavnagar, and Nageshri village in Jafrabad taluka in Amreli have the lowest Premonsoon WQI value concentrations, measuring correspondingly 58.11, 63.06, and 65.91.

The three villages with the highest Postmonsoon WQI value concentration in Bhavnagar are Raniwada in Mahuva taluka, Timbi in Jafrabad taluka in Amreli, and Bhuteshwar in Bhavnagar, respectively, 176.81, 154.07, and 152.92. The villages of Paniyali in Ghogha Taluka, Piprala in Talaja taluka in Bhavnagar, and Motha in Una taluka in Gir-Somnath had the lowest Postmonsoon WQI value concentrations, with respective values of 51.03, 61.15, and 58.05.

Tabel 1.3 Premonsoon and postmonsoon WQI values for Well Points nearby coastline stretch for the year 2021

Well No.	Village	Latitude	Longitude	Pre-monsoon WQI	Post-monsoon WQI
1	Ghogha	21.68	72.26	201.05	145.72
2	Koliyak	21.6	72.28	88.41	92.57
3	Lakhanka	21.51	72.25	139.78	86.67
4	Trapaj	21.42	72.19	104.15	62.67
5	Takhatgadh	21.36	72.13	76.71	74.94
6	Khandhera	21.28	72.07	157.93	154.76
7	Zanzmer	21.18	72.05	119.52	122.61
8	Kotda Nicha	21.13	71.96	78.19	83.16
9	Naip	21.09	71.85	67.18	73.62
10	Mahuva	21.06	71.74	53.3	100.68
11	Gadhada	21.03	71.74	160.33	149
12	Madhiya	21.04	71.67	143.18	184.96
13	Varahsvarup	20.88	71.44	120.91	116.04
14	Babarkot	20.87	71.41	95.27	94.2
15	Jafrabad	20.86	71.35	153.5	135.03
16	Balana	20.84	71.27	145.77	147.9
17	Dudhala	21.048	71.7	181.59	162.37
18	Simar	20.76	71.13	96.48	107.33
19	Khan	20.78	71.08	122.81	93.75
20	Delwada	20.77	71.04	113.38	122.47

Tabel 1.4 Premonsoon and postmonsoon WQI values for Well Points far from coastline stretch for the year 2021

Well No.	Village	Latitude	Longitude	Pre-monsoon WQI	Post-monsoon WQI
1	Bhuteshwar	21.69	72.14	189.02	152.92
2	Padva	21.59	72.21	118.88	121.29
3	Odarka	21.51	72.16	91.15	74.78
4	Paniyali	21.49	72.19	78.36	51.03
5	Piprala	21.38	72.08	72.53	61.15
6	Rampara	21.31	72.01	63.06	63.59
7	Vejodari	21.31	72.01	114.46	118.92
8	Raniwada	21.18	71.92	175.24	176.81
9	Bhadrod	21.14	71.81	143.47	100.29
10	Bhanvad	21.09	71.72	129.29	99.94
11	Maliya	21.06	71.73	87	122.89
12	Ganjavadar	21.05	71.52	106.74	144.5
13	Lothpur	20.96	71.43	152.27	142.41
14	Nageshri	20.92	71.33	65.91	141.66
15	Bhada	20.88	71.22	151.13	144.88
16	Timbi	20.88	71.19	137.12	154.07
17	Motha	20.82	71.13	58.11	58.05

18	Una	20.78	71.02	125.38	142.75
19	Siloj	20.81	71.01	141.57	150.56
20	Mota Desar	20.78	71	81.62	111.39

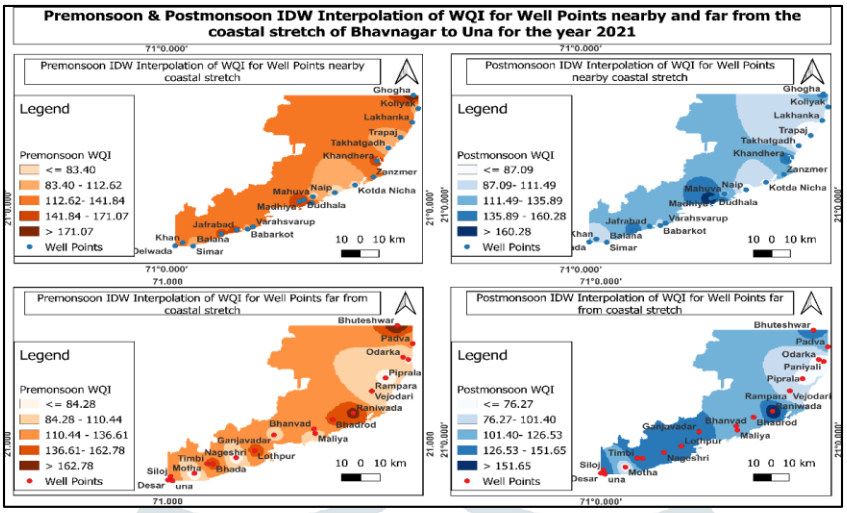

Figure 1.8 Premonsoon & Postmonsoon IDW Interpolation of WQI for Well Points nearby and far from the coastal stretch of Bhavnagar to Una for the year 2021

Piper trilinear diagrams for Well Locations near coastal stretch of Bhavnagar to Una (Premonsoon May-2017) and (Postmonsoon Oct-2017)

It can be seen that Na-Cl is the dominant water type by plotting major cation and anion concentrations on a Piper trilinear diagram, while mixed Ca-Mg-Cl water type is only slightly present in the well points during the premonsoon season whereas Na-Cl is the major water type that predominate, but mixed Ca-Mg-Cl and Ca-HCO3 water types are seen least in the well points close to the coastline stretch of Bhavnagar to Una during the postmonsoon season.

Tabel 1.5 Data on Main Cations and Anions for Nearby Coastal Stretch Well Points for Premonsoon (May 2017)

Well No.	Village	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	TDS
1	Ghogha	30	54	340	2.00	36	354	384	138.00	134
2	Koliyak	250	345	786	14.20	12	342	2200	295.00	4270
3	Lakhanka	45	126	345	2.30	0	207	640	219.00	1610
4	Trapaj	140	123	45	1.30	36	98	384	143	1010
5	Takhatgadh	25	66	486	2.40	36	427	560	90	1720
6	Khandhera	50	84	219	3.30	12	281	400	81	1150
7	Zanzmer	70	204	671	6.00	12	220	1560	48	2800
8	Kotda Nicha	675	510	1184	65.50	0	610	4200	33	7290
9	Naip	55	96	467	72.40	24	159	880	129	1910
10	Mahuva	55	24	49	3.60	7	193	120	0	450
11	Gadhada	75	90	741	202.6	36	964	1320	214	3870
12	Madhiya	325	375	1530	31.1	12	342	3600	296	6530
13	Varahsvarup	135	102	234	83.0	24	488	560	19	1680
14	Babarkot	195	168	908	19.3	0	317	1920	133	3680
15	Jafrabad	115	72	417	3.4	0	85	840	105	1680
16	Balana	40	51	213	0.7	0	378	256	53	1010
17	Dudhala	300	705	1402	3.4	0	98	4400	390	7320
18	Simar	150	186	786	23.5	12	476	1600	205	3440
19	Khan	60	57	96	1.7	12	541	120	29	830
20	Delwada	80	75	583	5.9	12	549	840	95	2250

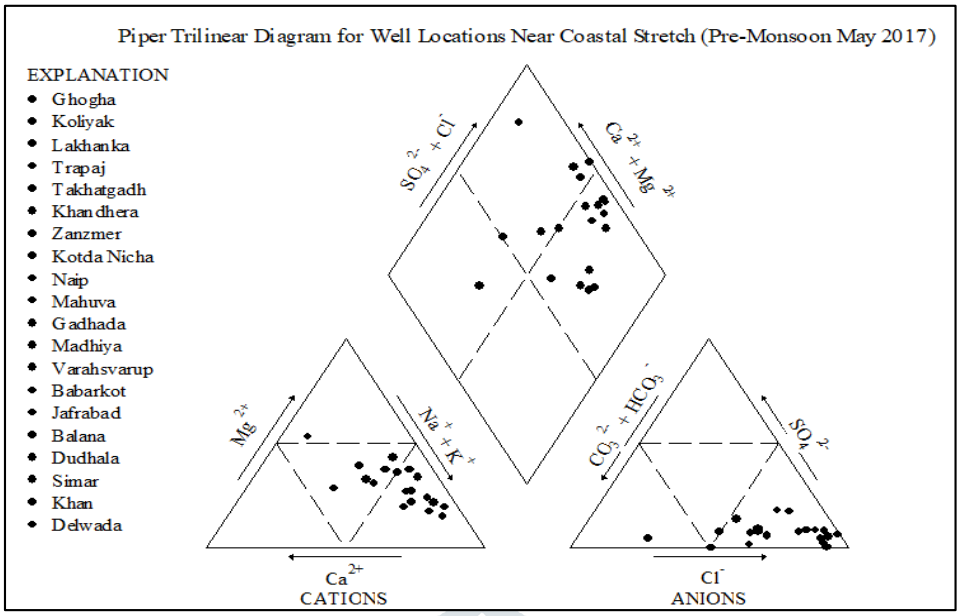

Figure 1.9 Piper Trilinear Diagram for Well Locations Near Coastal Stretch (Pre-Monsoon May 2017)

Tabel 1.6 Data on Main Cations and Anions for Nearby Coastal Stretch Well Points for Postmonsoon (Oct 2017)

Well No.	Village	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	TDS
1	Ghogha	60	36	218	2.30	36	366	240	71.00	1030
2	Koliyak	60	114	346	3.90	12	342	600	167.00	1660
3	Lakhanka	85	105	313	6.30	12	244	600	224.00	1600
4	Trapaj	60	39	68	1.20	12	134	184	43	550
5	Takhatgadh	50	93	221	3.10	24	256	432	57	1160
6	Khandhera	45	18	10	2.40	2	168	48	0	290
7	Zanzmer	55	33	420	2.60	36	171	600	90	1420
8	Kotda Nicha	70	105	750	3.60	0	159	1400	71	2580
9	Naip	40	36	174	7.00	0	268	264	38	830
10	Mahuva	40	42	507	14.90	36	451	600	114	1810
11	Gadhada	60	69	330	18.2	0	244	560	162	1450
12	Madhiya	375	495	639	4.4	12	293	2800	181	4800
13	Varahsvarup	80	51	311	4.0	0	256	568	52	1330
14	Babarkot	130	111	821	13.8	0	244	1560	138	3030
15	Jafrabad	75	42	68	5.4	12	329	136	29	700
16	Balana	30	60	172	1.6	12	293	240	58	880
17	Dudhala	325	285	1254	15.9	12	256	3000	238	5400
18	Simar	65	132	326	14.8	12	500	640	90	1780
19	Khan	60	15	29	2.1	14	236	40	0	400
20	Delwada	50	42	500	42.5	32	560	600	98	2250

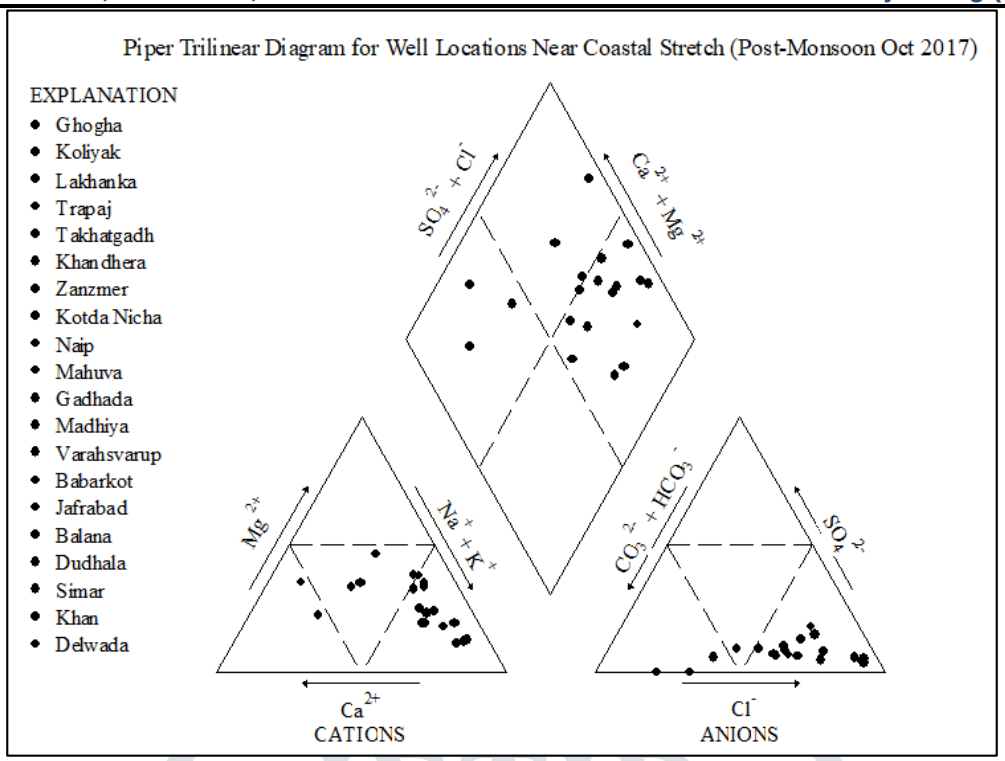

Figure 1.10 Piper Trilinear Diagram for Well Locations Near Coastal Stretch (Post-Monsoon Oct 2017)

Piper trilinear diagrams for Well Locations away from coastal stretch of Bhavnagar to Una (Premonsoon May-2017) and (Postmonsoon Oct-2017)

It can be seen that Na-Cl is the major water type dominant by plotting major cation and anion concentration on a Piper trilinear diagram, while there is a slight content of mixed Ca-Mg-Cl water type is seen in the well points during the premonsoon season whereas Na-Cl water type and mixed Ca-Mg-Cl water type are equally prominent in the well points away from coastal length of Bhavnagar to Una during the postmonsoon season.

Tabel 1.7 Data on Main Cations and Anions for Farby Coastal Stretch Well Points for Premonsoon (May 2017)

Well No.	Village	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	TDS
1	Bhuteshwar	200	180	1463	3.20	12	659	2400	429.00	5360
2	Padva	375	255	818	2000	0	512	2000	457.00	4450
3	Odarka	85	126	162	1.90	24	451	344	129	1340
4	Paniyali	100	90	76	2.20	12	268	240	76	900
5	Piprala	60	93	114	17.50	12	293	288	119	1000
6	Rampara	50	63	105	1.00	0	317	192	48	790
7	Vejodari	70	90	958	7.60	36	525	1280	324	3290
8	Raniwada	105	156	449	6.80	0	317	920	200	2190
9	Bhadrod	40	66	1180	0.40	36	573	1040	900	3840
10	Bhanvad	175	450	1739	3.6	12	220	4000	157	6790
11	Maliya	70	63	444	21.2	36	598	560	81	1870
12	Ganjavadar	65	39	463	2.8	24	610	400	171	1790
13	Lothpur	160	201	1056	7.1	0	451	2000	219	4130
14	Nageshri	50	87	622	1.0	24	500	880	90	2270
15	Bhada	45	51	372	6.7	36	390	448	76	1440
16	Timbi	40	66	626	1.3	48	659	680	81	2220
17	Motha	65	63	116	1.1	0	512	168	19	940
18	Una	75	87	524	1.4	24	512	760	110	2110
19	Siloj	40	42	398	1.4	36	598	336	81	1540
20	Mota Desar	75	108	372	0.0	0	427	680	84	1760

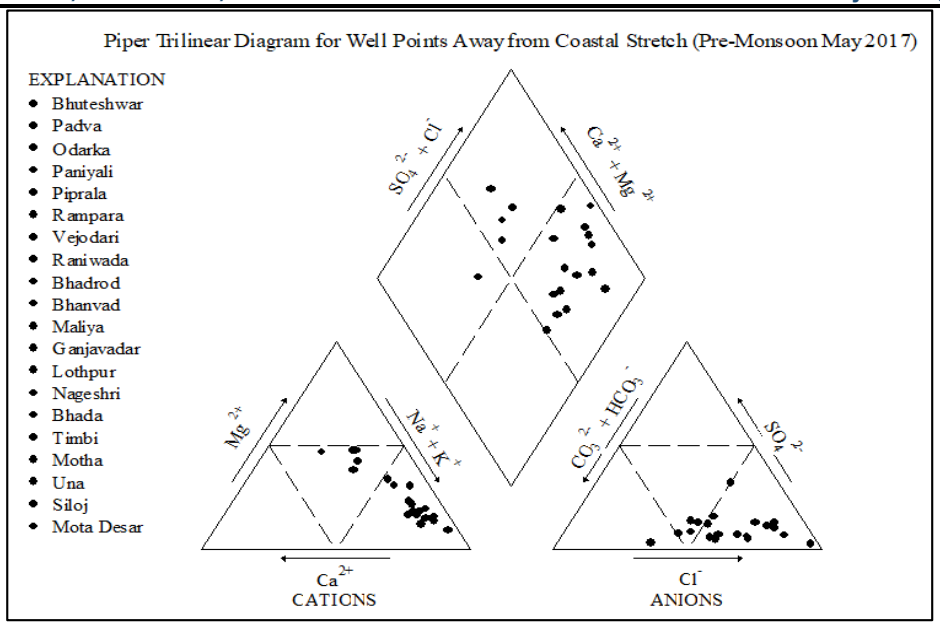

Figure 1.11 Piper Trilinear Diagram for Well Points Away from Coastal Stretch (Pre-Monsoon May 2017)

Tabel 1.8 Data on Main Cations and Anions for Farby Coastal Stretch Well Points for Postmonsoon (Oct 2017)

Well No.	Village	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	TDS
1	Bhuteshwar	55	90	1322	4.10	36	695	1600	466.00	4280
2	Padva	45	84	213	240	24	390	240	124.00	1150
3	Odarka	45	51	69	5.40	12	159	160	86	590
4	Paniyali	45	48	49	2.40	24	232	104	0	520
5	Piprala	60	57	87	1.10	342	43	2	0	760
6	Rampara	65	48	114	0.90	12	220	264	0	730
7	Vejodari	40	60	410	2.30	36	281	560	95	1500
8	Raniwada	50	36	560	0.70	36	427	600	124	1860
9	Bhadrod	40	42	507	14.90	36	451	600	114	1810
10	Bhanvad	50	30	433	2.0	36	500	376	86	1540
11	Maliya	70	36	156	13.7	36	256	248	14	840
12	Ganjavadar	30	27	485	3.8	48	817	232	105	1770
13	Lothpur	50	66	752	3.6	24	427	1040	162	2530
14	Nageshri	50	162	201	6.0	12	329	560	105	1440
15	Bhada	60	90	230	12.5	12	586	328	48	1370
16	Timbi	55	63	263	1.9	24	366	320	52	1180
17	Motha	50	78	84	0.9	24	390	160	29	820
18	Una	60	69	210	2.1	24	159	464	62	1050
19	Siloj	35	45	330	4.9	36	403	368	62	1290
20	Mota Desar	75	42	133	1.8	12	73	352	19	720

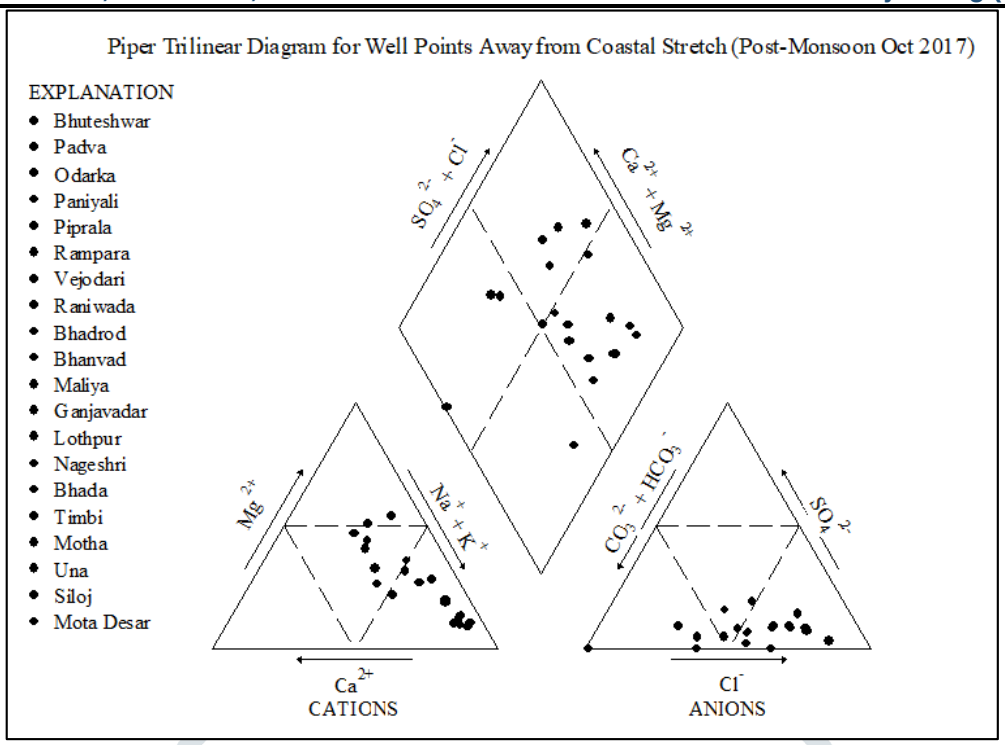

Figure 1.12 Piper Trilinear Diagram for Well Points Away from Coastal Stretch (Post-Monsoon Oct 2017)

Piper trilinear diagrams for Well Locations near coastal stretch of Bhavnagar to Una (Premonsoon May-2021) and (Postmonsoon Oct-2021)

It can be seen that Na-Cl is the major water type dominant by plotting major cation and anion concentration on a Piper trilinear diagram while mixed Ca-Mg-Cl water type is least common in the well points during premonsoon season whereas Na-Cl is the major water type dominant, but minimal amount of mixed Ca-Mg-Cl water type is evident in the well points close to the coastline stretch of Bhavnagar to Una during postmonsoon season.

Tabel 1.9 Data on Main Cations and Anions for Nearby Coastal Stretch Well Points for Premonsoon (May 2017)

Well No.	Village	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	TDS
1	Ghogha	150	246	1120	5.70	0	366	1800	910	4620
2	Koliyak	95	153	635	13.40	0	354	880	610.00	2770
3	Lakhanka	185	249	789	11.80	0	281	1640	570.00	3750
4	Trapaj	90	156	149	1.30	0	171	384	324	1330
5	Takhatgadh	50	126	297	2.30	0	305	576	109	1500
6	Khandhera	35	60	261	4.40	12	244	392	92	1110
7	Zanzmer	175	315	1300	7.80	0	244	3000	108	5150
8	Kotda Nicha	90	126	661	7.20	0	159	1320	88	2480
9	Naip	40	63	398	58.40	12	439	560	125	1700
10	Mahuva	30	42	79	5.40	0	183	192	0	530
11	Gadhada	60	102	613	22.8	24	622	920	20	2400
12	Madhiya	200	315	2150	14.3	0	207	3800	890	7590
13	Varahsvarup	40	63	287	1.5	0	220	384	100	1140
14	Babarkot	65	108	821	15.1	0	220	1440	138	2820
15	Jafrabad	35	60	563	11.8	12	342	840	48	1920
16	Balana	70	108	676	1.7	0	354	1040	135	2440
17	Dudhala	125	570	1700	9.7	0	171	4200	280	7070
18	Simar	85	171	975	41.7	0	232	1440	830	3780
19	Khan	225	420	1280	15.8	12	281	3000	560	5810
20	Delwada	40	105	573	65.2	24	488	880	114	2310

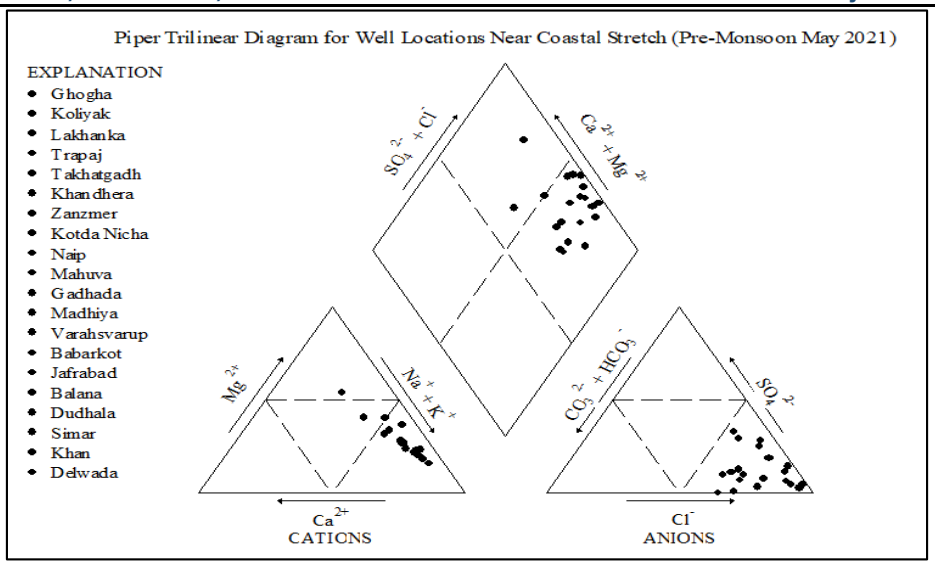

Figure 1.13 Piper Trilinear Diagram for Well Locations Near Coastal Stretch (Pre-monsoon May 2021)

Tabel 1.10 Data on Main Cations and Anions for Nearby Coastal Stretch Well Points for Postmonsoon (Oct 2021)

Well No.	Village	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	TDS
1	Ghogha	50	45	120	13.68	35	230	190	12.00	700
2	Koliyak	50	105	470	13.7	0	293	680	332	1960
3	Lakhanka	60	90	364	0.8	0	451	448	266	1690
4	Trapaj	40	78	120	3.7	0	354	216	75	890
5	Takhatgadh	35	99	162	3.2	0	256	336	107	1020
6	Khandhera	40	66	144	14.7	0	415	200	64	950
7	Zanzmer	200	360	1360	5	2	281	3200	86	5550
8	Kotda Nicha	90	132	432	25.4	0	439	800	116	2070
9	Naip	35	57	319	42.4	12	281	480	108	1340
10	Mahuva	30	42	313	4.9	24	354	352	94	1220
11	Gadhada	60	90	658	14.5	24	488	1545	115	2430
12	Madhiya	150	300	1800	17.4	0	305	3600	210	6390
13	Varahsvarup	30	48	175	8.7	12	317	240	14	850
14	Babarkot	40	75	443	17.2	0	207	760	45	1620
15	Jafrabad	40	66	287	1.4	0	232	376	104	1150
16	Balana	35	51	167	6.7	0	244	208	28	780
17	Dudhala	150	360	2100	7.2	0	171	4000	590	7400
18	Simar	50	90	561	11.2	24	403	760	167	2100
19	Khan	200	330	1070	13.6	0	159	2800	96	4680
20	Delwada	70	138	489	57.7	12	634	800	149	2360

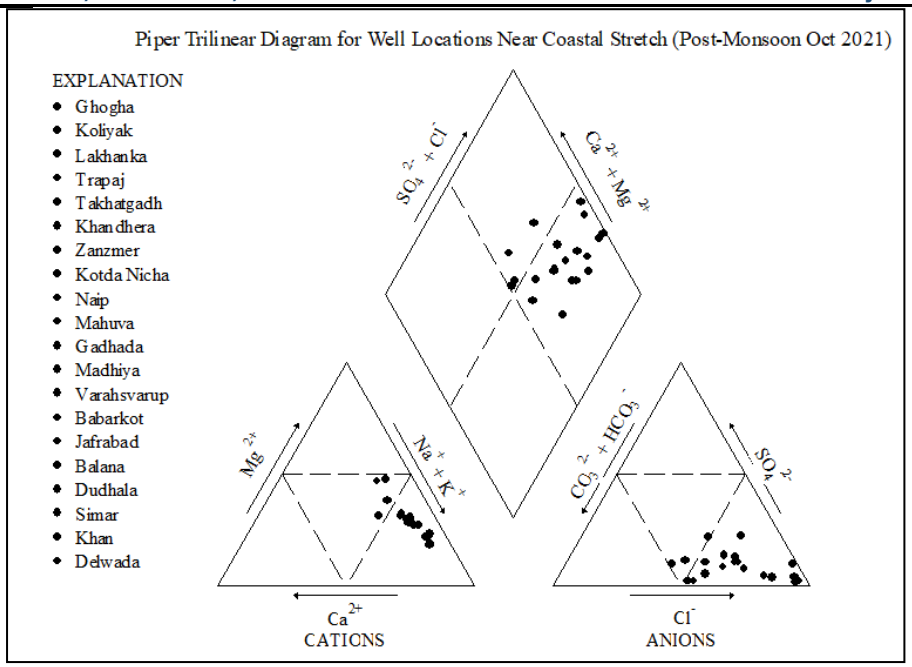

Figure 1.14 Piper Trilinear Diagram for Well Locations Near Coastal Stretch (Post-monsoon Oct 2021)

Piper trilinear diagrams for Well Locations away from coastal stretch of Bhavnagar to Una (Premonsoon May-2021) and (Postmonsoon Oct-2021)

It can be seen that Na-Cl is the major dominant water type, by plotting major cation and anion concentration on a Piper trilinear diagram while mixed Ca-Mg-Cl and Ca-Na-HCO3 water types are seen least in the well points during premonsoon season whereas Na-Cl is the major water type dominant, while minor contents of Ca-HCO3, mixed Ca-Mg-Cl, and Ca-Na-HCO3 water types are seen in the well points away from the coastal stretch of Bhavnagar to Una during the postmonsoon period.

Tabel 1.11 Data on Main Cations and Anions for Farby Coastal Stretch Well Points for Premonsoon (May 2021)

Well No.	Village	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	TDS
1	Bhuteshwar	50	90	222	16.40	24	842	128	46.00	1430
2	Padva	50	84	376	352	12	512	352	320	1720
3	Odarka	70	162	341	4.80	0	512	640	162	1920
4	Paniyali	30	42	83	3.60	0	256	128	0	560
5	Piprala	35	75	140	4.20	0	305	216	66	860
6	Rampara	55	99	146	1.10	0	232	304	121	990
7	Vejodari	75	165	997	6.80	0	268	1760	286	3570
8	Raniwada	150	258	906	16.60	0	122	1760	600	3880
9	Bhadrod	25	39	525	2.20	24	769	296	166	1880
10	Bhanvad	45	93	252	7.8	12	293	472	41	1240
11	Maliya	35	51	181	17.9	24	305	240	54	920
12	Ganjavadar	125	246	703	1.6	0	220	1760	58	3160
13	Lothpur	30	48	598	10.1	12	329	800	136	1970
14	Nageshri	50	120	603	12.4	12	512	840	162	2360
15	Bhada	65	99	644	5.2	12	464	1040	40	2390
16	Timbi	35	63	747	1.4	24	488	920	106	2420
17	Motha	60	138	318	8.4	12	305	760	55	1660
18	Una	40	66	287	7.2	0	220	536	44	1210
19	Siloj	20	30	534	1.8	24	671	392	139	1830
20	Mota Desar	45	93	250	26.7	12	427	360	105	1340

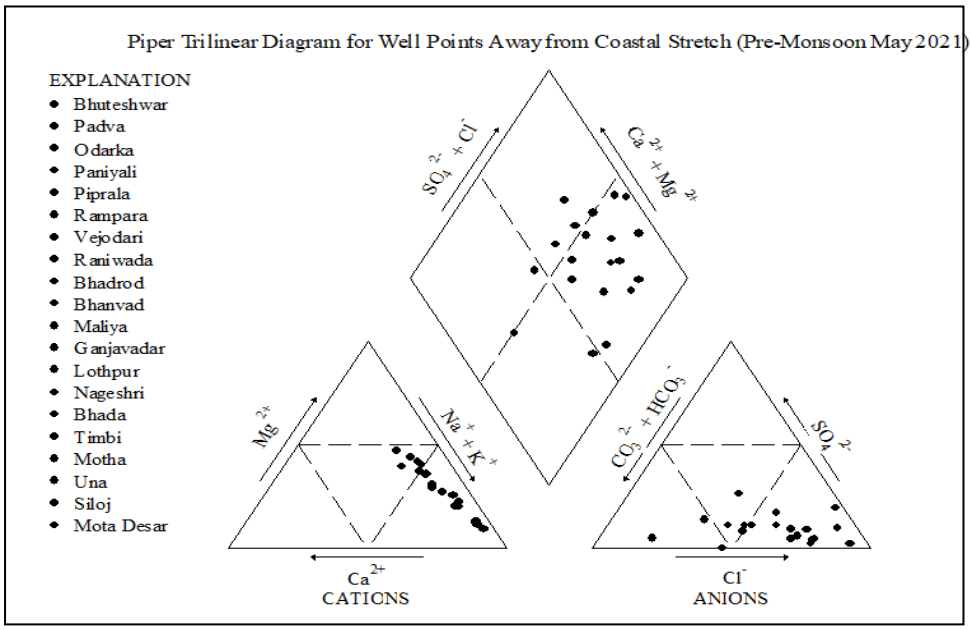

Figure 1.15 Piper Trilinear Diagram for Well Points Away from Coastal Stretch (Pre-monsoon May 2021)

Tabel 1.12 Data on Main Cations and Anions for Farby Coastal Stretch Well Points for Postmonsoon (Oct 2021)

Well No.	Village	Ca	Mg	Na	K	CO3	HCO3	Cl	SO4	TDS
1	Bhuteshwar	30	57	242	9.6	24	720	80	65	1240
2	Padva	30	51	300	136	12	769	136	41	1360
3	Odarka	30	48	62	3.2	0	281	96	0	530
4	Paniyali	25	51	78	1.1	12	195	144	0	520
5	Piprala	30	57	94	3.6	12	171	216	0	600
6	Rampara	35	54	108	4.1	0	183	240	54	680
7	Vejodari	55	96	964	3.5	0	598	1280	308	3310
8	Raniwada	140	231	655	13.3	0	305	1440	300	3130
9	Bhadrod	30	42	313	4.9	24	354	352	94	1220
10	Bhanvad	55	87	269	0.0	12	146	480	129	1220
11	Maliya	25	39	140	23.2	12	232	216	19	710
12	Ganjavadar	30	42	373	8.6	0	451	336	189	1440
13	Lothpur	30	42	516	7.6	24	525	520	154	1820
14	Nageshri	40	60	224	2.7	12	329	224	76	1010
15	Bhada	40	81	630	12.5	24	586	800	121	2310
16	Timbi	30	66	492	7.5	24	415	640	80	1770
17	Motha	35	93	262	2.1	24	415	376	63	1290
18	Una	40	66	314	5.0	12	207	512	98	1270
19	Siloj	30	45	237	7.7	24	549	168	24	1090
20	Mota Desar	35	63	216	11.2	0	146	424	56	970

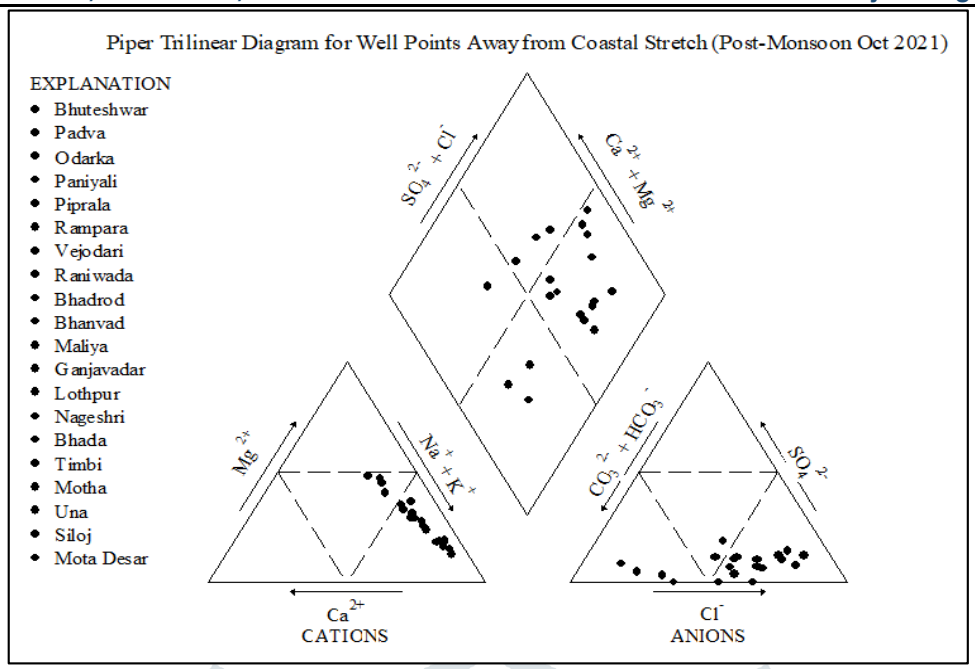

Figure 1.16 Piper Trilinear Diagram for Well Points Away from Coastal Stretch (Post-monsoon Oct 2021)

VI. CONCLUSION:

Groundwater quality has been observed to have significantly declined in the north-eastern part of the research region, more for well points close to the coastal length than for well points distant from the coastal stretch, and less in the south-western part. The subsequent over-exploitation of groundwater and its contamination by seawater intrusion are responsible for this disparity in hydrochemistry.

According to the WAWQI technique (by Brown et. al., 1972) standard for grading water quality, the area under examination for the year 2017 at well points close to coastal length had a total 60% (12 out of 20 wells) in premonsoon and 45% (9 out of 20 wells) in postmonsoon WQI values of greater than 100. A total of 55% (11 out of 20 wells) in the premonsoon and 40% (8 out of 20 wells) in the postmonsoon were found to have WQI values more than 100 for well points away from coastal stretches.

The villages of Dudhala, Gadhada, and Madhiya had the greatest WQI values (162.73-168.73) and Bhadrod, Khan, and Naip had the lowest WQI values (41.05-53.96) for well points close to the coastal stretch in year 2017. For well points away from coastal stretch, the villages of Siloj, Ganjavadar, and Bhanvad had the highest WQI values (141.98-159.54) and Rampara, Paniyali, and Motha had the lowest values (29.74-44.82).

A total of 65% (13 out of 20 wells) in the premonsoon and 60% (12 out of 20 wells) in the postmonsoon have WQI values more than 100 for the year 2021 at well points close to coastal stretch. And a total of 60% (12 out of 20 wells) in the premonsoon and 60% (12 out of 20 wells) in the postmonsoon had WQI values more than 100 for well points away from coastal stretches.

The villages of Ghogha, Khandhera, Gadhada, Mitiyala, and Dudhala had the highest WQI values in year 2021 for well points near to coastal stretch, while Bhadrod, Naip, Kotda Nicha, and Takhatgadh had the lowest WQI values (53.3-78.190. The villages of Rampara, Motha, Nageshri, and Piprala had the lowest WQI (58.11-72.53) and Bhuteshwar, Lothpur, Bhada, and Siloj had the highest WQI (141.57-189.02) for well points away from coastal stretch.

Premonsoon and postmonsoon seasons show that mixed Ca-Mg-Cl water type is least prevalent and Na-Cl is the major water type dominant with mixed Ca-Mg-Cl water type having a small presence in the well points area close to coastline stretch from Bhavnagar to Una. It can also be seen that Na-Cl is the predominant water type, whereas mixed Ca-Mg-Cl and Ca-Na-HCO3 water types are seen least during the premonsoon season, and during the postmonsoon season, Na-Cl is the predominant water type, whereas minor contents of Ca-HCO3, mixed Ca-Mg-Cl and Ca-Na-HCO3 water types are seen in the well points away from coastal stretch. This indicates that sodium (Na), chloride (Cl), and bicarbonate (HCO3) dominate the ionic concentration in the groundwater as a result of the weathering of minerals and the ion exchange process.

The study shows that the quality of groundwater in the Bhavnagar-Una portion of the Saurashtra coast is afflicted by sea water ingress and inherent salinity. Alarming drops in groundwater levels in the coastal stretch from Bhavnagar to Una , call for prompt action to implement recharge plans to halt further drops and increase groundwater supplies, it is essential to artificially recharge the groundwater.

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