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Review Article

Hydrochemical Investigation of Groundwater Arround Bicholim, North Goa, India

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ABSTRACT
Goa occupies a narrow strip of western India coast line, fifteen Km long and sixty-five Km wide with a total area of 3701 Km Sq. It lies between latitude N14º15' and N15º48' and longitude 74º40'1''E and 73º40'33''E. Goa is dominantly covered by the rocks of Dharwar supergroup of Archean Proterozoic age except for a narrow strip along the North-East corner occupied by the Deccan traps of upper Cretaceous to lower Eocene age. Forty five representative samples were collected from Bore well and open well and were subjected to chemical analysis to study the cations, anions and non-ionic parameters to decipher the chemical characters of Bicholim area. From the Hydro chemical investigation the sample are acidic as well as basic in nature, they have less TDS and low Electrical conductivity, as the water samples are fresh waters. Majority of the water samples are within the permissible limit for different applications. The Pipers classifications indicates 91% of the sample show carbonate hardness exceeds 50%, 2% of the samples shows non-carbonate alkali exceeds 50% and 6% show carbonate alkalis exceeds 50%. The details of the investigation are dealt in the paper.

Keywords: *Bicholim; Dendritic; Groundwater; Proterozoic; Laterites; Hydrochemical facies*

1. INTRODUCTION

The abundance of water on the earth is its unique feature that clearly distinguishes our “blue planet” from the others in the solar system. The earth’s hydrosphere is comprised of salt water and fresh water resources. Of the total volume of water on the earth, 94% is saline water while 6% is fresh water. Of this fresh water, 27% is glacial and 1% is usable portable surface water in the form of rivers, lakes, etc. The remaining 72% is groundwater, which is utilized for domestic needs and most vulnerable to contamination by human activities.

Groundwater is one of the earth’s most widely distributed and most important natural resources. Groundwater exists wherever water penetrates beneath the surface. The rocks beneath the surface are permeable enough to transmit water, and at places, the rate of infiltration is so sufficient that the rocks are saturated to an appreciable thickness. This water may be fresh or brackish in quality. As the fresh water constitutes very little quantity of the total water available, we must think as to how best we can exploit it, with the growth of population, today in many of the places water has become a critical source. In many places it is dwindling both in quality and quantity, creating problems for the communities involved.

1.1. Location and Accessibility

The study area is located in central portion of the North Goa District (Map 1.1). The study area can be located on Survey of India toposheet No. 48 E 1/4 on 1:50000scale. It lies between latitudes 15°32'00”N and 15°37'30”N, and longitude 73°59′30″E and 73°53’30’’E covers an area of about 90 square kilometers.

The area can be accessed at any time by roads. The Bicholim area is one of the major cities in the state of Goa it is linked by a network of good roads. The study area can also be approached by NH 17B which passed through the Bicholim city (Figure 1&2).

1.2. Landforms

The entire study area shows a very undulating terrain forming table toped hills and valleys. The highest elevation is 140m and lowest elevation is about 2m above mean sea level. The hills and valleys of this undulating region are generally aligned in NW-SE direction (western ghat ranges in north Goa). The trend of the hills is controlled by the structure (folding and schistosity) of the rock formations in the region.

1.3. Rainfall

The monsoon bursts over Goa in early June and by the end of September/early October it withdraws: during its tenure over Goa, the monsoon gives rise to annual rainfall in the vicinity of 350 cm. However, towards the Western Ghats, the rainfall

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tends to be a little more and is around 400 cm annually. From available records, some parts of Goa have had extensive rainfall e.g. Colem had rainfall of 563.0 mm on the 24th August 1934 (figure 3).

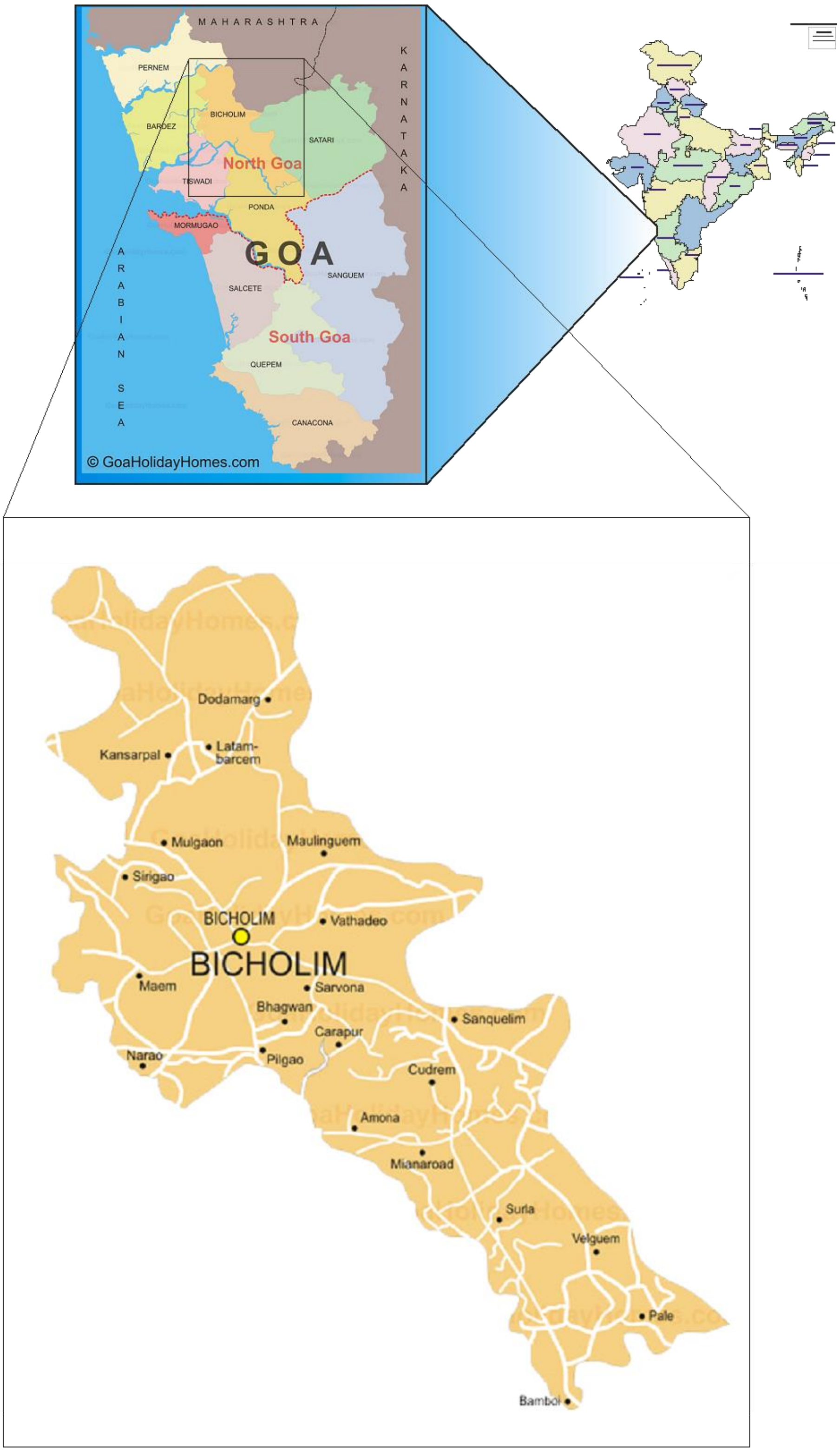

Figure 1: Location map of the study area

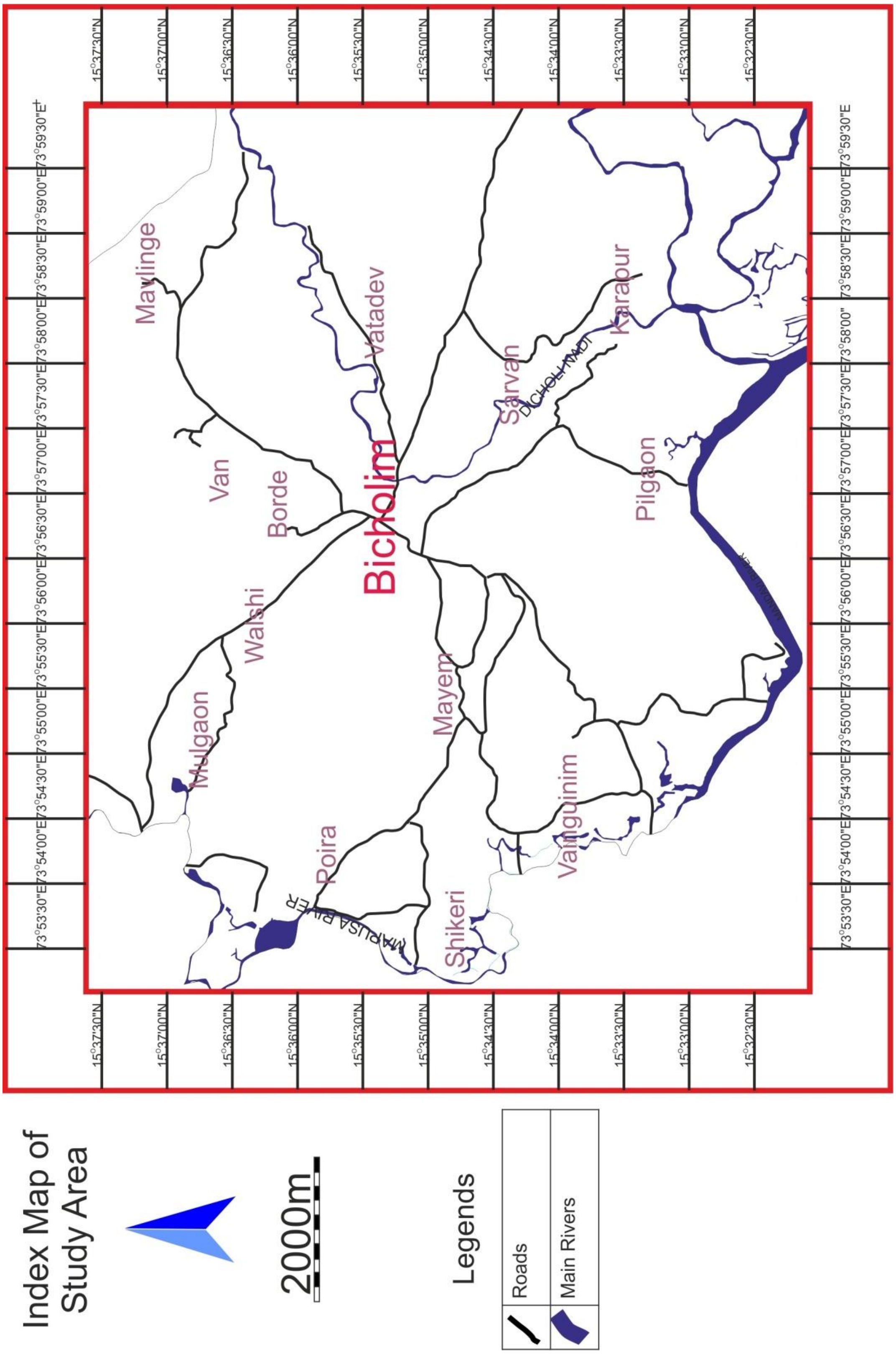

Figure 2: Index map of the study area.

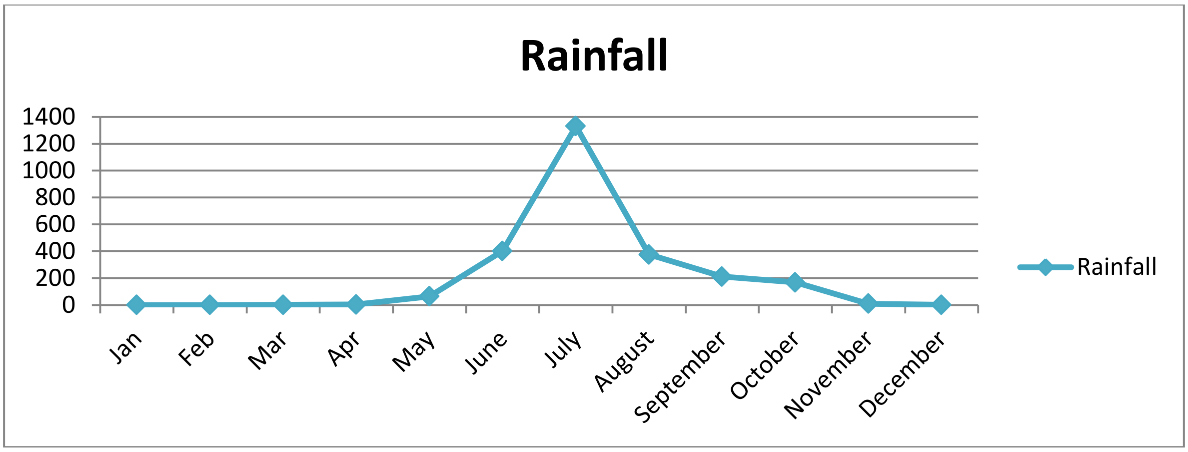

Figure 3: Graph of rainfall data.

1.4. Temperature

Variations of temperature in Goa are minimal. The month of May is perhaps Goa's hottest month when the temperature is around 30°C while the "cool" month of January touches temperature lows around 20°C. However, oddly enough, the day temperatures touch the lowest during the monsoon months of July and August and not in the "cold weather" months of January and February. This, however, is not the case when one considers night temperatures: the 'cold weather' months, this time, are true to expectations might temperatures generally hover around 20°C in Jan /Feb (figure 4)

1.5. Humidity

With proximity to the Arabian sea, many rivers and lakes, the humidity in Goa is relatively high; mainly around 60%.

1.6. Wind Speed

As the Goa is situated on the western coastline it is affected by the south west monsoon winds which not only bring it precipitation in the form of rain but are also responsible so some extent for variation in wind speeds. The graph shows brief description of variation in wind speed throughout the entire year (figure 5).

1.7. Drainage system of the area

The drainage pattern of the study area observes is dendritic, the drainage is very dense in most of the area this indicates the area is having hilly topography. In the eastern part of area the water is drained to Dichloli nadi and in south to the Mondovi river, the river Dichloli nadi also joins to Mondovi in south east part of the area (figure 6).

1.8. Geological setting

The study area belongs to the Bicholim Formation. The formation overlies the Sanvordem Formation conformably and it includes quartz-chlorite-amphibole schist, ferruginous pink phyllite, limestone, manganiferous chert breccias and banded ferruginous quartzite. The average true thickness of the formation is about 1,400m. The formation contains iron and manganese ore deposits of Goa, the treasure house and backbone of Goa's economy. Broadly the northern portion of the formation lying to the north of Gaois rich in iron ore deposits, the southern portion of the formation south of Sanvordem is rich in manganese ore deposits and the central portion contains both iron and manganese ore deposits of medium grade and smaller size. This pattern of distribution of this iron and manganese ore deposits is essentially due to facies change in the original sedimentation. The name Bicholim Formation is formally proposed to these rocks in view of the fact that the bigger iron ore deposits occur at Bicholim. The quartz-chlorite-amphibole schist is the dominant litho unit of the formation and is uniformly distributed in it (Table 1).

1.9. Laterite

Laterite is a residual weathered (rotted) layer of rock several meters in thick, which forms in wet tropical climates. It forms due to the concentration of oxides and hydroxides of iron and aluminum, when other elements are leached away during decomposition of silicate minerals. Laterite has a unique characteristic of being hard on top and soft below. A typical Laterite profile consists of 8 to 12 m of massive (hard) Laterite exposed on the top of hills that are often plateaus. The massive Laterite (duricrust) is followed by or grades into a layer of gravely Laterite of varying thickness.

1.10. Occurate Groung water and aquifer Charecteristics

Laterites are the important water bearing formations. Laterites are occurring in plateau areas of detrital origin generally occupying valley portions. Besides inherent porosity, the laterites are highly jointed and fractured, which control their water bearing capacity. The thickness of laterites extends up to 30 m. Groundwater occurs under water table condition in lateritic formation. In the

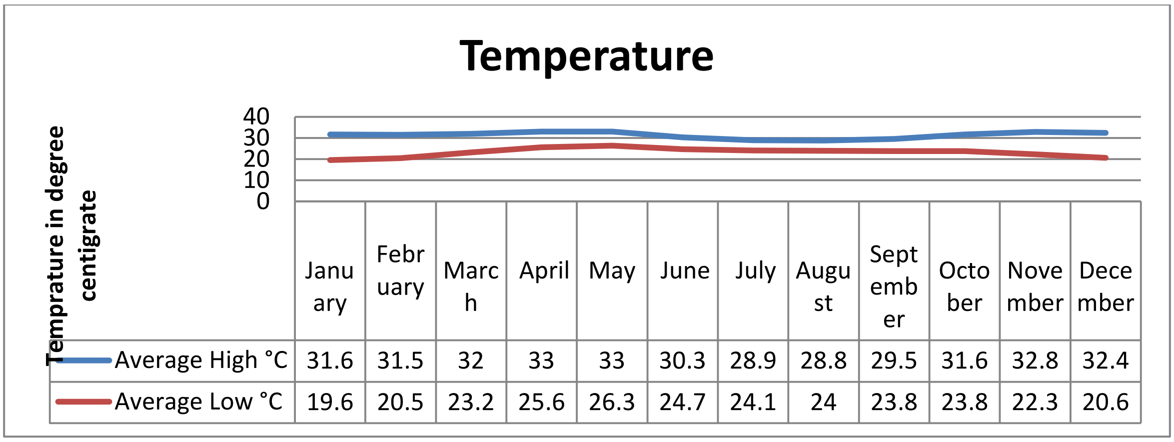

Figure 4: Graph of temperature.

Figure 5: Graph of windspeed.

plateau area and high grounds, depth of wells range from 9.40 to 26.60 m below ground level and depth to water level varies between 8.20 – 21.90 m below ground level, whereas wells located in topographic lows range in depth from 3.10 – 11.95 m below ground level and depth to water level varies from 1.5 – 8.40 m below ground level. Specific capacities vary between 1.73 to 3205 m^3/day/m.The population of the study area is mostly dependent on the groundwater resources for irrigation during the winter or summer season crop; however groundwater is used throughout the year for the consumption and portable purpose. In the eastern part of the study area the source of water for portable purpose excluding use for consumption is used from the river Dicholi Nadi.

2. Previous Work Carried in the Study Area

While detailed geological work has been undertaken in Goa since 1962, most of the hydrogeological work has been done much later. Short-term water supply investigations have been carried out by the officers of the Geological Survey of India from the Southern Region prior to 1970. [1], carried out the first systematic hydrogeological survey in the northern part of Goa. Later Sharma (1977) undertook systematic hydrogeological studies in parts of Southern Goa. Suitable areas were demarcated for development of groundwater using the shallow aquifers. Suggestions for drilling and construction of tube wells were put forth and the quality of groundwater for domestic consumption was studied for the Southern Goa stretch. [2]. concluded from his study that the rivers and their perennial tributaries in Goa retain high discharges mainly due to the effluence of the leaky Laterites all along their course, and more particularly in the post-monsoon period. [3], studied the rainfall contribution to groundwater recharge as 16% and evapotranspiration and surface runoff as 32% and 52% respectively. [4]. suggested the optimal design of groundwater structures together with proper selection of pumping unit in theterritory to avoid hazards of seawater intrusion. [5]. Carried out a systematic hydrogeological investigation in parts of Goa. [6] have carried out detailed investigations of groundwater potential, availability, and its vulnerability to pollution, seawater intrusion using GIS, MODFLOW, DRASTIC and GALDIT

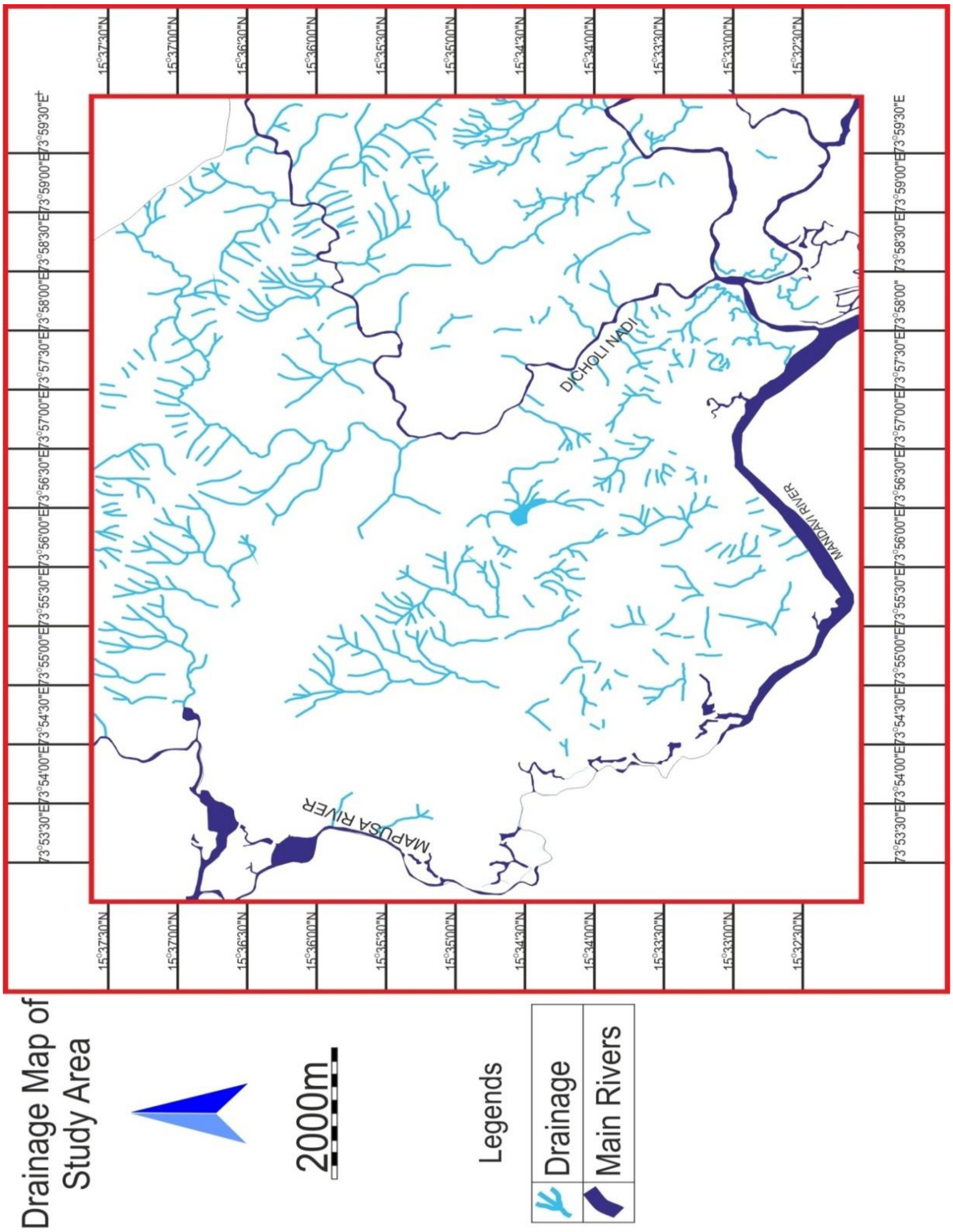

Figure 6: Map showing drainage of the study area.

methods in the north Goa coastal area. [6]. has carried out a detailed study on impact assessment and remediation of open-cast mine dewatering on rural drinking water supplies in the mining belt of Goa. Considerable amount of studies have been done by M.Sc. Geology students of Department of Earth Science, Goa University towards their dissertations involving groundwater and hydrogeological studies in various parts of Goa. Preliminary assessment of salt water – freshwater interface between Fort Aguada and Candolim coast – North Goa has been studied by [7]. The study reveals that saltwater intrusion is directly related to excessive pumping in randomly distributed extraction structures, the existing hydrogeological conditions the availability of groundwater will be a bare minimum. Assessment of hydrogeological regime in the mining district of North Goa is studied by Pednekar (1998). Gonsalves and D' Souza (1998) carried out a study on the quality assessment of groundwater in and around Calangute area, in North Goa. [8]. studied the sea water intrusion in the coastal Bardez Taluka for Baga watershed area. [9]. studied the hydrogeology

Table 1. Chronostratigraphic sequence of Goa – (Adopted from Gokul et al, 1985).

<table>
<tr><td colspan="3">Sub-recent to recent</td><td></td><td>Sea sand, alluvium, laterite</td></tr>
<tr><td colspan="3">Sub cretaceous to lower Eocene</td><td>Deccan Trap</td><td>Basalt</td></tr>
<tr><td colspan="3" rowspan="2">Proterozoic</td><td>Basic Intrusive</td><td>Dolerite, Gabbro
Pegmatite vein, Quartz, Porphyritic Granite,</td></tr>
<tr><td>Acidic Intrusive</td><td>Hornblende Granite, Felspathic Granite, Granite Gneiss</td></tr>
<tr><td rowspan="4">ARCHEAN TO PROTEROZOIC</td><td rowspan="4">DHARWAR SUPER GROUP</td><td rowspan="4">GOA GROUP</td><td>Vageri Formation</td><td>Metabasalt, Metagreywacke.</td></tr>
<tr><td>Bicholim Formation</td><td>Banded ferruginous Quartzite, Manganiferous Chert, Breccias with Pink ferruginous Phyllite, Limestone, Pink ferruginous phyllite, Quartz-Chlorite-Amphibolite schist</td></tr>
<tr><td>Sanvordem Formation</td><td>Argillite, Quartzite, Tilloid Metagreywacke.</td></tr>
<tr><td>Barcem Formation</td><td>Metagabbro, Peridotite, Talc – chlorite schist, Variegated phyllite, Quartz – chlorite schist, Red phyllite, Quartz porphyry, Massive Schistose and Vesicular & Metabasalt.</td></tr>
<tr><td colspan="5">(>3000 Ma) Basement Trondhjemite Gneiss</td></tr>
</table>

and groundwater recharge in Goa state. [10]. studied the hydrogeology and groundwater balance of a small watershed in the mining area of North Goa. This study reveals that groundwater in the area is developed to the tune of only 44% despite mining activities, so there is further scope for the development of groundwater in the area. Hydrogeological studies and morphometric analysis of Verna sub-watershed of Zuari river basin, South Goa is studies by [11]. This study suggested that the depth to water table in the area is shallow (4m-8m) and the overlying unsaturated layer is highly permeable; therefore the shallow aquifer is vulnerable to pollution. Assessment of groundwater quality and hydrogeological studies in and around Panaji, Apeksha (2011). This study reveals that rainfall is found to be the main source responsible for recharging the shallow aquifer system.

The ground water of Goa are studied by considering the following objectives

- To study the primary chemical parameters of the water in the areas around Bicholim town of Goa.
- The primary objective is to analyze the water quality by studying the primary chemical parameters and to classify the water in various categories based on the parameters analyzed.
- By doing this we get an idea of water quality and can demarcate the wells as useful for domestic use, industrial use or agricultural use.

Also to find the extent of sea water intrusion in the area by comparing the salinity of specific wells

3. GEOCHEMISTRY

Groundwater is an important natural resource amongst the commonly occurring substances in nature, and an important source of global water supply. Groundwater demands as much attention to quality as its quantity to optimize its use for various purposes. Further, knowledge of groundwater remains incomplete as long as its chemical nature remains unknown. Proper scientific planning, development, exploration and exploitation are possible only when its chemistry is fully understood.

Groundwater acquires chemical characteristics due to the interplay of meteorological, geological, pedagogical and topographical conditions that have a bearing on the accumulation of salts in it. These derived constituents and their important properties are analytical determined to know the quality of water. The term “quality” includes the physical, chemical and biological characteristics in nature. Water gets affected by many factors, which are mostly derived ones, and these are the basic criteria in the determination of water quality.

The quality studies of water not only explain the concentration of different ions, but also its occurrence, Geological history of the rocks, discharge, movements and storage [7]. and explain its suitability to domestic, irrigational and industrial purposes.

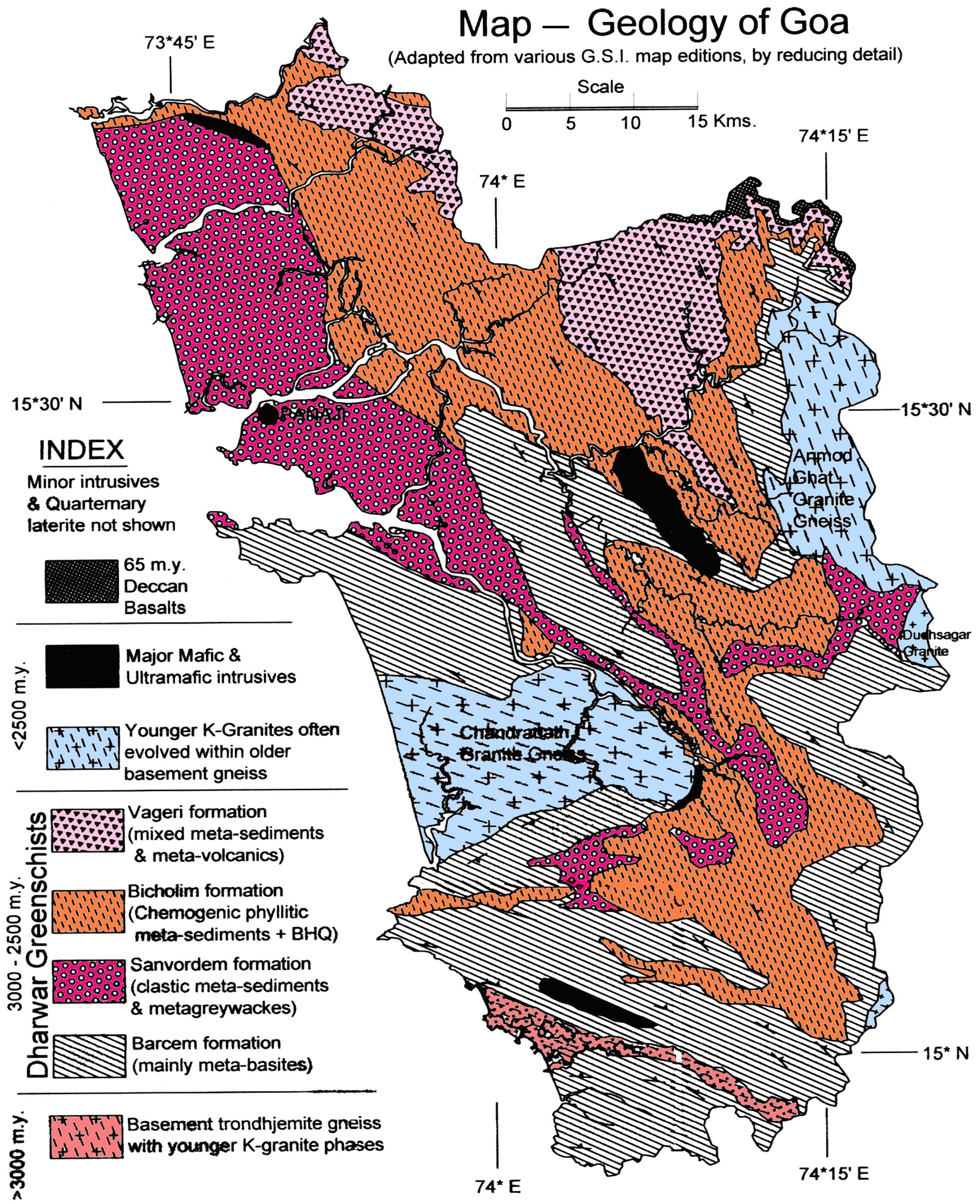

Figure 7. Geological map of Goa.

3.1. Hydrogeochemistry

Groundwater quality study is the most significant part of the hydrogeological investigations. Groundwater and less polluted compared with surface water. During precipitation water seeps through soil and rocks and this physical contact between mineral matter and water, and environmental conditions modify its physical, chemical, and biological characters by the organic action in soil and the decomposition of minerals constituents in the rocks through groundwater passes and results in change in quality. Also, the weathering process plays an important role in the quality saturation and implies to understand the groundwater recharges and discharge, storage and movement in different rock units and structural settings. The quality also helps to know the suitability for domestic, agricultural and industrial purposes.

In view of the above, the presence of various ionic constituents and relative variations in the groundwater were studied. In Bicholim area of Goa (Figure 7), 45 samples were collected in 2012 in one liter opaque polythene canes. A chemical

Table 2: Results of the chemical analyses of the ground water sample of the study area.

sample no.	Location	source	EC	PH	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	TH	TDS
1	Shikeri 1	OW	30	5.23	3.2064	0.487295	13.911	1.197	1046.794	0	79.52	9.4	10.0116	80
2	Shikeri 2	OW	30	5.05	4.8096	0.487295	5.056	0.128	695.1904	0	71	14	14.0147	100
3	Shikeri 3	OW	60	5.04	5.6112	0.487295	0.818	0.11	644.3888	0	83.78	9.4	16.0163	60
4	Shikeri 4	OW	80	5.13	7.2144	1.461884	2.78	0.992	1842.786	0	99.4	5	24.0300	40
5	Shikeri 5	OW	120	5.22	8.016	2.923769	2.3	1.113	1341.984	0	103.66	9.4	32.0472	20
6	HW 1	OW	250	4.94	8.016	0.487295	3.23	1.558	591.984	0	78.1	9.4	22.0211	20
7	HW 2	OW	20	4.77	9.6192	2.436474	8.232	0.15	640.3808	0	25.56	5	34.0452	20
8	HW 3	OW	500	5.29	9.6192	0.97459	0	3.51	540.3808	0	19.88	5	28.0295	20
9	HW 4	OW	2540	5.2	40.08	42.88195	280.612	0.34	459.92	0	701.48	34	276.539	1140
10	HW5	OW	450	5.22	13.6272	1.461884	138.807	0.123	736.3728	0	130.64	18	40.0427	120
11	KW1	OW	70	4.19	4.8096	0.97459	10.173	0.096	1995.19	0	21.3	9.4	16.0200	220
12	KW2	OW	30	5.86	82.5648	0	2.45	0.076	267.4352	0	66.74	9.4	400.670	80
13	GK 1	OW	60	3.8	4.8096	1.461884	2.264	0.027	395.1904	0	31.24	5	18.0252	140
14	GK 2	OW	30	3.53	4.008	0	3.404	0.509	295.992	0	19.88	5	32.2303	60
15	VG 1	OW	20	3.6	4.008	2.923769	0	0.192	1695.992	0	19.88	9.4	22.0392	100
16	VG 2	OW	20	4.65	3.2064	0.487295	0.711	0.576	1246.794	0	19.88	5	10.0116	100
17	VG 3	OW	30	5.01	2.4048	2.436474	0	0.636	697.5952	0	19.88	5	16.0308	60
18	VG 4	OW	30	5.17	4.008	2.436474	2.476	2.537	245.992	0	19.88	5	20.0340	20
19	GK	OW	50	7.26	5.6112	0	0.704	0.366	394.3888	0	22.72	9.4	22.9161	990
20	GK	OW	230	7.4	12.024	5.847538	0	1.587	1137.976	0	51.12	9.4	54.0865	80
21	CM	OW	250	7.64	20.8416	2.923769	8.567	0.429	829.1584	0	45.44	0	64.0727	80
22	Poira 1	OW	70	6.66	4.008	0.97459	6.22	0.122	295.992	0	25.56	14	14.0184	100
23	Poira 2	OW	110	7.13	9.6192	0.487295	1.54	1.754	690.3808	0	19.88	9.4	26.0243	20
24	Sarvana 1	OW	50	6.58	3.2064	0	2.533	0.27	396.7936	0	17.04	5	43.6262	30
25	Sarvana 2	OW	30	6.71	7.2144	2.436474	1.902	0.361	442.7856	0	15.62	9.4	28.0404	40
26	Vathadev1	OW	40	4.7	5.6112	2.923769	1.069	3.878	294.3888	0	28.4	5	26.0424	100

27	Valshi 1	OW	170	6.77	20.04	6.334833	1.507	0.279	779.96	0	25.56	9.4	76.1077	240
28	Valshi 2	OW	150	6.45	12.8256	7.309422	3.153	0.766	287.1744	0	25.56	0	62.1038	80
29	Mulgaon1	OW	150	6.35	10.4208	4.385653	0.873	0.141	489.5792	0	28.4	0	44.0677	260
30	Mulgaon2	OW	150	7.09	9.6192	2.436474	7.383	0.838	740.3808	0	46.86	0	34.0452	200
31	Mulgaon3	OW	30	6.4	6.4128	2.923769	3.91	0.096	593.5872	0	21.3	5	28.0440	200
32	Vathadev2	OW	160	8.1	22.4448	3.411064	1.539	1.426	827.5552	0	19.88	5	70.0811	220
33	Vathadev3	OW	90	6.57	6.4128	6.822128	0.954	0.644	743.5872	0	28.4	0	44.0858	180
34	Vathadev4	OW	130	6.12	3.2064	3.411064	0	1.72	296.7936	0	21.3	5	22.0429	160
35	Maullige1	OW	60	7.17	3.2064	3.898359	0.685	1.691	346.7936	0	31.24	9.4	24.0481	80
36	Maullige2	OW	50	6.13	4.008	2.923769	2.42	0.616	345.992	0	26.98	14	22.0392	40
37	Maullige3	OW	30	6.4	4.008	4.385653	0	4.145	345.992	0	25.56	14	28.0549	100
38	Van	OW	80	6.6	4.8096	4.872948	0	4.6	345.1904	0	35.5	0	32.0617	120
39	Borde	OW	50	5.73	7.2144	1.461884	0	0.604	292.7856	0	31.24	0	24.0300	80
40	Sarvana	OW	190	7.16	11.2224	5.847538	0	0.326	488.7776	0	34.08	5	52.0849	20
41	Karapur	OW	270	7.81	19.2384	3.898359	0	1.357	530.7616	0	46.86	5	64.0800	160
42	Pilgaon 1	OW	50	7.34	5.6112	0	0	2.16	394.3888	0	24.14	5	14.0111	40
43	Pilgaon 2	OW	80	7.09	3.2064	2.436474	0.513	1.105	346.7936	0	32.66	9.4	18.0324	60
44	Mat 1	OW	80	7.02	6.4128	4.385653	0	1.295	243.5872	0	39.76	9.4	34.0597	60
45	Mat 2	OW	120	7.68	8.8176	4.872948	0	1.255	491.1824	0	22.72	5	42.0697	200

Note, EC = Electrical conductivity in µS /cm; all other values except pH are in ppm. TH = Total Hardness, TDS = Total dissolved solids; OW = Open well.
VG – Vaiginem; GK- Gaonkarwada; CM- Chimulwada.HW- Haldanwadi; KW- Kelbaiwada.

analysis of all collected samples was undertaken following the standards procedure as described by Trivedi and Goel (1984).Generally chemical characters are broadly classified as physical and chemical parameters. The physical parameters are specific electric conductivity, hydrogen ion concentration (pH), total dissolved solids and chemical parameters are major ionic concentration. The concentration expressed in parts per million (ppm) are converted into equivalent parts per million (epm) wherever necessary. The analysis of any sample is complete, if total anions in epm are equal to total cations in epm. However up to 5% error is permissible to consider the samples for further interpretation.

3.2. Electrical Conductivity (EC)

It is the ability of the substance to conduct the electrical current on various ionic species. The ionic simulation is related to the molecular weight and electrical charge of the solute and varies with temperature. Thus, at a standard temperature, electrical conductivity indicates the degree to which water is mineralized (concentration of dissolved constituents present). Its unit is recorded on µS /cm at 25^0 C. The maximum and the minimum EC of the groundwater in the study area is 2540 µS /cm and 20 µS /cm respectively.

3.3. Hydrogen ion concentration (pH)

It is defined as the pH of water, which is the negative logarithm to the base ten of the hydrogen ion concentration. The pH of natural water is most often controlled by the carbon-dioxide-bicarbonate-carbonate system. The pH values of 7.0 denote the natural water or one in which there is a balance between dissociated hydrogen and hydroxyl ions. An excess of hydrogen ion indicates an acid solution with corresponding pH values less than 7.0. Conversely, and excess of hydroxyl ion indicates a basic solution which has pH value greater than 7.0. The pH in study area ranges from 3.53 to 8.1; the samples are acidic as well as basic.

3.4. Total dissolved solids (TDS)

The total dissolved solids is the measure for all the solids present in solution either in ionized state or non-ionized state and exclude the suspended collide or dissolved gases. The values of TDS in pure water ranges from less than 10 ppm, to more than 300,000 ppm for brines. Water for domestic and industrial uses should have less than 1000 ppm and for agricultural uses it should be below 3000 ppm [12]. The total dissolved solids ranges from 20 ppm to 1140 ppm in the study area.

3.5. Total hardness (TH)

The total hardness of water is mostly influenced by the concentration of divalent metallic cations (viz. Ca and Mg). Total hardness is calculated by using the following formula (Todd, 1959). TH=2.497 Ca+4.115 Mg and expressed as equivalent of calcium carbonate. If the hardness exceeds alkalinity, the excess is termed as non carbonate hardness (NCH). In the study area hardness ranges from 10.01ppm to 400.67ppm.

3.6. Chemical parameters

The chemical parameter are major ion like Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, CO^{-}_{3}, HCO_3^{-}, Cr^{-} and SO^{-}_{4}. These are utilized in determining the total alkalinity, total hardness of water and other relative complex parameters (Table 2).

3.7. Calcium

Calcium is one of the alkaline earth metals and one of the most abundant cations in the surface and groundwater. It is one of the freely dissolving ions from many rocks and soils. In igneous and metamorphic rocks weathering releases calcium from minerals such as feldspars, amphiboles, pyroxenes, apatite, fluorite, wollastonite etc. Calcium compounds are stable in water under the presence of carbon dioxide and precipitation of calcium salts. In the study area the concentration of calcium varies from 2.40 ppm to 82.56 ppm. According to WHO limit the maximum allowable limit of calcium for drinking standards is 200 ppm.

3.8. Magnesium

Ferromagnesian minerals like olivine’s, pyroxenes, amphiboles, micas, chlorite and serpentine in igneous and metamorphic rocks are the principle sources of magnesium. Magnesite and clay minerals also produce magnesium in groundwater. In addition magnesium is also found in sea water, subterranean brines and salt beds. It has been estimated that magnesium constitutes 2.5% of the earth`s crust making it the 8^{th} most abundant chemical element and 6^{th} most abundant metallic element. Magnesium salts are highly soluble and magnesium tends to remain in solution after the calcium salts have been precipitated. Normally, groundwater consists of 1 ppm to 40 ppm of magnesium. But in magnesium rich water, the concentration, may reach up to 100 ppm magnesium concentration in groundwater samples of the study area varies between 0 ppm to 42.8 ppm.

3.9. Sodium and potassium

Sodium is more prominent in groundwater than potassium. The major source for potassium is potash feldspars, leucite, biotite, orthoclase and clay minerals. The primary source of most sodium in natural in natural water is from the release of soluble produce during the weathering of plagioclase feldspars, and leaching of nepheline, sodalite, stillbite, glucophane, etc. In area of evaporate deposits, the solution of halite is also important. Clay mineral and zeolites may, under certain conditions, release large quantities of exchangeable sodium.[12] referred to potassium as commonly less than 1/10 the concentration of sodium in groundwater. The sodium content ranges from 1 to 20 ppm, common in areas of igneous and metamorphic rocks that are also regions of moderate to high rainfall. The solubility of potassium salts is high and is similar in magnitude to the solubility of sodium salts. Most potable groundwater generally contains 1 to 5 ppm of potassium. The concentration will not increase with increase in TDS. Water with TDS 1000 to 5000 ppm has 100 ppm sodium; exception is water from gypsum beds and water from limestone aquifers. It is an essential nutrient for both plant and animal life.[13] Explains that an increase in sodium with concomitant reduction of calcium and magnesium, preponderance of sodium over chloride ions or alternations of calcium bicarbonate to sodium bicarbonate, may be indicative of Base exchange enrichment of sodium. In the study area ranges from similarly for potassium the value ranges from 1.05 ppm to 162.04 ppm.

3.10. Carbonate and Bicarbonate

Carbonates, bicarbonates along with hydroxides produce alkalinity in natural water. The relative amount of these anions depends on the pH of the water and other factors. Bicarbonates increase as pH decreases. Bicarbonate ion served as the main buffer in aqueous freshwater systems and provides carbon dioxide for photosynthesis. Water in contact with the carbonate rocks such as limestone`s and dolomites contributes bicarbonates and carbonates to the aqueous system. They are also generally derived from dissolved carbon dioxide in the atmosphere and in the soil. Sometimes the carbon dioxide is generated from the diagenesis of the organic matter present in the soil may be used to form HCO_3 in water. Generally the concentration of the bicarbonate in the groundwater is between 10 ppm and 800 ppm and carbonate concentration is generally less than 10 ppm. Among the samples collected from the study area none of the samples contain carbonate ions. The concentration of bicarbonate varies from 250ppm to 2000 ppm.

3.11. Chloride

Chloride is a major inorganic ion that occurs in variable concentration in that natural water and is an important factor in the groundwater for deciding its utility for drinking and irrigation purpose. In igneous and metamorphic rocks, sodalite micas and hornblendes are the principle sources of chlorides. The enrichment of the chlorides in saline water zone may be due to evaporation. Chloride never precipitates from water by natural processes and remains there once it gets enriched in the groundwater. Chloride in water is a strong oxidizing agent than oxygen and chloride with oxygen slowly decompose water. Large amount of chloride where calcium and magnesium are also present, increase water corrosiveness and may adversely affect metallic equipments. Chloride content in natural water ranges from 0.1 ppm to 15,000 ppm for brines [12]. The recommended concentration for chloride in drinking water is 250 ppm and permissible limit is 600 ppm (WHO, 1984). The chloride content in the study area varies from 15.6 ppm to 701.4 ppm with most of the samples within the permissible limit for drinking water.

3.12. Sulphate

Sulphate is present as both organic and inorganic compounds in the environment. It is present mostly in the form of sulphates and is formed by the oxidation of suphides in the rocks. Weathering of soil and rocks, atmospheric precipitation and dry fall out and anthropogenic inputs such as the use of fertilizers contributes sulphates to the groundwater. The chemical reduction of the sulphur may take place in certain type of bacteria. Water which has been subjected to reduction contains less sulphate; suphate reducing bacteria are more active in the soil through which recharge water has been percolated [12]. Normally the concentration of sulphate in groundwater varies between 1 ppm and 100 ppm. If the sulphate concentration in groundwater exceeds 250 ppm the water may acquire bitter taste and can produce laxative effects. The sulphate concentration in the water sample of the study area ranges from 0 to 34 ppm.

4. CHEMICAL CLASSIFICATION OF GROUNDWATER

For systematic presentation of the composition of natural water and to know the types, quality and its potential uses, (based on chemistry of water) many classifications, graphical methods and formulae have been proposed by many workers from time to time [13]. The suitability of groundwater of the area has been evaluated following the classification schemes proposed by some of the above mentioned workers and are given in the following pages.

4.1. Hydrochemical facies

The term hydrochemical facies is used to describe the bodies of the groundwater in an aquifer that differ in their chemical composition and highlight the significant ions present in the groundwater. The facies are a function of the lithology, residence time, environment and flow pattern of an aquifer. The concept of hydrochemical facies for the groundwater has been proposed by many earlier

Table 3:.Derived hydrochemical parameters of ground warter of the study area.

S.N	Location	source	Na %	SAR	RSC	PI Doneen	Ionic strength	Indices of base exchange		$CaCO_3$ saturation indices		CR
								CA I	CA II	Eq.Ca	Eq. pH	
1	Shikeri 1	OW	17.7	9.95	12.60	97.922	0.0219	-5.687	-0.735	-68.86	-1.17	0.116
2	Shikeri 2	OW	4.82	1.52	1.261	50.199	0.0188	-0.715	-0.122	-42.88	-1.15	0.165
3	Shikeri 3	OW	0.78	0.60	-1.01	35.99	0.0190	0.392	0.0863	-39.61	-1.13	0.128
4	Shikeri 4	OW	2.27	2.39	5.55	42.044	0.0454	-1.992	-0.184	-6.833	-0.32	0.078
5	Shikeri 5	OW	1.71	1.47	1.697	37.555	0.0353	-0.606	-0.079	-14.60	-0.53	0.116
6	HW 1	OW	2.79	1.92	1.607	58.382	0.0162	-0.756	-0.168	-604.2	-1.40	0.202
7	HW 2	OW	3.63	2.04	3.165	63.622	0.015	-4.427	-0.301	-800.6	-1.69	0.064
8	HW 3	OW	1.68	1.03	1.39	52.615	0.0133	-2.566	-0.160	-76.18	-1.15	0.061
9	HW 4	OW	17.5	9.25	-1.11	78.988	0.032	0.026	0.063	-183.2	-1.62	2.225
10	HW 5	OW	32.3	14.8	10.2	110.15	0.0172	-2.85	-0.27	-225.5	-1.69	0.27
11	KW 1	OW	8.66	7.37	18.76	75.408	0.0405	-31.42	0.019	-126.4	-1.47	0.019
12	KW 2	OW	0.23	7.35	-1.90	34.651	0.0097	0.930	0.382	-157.4	-0.89	0.388
13	GK 1	OW	1.96	0.94	0.691	56.178	0.0104	-0.825	-0.110	-17318	-2.99	0.124
14	GK 2	OW	4.64	2.07	1.90	86.430	0.0070	-3.497	-0.395	-30569	-3.51	0.112
15	VG 1	OW	0.16	0.14	-0.10	20.386	0.0425	0.070	0.0014	-1238.	-2.05	0.223
16	VG 2	OW	1.80	1.61	3.967	43.318	0.0294	-7.218	-0.197	-161.1	-1.12	0.026
17	VG 3	OW	0.81	0.41	0.37	36.115	0.017	-0.705	-0.034	-91.20	-1.51	0.047
18	VG 4	OW	4.36	1.35	1.05	79.04	0.006	-1.946	-0.263	-722.4	-2.25	0.135
19	GK	OW	0.95	0.57	0.225	48.94	0.010	-0.56	-0.053	-0.082	0.665	0.10
20	GK	OW	0.51	0.38	-0.41	27.15	0.029	0.185	0.014	0.778	1.494	0.071
21	CM	OW	1.94	1.45	2.21	48.24	0.020	-1.713	-0.161	0.652	1.538	0.077
22	Poira 1	OW	6.43	2.38	1.93	87.62	0.007	-2.980	-0.417	-41.94	-0.53	0.170
23	Poira 2	OW	1.63	1.18	1.923	49.58	0.016	-3.574	-0.174	0.558	0.924	0.054
24	Sarvana 1	OW	4.18	2.15	2.510	79.50	0.009	-5.332	-0.387	-15.81	-0.21	0.073
25	Sarvana 2	OW	1.24	0.72	0.760	51.25	0.011	-1.960	-0.115	-13.35	-0.01	0.071
26	Vathadev1	OW	3.23	1.17	1.254	58.88	0.011	-2.001	-0.182	-13.35	-0.31	0.098
27	Valshi 1	OW	0.37	1.17	0.868	68.62	0.007	-1.062	-0.172	-4216.	-2.48	0.153
28	Valshi 2	OW	1.12	0.43	-0.04	52.23	0.007	0.095	0.014	-36.93	-0.69	0.125
29	Mulgaon1	OW	0.39	0.19	-0.29	37.033	0.012	0.511	0.051	-10.01	-0.25	0.081
30	Mulgaon2	OW	3.56	2.20	3.394	60.64	0.017	-2.486	-0.270	0.418	0.765	0.089
31	Mulgaon3	OW	2.38	1.22	1.813	53.66	0.014	-3.052	-0.186	-8.883	-0.16	0.059
32	Vathadev2	OW	0.59	0.46	0.631	34.43	0.020	-1.093	-0.044	0.969	2.048	0.040
33	Vathadev3	OW	0.75	0.37	0.191	34.11	0.018	-0.139	-0.009	-7.252	0.093	0.053
34	Vathadev4	OW	1.60	0.49	0.337	55.91	0.007	-1.130	-0.078	-53.50	-1.18	0.075
35	Maullige1	OW	2.08	0.70	0.134	52.91	0.009	-0.332	-0.049	-3.160	-0.01	0.155

36	Maullige2	OW	2.56	0.95	0.527	58.56	0.009	-0.999	-0.127	-31.82	-0.95	0.152
37	Maullige3	OW	3.01	1.02	0.664	60.32	0.009	-1.231	-0.148	-41.86	-0.79	0.146
38	Van	OW	2.87	0.99	0.633	59.85	0.009	-0.563	-0.99	-39.70	-0.57	0.144
39	Borde	OW	0.37	0.16	-0.51	44.01	0.008	0.703	0.129	-226.9	-1.19	0.150
40	Sarvana	OW	0.11	4.12	-0.89	32.44	0.013	0.909	0.107	-0.137	0.543	0.108
41	Karapur	OW	0.31	0.20	-0.92	33.64	0.015	0.671	0.100	0.306	1.41	0.134
42	Pilgaon 1	OW	1.89	1.09	1.074	60.30	0.010	-1.618	-0.167	-0.253	0.681	0.099
43	Pilgaon 2	OW	1.69	0.65	1.143	51.35	0.009	-0.179	-0.028	-2.018	0.050	0.160
44	Mat 1	OW	0.71	0.25	-0.85	45.61	0.007	0.651	0.174	-3.764	-0.22	0.270
45	Mat 2	OW	0.53	0.26	-0.10	38.69	0.0129	0.185	0.014	-0.263	1.018	0.075

OW- open well; VG – Vaiginem; GK- Gaonkarwada; CM- Chimulwadi, HW- Haldanwadi; KW- Kelbaiwada.

Table 4: Classification of ground water of the study area.

Sl. No.	Location	Source	Handa's classification			Scholler's water type	Stuyzand's classification				USSL Classification
			Hard ness	salinity	Sodium hazard		Based on Cl	Based on alkali	Facies: cation	Facies: anion	
1	Shikeri 1	OW	B2	C3	S3	III	F	ALK-VERY-HIGH	Na+k	HCO_3	C1S1
2	Shikeri 2	OW	B1	C3	S1	III	F	ALK-HIGH	Ca	HCO_3	C1S1
3	Shikeri 3	OW	A1	C3	S1	III	F	ALK-HIGH	Ca	HCO_3	C1S1
4	Shikeri 4	OW	B2	C5	S2	III	F	ALK-VERY-HIGH	Ca	HCO_3	C1S1
5	Shikeri 5	OW	B1	C4	S1	III	F	ALK-VERY-HIGH	Ca	HCO_3	C1S1
6	HW 1	ow	B1	C3	S1	III	F	ALK-HIGH	Ca	HCO_3	C2S1
7	HW 2	ow	B1	C3	S1	III	g-oligohaline	ALK-HIGH	Ca	HCO_3	C1S1
8	HW 3	OW	B1	C3	S1	III	g-oligohaline	ALK-HIGH	Ca	HCO_3	C2S1
9	HW 4	OW	A3	C5	S3	IV	B-Brackish	ALK-MOD-HIGH	Na+k	Cl	C4S3
10	HW 5	OW	B2	C3	S3	III	F-Fresh	ALK-HIGH	Na+k	HCO_3	C2S3
11	KW 1	OW	B2	C5	S3	III	g-oligohaline	ALK-Extremely High	Na+K	HCO_3	C1S1
12	KW 2	OW	A1	C2	S1	III	F-Fresh	ALK-MOD-HIGH	Ca	HCO_3	C1S1
13	GK 1	OW	B1	C2	S1	III	F-Fresh	ALK-MOD-HIGH	Ca	HCO_3	C1S1
14	GK 2	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
15	VG	OW	A1	C5	S1	III	g-oligohaline	ALK-VERY-HIGH	Mg	HCO_3	C1S1
16	VG 2	OW	B1	C3	S1	III	g-oligohaline	ALK-VERY-HIGH	Ca	HCO_3	C1S1
17	VG 3	OW	B1	C3	S1	III	g-oligohaline	ALK-High	Mg	HCO_3	C1S1
18	VG 4	OW	B1	C2	S1	III	g-olgohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
19	GK	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
20	GK 2	OW	A1	C3	S1	III	F-Fresh	ALK-VERY-HIGH	Ca	HCO_3	C1S1
21	CM	OW	B1	C3	S1	I	F-Fresh	ALK-HIGH	Ca	HCO_3	C2S1
22	POIRA 1	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
23	POIRA 2	OW	B1	C3	S1	III	g-oligohaline	ALK-HIGH	Ca	HCO_3	C1S1

24	SARVANA	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
25	SARVANA 2	OW	B1	C3	S1	III	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
26	VATHADE V 1	OW	B1	C3	S1	IIII	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
27	VALSI 1	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
28	VALSI 2	OW	A1	C2	S1	I	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
29	MULGAON	OW	A1	C3	S1	I	g-oligohaline	ALK-HIGH	Ca	HCO_3	C1S1
30	MULGAON 2	OW	B1	C3	S1	I	F-Fresh	ALK-HIGH	Ca	HCO_3	C1S1
31	MULGAON 3	OW	B1	C3	S1	III	g-oligohaline	ALK-HIGH	Ca	HCO_3	C1S1
32	VATADEV2	OW	B1	C3	S1	III	g-oligohaline	ALK-HIGH	Ca	HCO_3	C1S1
33	VATADEV 3	OW	B1	C3	S1	I	g-oligohaline	ALK-HIGH	Mg	HCO_3	C1S1
34	VATADEV 4	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Mg	HCO_3	C1S1
35	MAULINGE 1	OW	B1	C2	S1	III	F-Fresh	ALK-MOD-HIGH	Mg	HCO_3	C1S1
36	MAULINGE 2	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Mg	HCO_3	C1S1
37	MAULINGE 3	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Mg	HCO_3	C1S1
38	VAN	OW	B1	C2	S1	I	F-Fresh	ALK-MOD-HIGH	Mg	HCO_3	C1S1
39	BORDE	OW	A1	C2	S1	I	F-Fresh	ALK-MOD-HIGH	Ca	HCO_3	C1S1
40	SARVANA	OW	A1	C3	S1	III	F-Fresh	ALK-HIGH	Ca	HCO_3	C1S1
41	KARAPUR	OW	A1	C3	S1	III	F-Fresh	ALK-HIGH	Ca	HCO_3	C2S1
42	PILGAON1	OW	B1	C2	S1	III	g-oligohaline	ALK-MOD-HIGH	Ca	HCO_3	C1S1
43	PILGOAN 2	OW	A1	C2	S1	III	F-Fresh	ALK-MOD-HIGH	Mg	HCO_3	C1S1
44	MATTAH1	OW	A1	C2	S1	III	F-Fresh	ALK-MODERATE	Mg	HCO_3	C1S1
45	MATTAH 2	OW	A1	C3	S1	III	g-oligohaline	ALK-HIGH	Ca	HCO_3	C1S1

OW- open well; VG – Vaiginem; GK Gaonkarwada; CM- Chimulwada. HW- Haldanwadi; KW- Kelbaiwada

Table 5: Charecterisation ofground water of the study area on the basis of Piper's Trilinear diagram.

Sub-division no. of Diamond shaped field	Characterization of Sub-division Of diamond shaped field	No. of Samples	%
Area 1	Alkaline earths exceed alkalis (Ca+Mg>Na+K)	0	-
Area 2	Alkalis exceed alkaline earths (Na+K>Ca+Mg)	0	-
Area 3	Weak acids exceed strong acids ($HCO_{3,}$ CO_3>$SO_{4,}$Cl)	0	-
Area 4	Strong acids exceeds weak acids (SO_4,Cl>$HCO_{3,}$ CO_3)	0	-
Area 5	Carbonate hardness(Secondary alkalinity) Exceeds 50%	38	84.242%
Area 6	Non-carbonate hardness (secondary salinity) Exceeds 50%	3	6.666%
Area 7	Non-carbonate alkalis(primary salinity) exceed 50%	1	2.242%
Area 8	Carbonate alkalis (primary alkalinity) Exceeds 50%	3	6.666%
Area 9	No one cation and anion pair exceeds 50% (Mixed type)	0	-

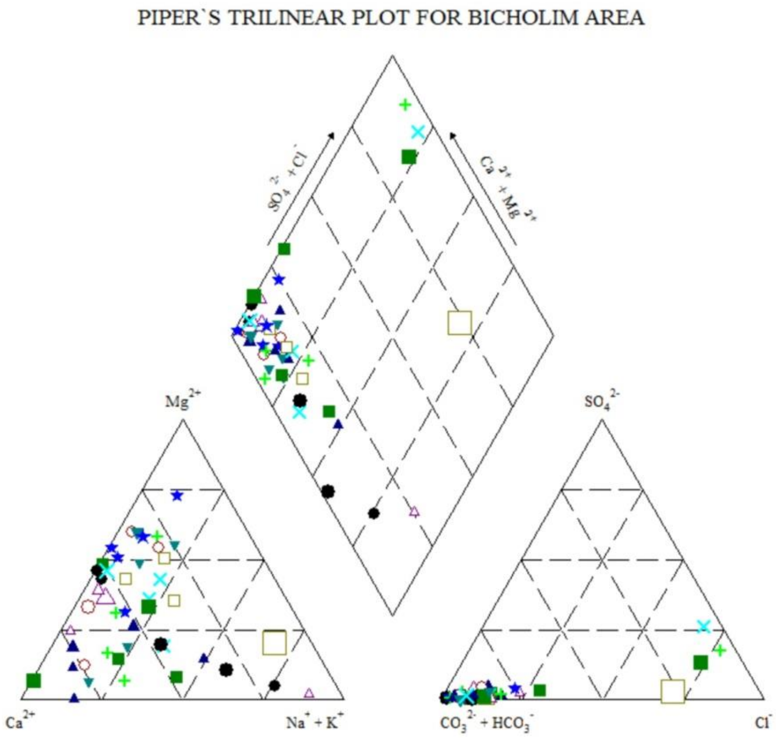

Figure 8: Piper's Trilinear diagram of water of the study area.

workers viz., [13], [18]. The hydrogeochemical facies mainly highlight significant cations and anions present in groundwater of a particular location. The hydrochemical facies of groundwater of the study area were studied following Piper's schemes.

*4.2. Classification of groundwater on the basis of piper's trilinear diagram (*Figure 8*)*

The piper trilinear diagram is used to understand problems related to evaluation of groundwater chemistry [14]. Based on the Piper's trilinear classification, the groundwater of the area under investigation are categorized and represented as shown in the table 5.

The groundwater of Bicholim area mainly occurs in the lateritic terrain. The table depicts that the plot of percentage of cations and anions in the piper diagram. Around **38 samples** fall under the **Area 5** which indicates carbonate hardness (secondary alkalinity) exceeds 50% of the chemical properties of water which are dominated by alkaline earth (Ca, Mg) and weak acid (HCO_3, CO_3). **Sample No 9** from Haldanwadi area falls under **Area 7** that indicates that non-carbonate alkali`s (primary salinity) exceeds 50%. Also **Sample No 1, 10 and 11** fall under **Area 8** which indicates carbonate alkali`s (primary alkalinity) exceeds 50%. Some samples falls under **Area 6** showingNon-carbonate hardness (secondary salinity) Exceeds 50%.

4.3. Hydrogeochemical classification

A variety of classifications are employed to interpret the groundwater quality, types and its potential uses. The different hydrochemical parameters have been considered for these classifications have been proposed based on these hydrochemical parameters ([13], [18] [15], [12]; etc) (table 3 and 4). Groundwater of Bicholim area has been classified following the classification schemes proposed by some of the above mentioned workers which are described in the following paragraphs.

The analysis and some part of interpretation of the hydrogeochemical data has been accomplished using the HYCHEM software. It is very useful software that does many things like conversion of 'ppm data' to 'epm data', calculation of different parameters like SAR, NCH, PI, CR, IBE, Ionic strength and CaCO3 saturation indices etc. It also undertakes classification as suggested by different workers, including the graphical methods.

SAMPLE CODE=SAMPLE 23 OW

EC(mmhos) = 110 TDS (ppm) = 20
pH = 7.13 ORP = 0
DDO = 0 Temp.(centig) = 25

Conc/Ion	Ca	Mg	Na+K	HCO3	CO3	Cl	NO3	SO4
ppm	175.0	8.0	59.0	690.4	0.0	19.9	0.0	9.4
epm	8.7	0.7	2.6	11.3	0.0	0.6	0.0	0.2
%	73.0	5.5	21.5	93.7	0.0	4.6	0.0	1.6

Sodium Adsorption Ratio = 1.183824
Residual Sodium Carbonate= 1.923162
Non-carbonate Hardness =-96.15807
Permeability Index (Doneen)= 49.58866
IONIC STRENGTH = 0.0168 CORROSIVITY RATIO = 0.0547
INDICES OF BASE EXCHANGE = -3.5747 -0.1742

CaCO3 SATURATION INDICES :
Equilibrium Ca method= 0.5581 Equilibrium pH method= 0.9245
GIBB'S PLOT : MECHANISM CONTROLLING THE CHEMISTRY = PRECIPITATION

HANDA'S CLASSIFICATION :
Hardness =B1 Temporary
Salinity =C3 Moderate
Sodium hazard =S1 Low

SCHOELLER'S WATER TYPE (r=epm)
III Since rCL > rSO4 > rCO3

PIPER'S HYDROGEOCHEMICAL FACIES:
Cations = Ca+Mg, Na+K Anions = HCO3+CO3
SIGNIFICANT ENVIRONMENT : RECENT RECHARGE WATER

STUYFZAND'S CLASSIFICATION:
WATER TYPE(Based on Cl) =g-Oligohaline
SUB-TYPE(Based on Alk) =ALK-HIGH
FACIES =Ca HCO3
SIGNIFICANT ENVIRONMENT :
(+) Na+Mg SURPLUS INDICATES FRESHWATER INTRUSION-ANYTIME ANYWHERE

USSL CLASSIFICATION :
Salinity =C1 Sodium hazard = S1

4.4. Irrigation water classification

The suitability of the groundwater for irrigation has to be decided on the effects of the water on plants and also the soils. The irrigation water, which accumulates salts in the soils will cause changes in soil structures, permeability and aeration, thus indirectly affecting the plant growth. The characteristics of an irrigation water that are most important in determining its quality are is total concentration of soluble salts, relative proportion of sodium to other cations and concentration of other toxic elements like boron, under some conditions the bicarbonate concentration is related to the concentration of calcium and magnesium is also important characteristics.

Quality standards for irrigation water are based on the total salt concentration of the water as it affects crop yield through osmotic effects, the concentration of specific ions that may be toxic to plants or that have an unfavorable effect on crop quality, the concentration of cations that can cause deflocculating of the clay in the soil and that resulting damage to soil structure and down in infiltration rate. The rigorous universal standards for irrigation water cannot be formulated.

Irrigation water with high sodium content reduce soil permeability and harden the soil which is due to replacement of Ca^{+2} and Mg^{+2} ions on the clays and colloids by Na^{+} ions . Different classifications are in vogue for irrigation water most of which use sodium concentration as main quality criteria.

Table 6: Classification of ground water of study area (Wilcox, 1948).

Water Class	Number Of Samples	Percentage
Excellent-Good	44	98%
Good-Permissible	-	-
Permissible-Doubtful	-	-
Doubtful-Unsuitable	1	2%
Unsuitable	-	-

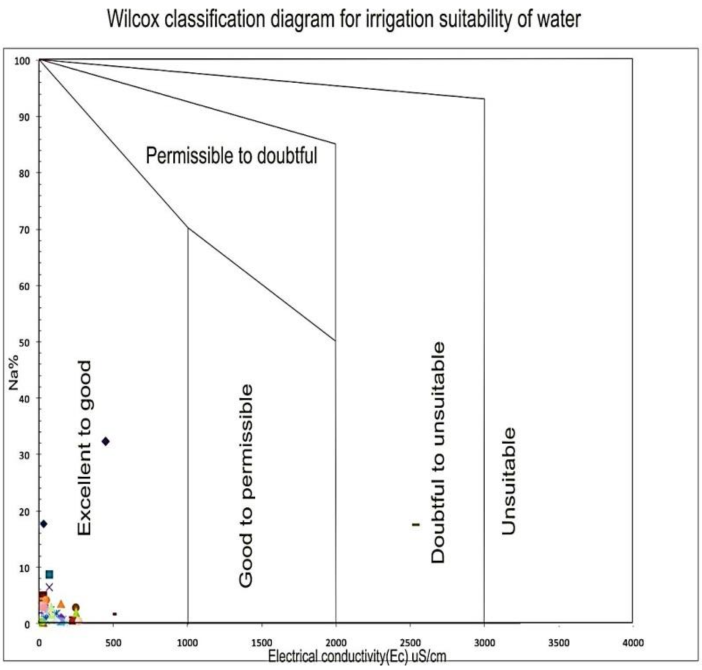

Figure 9: Wilcox Classification Diagram for irrigation suitability of water.

[16] has proposed a diagram for classifying irrigation water wherein he uses soluble sodium percentage (Na %) and the electrical conductivity of the ground water. The sodium percentage for natural water of study area has been determined by using the formula

Na %=(Na+k)/ (Ca+Mg+Na+k) X100

The water is classified on the basis of the position of plots in the diagram into 5 qualitative classes of irrigation suitability viz.

The natural water of the study area is plotted in the Wilcox diagram fig.2.2 and the resultant classification is presented in the table 6.

4.5. Sodium Adsorption Ratio (SAR)

Sodium concentration is an important factor as it reacts with soil and reduces its permeability. SAR has been calculated using the USDA formula table 7.

$$SAR=\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Groundwater samples of the region have SAR ranging from 0.20 to 9.95 suggesting excellent quality as per Richards (1954) classification.

4.6. United states salinity laboratory classification for irrigation suitability

This uses the sodium adsorption ratio (SAR) instead of soluble sodium percentage. The SAR which represents the sodium hazard and electrical conductivity representing the salinity hazard are in the USSL diagram (figure 9). The ground water is divided into 4 classes based on salinity hazards and Based on the sodium hazard 4 classes as follows:

salinity hazards	classes	sodium hazard	classes
Low salinity	C1	Low sodium hazard	S1
Medium salinity hazards	C2	Medium sodium hazard	S2
High salinity hazards	C3	High sodium hazard	S3
Very high salinity hazards	C4	Very high sodium hazard	S4

The plot of the water samples in the USSL diagram assigns a combination of salinity hazard and sodium hazard classes to the water based on which the irrigation quality of the water is assessed using USSL classification of the study area (figure 10), ground water sample collected are presented in the table 8.

Table 7: Sodium adsorption ratio classifications (after Richards 1954).

SAR	Water Class	Number Of Samples	Percentage
<10	Excellent	43	96
10-18	Good	1	2
18-26	Fair	1	2
>26	Poor	-	-

Table 8: USSL classifications for irrigation water

SAR	Water Class	Number Of Samples	Percentage
<10	Excellent	43	96
10-18	Good	1	2
18-26	Fair	1	2
>26	Poor	-	-

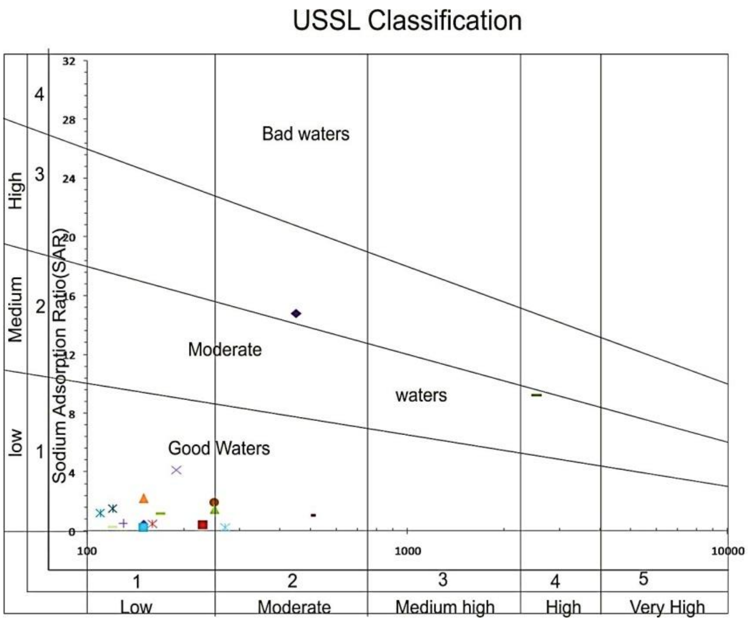

Figure 10: Graph of USSL Classification

4.7. Corrositivity ratio

The magnitude of the corrosiveness of water can be assessed by using a perimeter known as Corrositivity ratio (CR) table.9, which can be determined by using the following formula.

$$CR = \frac{\frac{Cl}{35.5+2SO4}}{2(CO_3 + \frac{HCO_3}{100})}$$

The water having the Corrositivity ratio less than 1 is safe and non corrosive. Corrositivity ratio greater than 2 is suggestive of corrosiveness. Most of the groundwater of the study area falls in the Cr zone less than 1 and so they are safe, suitable and less corrosive and hence can be used for domestic or industrial purposes. The Corrositivity of the water of the study area ranges between 0.026 and 2.225.

4.8. Factors controlling the chemistry of water

The mechanisms that control the groundwater have been studied earlier by [17], etc. The chemistry of groundwater is controlled by various processes, like atmospheric precipitation, evaporation, dissolution and hydrolysis of mineral matter, adsorption and Ion exchange (Matthews, 1982). Many secondary factors like temperature, oxidation, reduction and biological processes affect the above mentioned processes

4.9. $CaCO_3$ saturation indices

The $CaCO_3$ saturation indices (table 10) are another measure to know the suitability of water with respect to its scaling or corroding tendency and are useful for ascertaining the suitability of water for some processes in industries, the $CaCO_3$ saturation indices are positive (i.e. greater than 0), the water is over saturated with calcium carbonates and such wares have tendency for scale formation. The water with negative indices (i.e. less than 0) is under saturated with calcium carbonate and such water have tendency to corrode. The water with saturation indices equal to zero are in equilibrium with $CaCO_3$ and such water are good for certain industrial processes like in boilers. The deep aquifer water of the study area are under saturated and therefore they don't have tendency for scale formation.

4.10. Ionexchange

Apart from the geological and other mechanisms discussed in the earlier paragraphs there are some other mechanisms that cause a change in quality of groundwater either during its movement or during its stay in the aquifer. These have been studied earlier by many workers. Change in chemical composition may be due to chemical precipitation, which may remove ions in solution by forming insoluble compounds, this may be due to change in pressure or temperature conditions or due to mixing of groundwater involving chemical reactions and change in pH. The more common and important reason for change in chemical composition is ion exchange phenomenon. Substances like clay minerals and organic matter can exchange the cations and anions present in the water. Clay minerals like kaolinite and illite exchange in low capacity as the ions are held at the edges only where as the ion exchange capacity is high in case of montmorillonite and vermiculite as the substitution cab take place within the structure. The process involved is known as base of cation exchange.

4.11. Indices of Base Exchange

The indices of bases exchange proposed by [18] are helpful in knowing the Base Exchange phenomenon in groundwater. The indices of Base exchange can be determined using the following equations.

$$CAI = Cl(Na + K)/\text{Cl in meq /l}$$

$$CAII = \frac{Cl(Na + K)}{(SO_4 + HCO_3 + NO_3)}$$

The control values for these indices indicates an exchange between the Na and k in the water wit Mg + Ca in the soil or rock, if the indices are negative, then there is a reverse exchange. Indices of base exchange determined for the groundwater of the study area show both positive and negative indices, but the major portion of the area is negative indices. Groundwater with negative indices of base exchange clearly indicates an exchange between the Ca + Mg from groundwater with Na + k in the rock or soils. The negative indices of base exchange all explains that most of the groundwater have lesser residence time (Freeze and Cherry 1979, Fatter 1980)

5. CONCLUSION

The study area lies between latitude 15 °59'00" N and 15°37'30" N and 73°59'13" E and 73°53'30" E longitude and comprises a total area of about 90 km^2. The area show`s very undulating terrain forming hills and valleys. The highest elevation is 140 m and lowest elevation is 2 m above MSL. The trend of terrain is NW-SE which is controlled by folds and schistosity of rock formation. The study area is situated on the western coastline and is affected by the south west monsoon, which brings precipitation to the study area. The area shows very well developed dendritic drainage pattern and it indicates the water drainage to Dichloli river and Mondovi river. The stratigraphical sequence of the area consists of Bicholim formation which overlies the Sanvordem formation containing quartz-chlorite-amphibolites schist, ferruginous pink phyllite , limestone , manganiferous chert , breccias and BFQ`s.

Hydrologically the area covers lateritic formations and are highly jointed and fractured they control the groundwater potentiality and its vulnerability to pollution and sea water intrusion. According to the above studies the area reveals that rainfall is found to be the main source of recharging the shallow aquifer system.

Aim and objectives of the study is to analyze the primary chemical parameters of water, its quality, classify the water into categories based on various parameters, to demarcate wells to be used for domestic, industrial and irrigational purposes, depending upon water quality to determine the extent of sea water intrusion in the area by comparing the salinity of wells.

The water has been classified into ionic and non ionic parameters based on EC, TDS, TH, Hydrochemical facies, Salinity, Sodium Hazard Percentage, USSL Classification, Wilcox Classification and following conclusions are observed:

The pH in the study area varies considerably and the samples are acidic as well as basic in nature. From the quantum of TDS and EC it can be concluded that most of water samples are fresh water samples and hence have low electrical conductivity.

Total Hardness of ground water samples in study area varies from 10.01 ppm to 400.6 ppm. Most of the water samples are soft in nature with hardness ranging from 0 to 75 ppm and only 2 samples are moderately hard to hard.

Table 9: Corrositivity ratio of study area.

Sl.No	Range Of CR	Character Of Water	Frequency	Percentage
1	<1	Safe	44	98%
2	>2	Unsuitable	1	2%

Table 10: Depicting $CaCO_3$ Saturation Indices of the study area.

Sl.No	$CaCO_3$ Saturation Indices	Frequency	Percentage
1	Under saturated	39	87%
2	Equilibrium	-	-
3	Oversaturated	6	13%

In the study area the carbonates are totally absent. While bicarbonates are relatively high in the area such as shikeri 4, shikeri 5, kelbaiwada 1,vainginem1,Vainginem 2, Gaonkarwada 2, are more than 1000 ppm.

Sulphate (SO_4) content in the study area is scarce, with highest value reported in the sample no 9 from the Haldanwadi 4 ppm

According to the investigations about 98% of the water samples are within permissible limit and these was further confirmed by USGS classification the water can be used for various purposes like domestic, irrigation and industrial.

According to Handa's classification most of the samples show Carbonate hardness and low to medium salinity and show low sodium hazard. Stuyfzand's classification 97% of samples falls under oligohaline to fresh water category and 95% of samples show alkali - moderately high, alkalinity to alkali high, alkalinity based on alkali concentration.

According to Schoeller classification, 82% of samples consists $rCl > rSO_4 > rCO_3$ this indicates

type III water.

According to USSL and WILCOX classification 98% of water samples from the area are excellent to good quality for irrigation.

Piper`s Trilinear classification gives us a conclusion that 91% of the sample show carbonate hardness exceeds 50%, 2% samples show non-carbonate alkali exceeds 50% and 6% show carbonate alkali`s exceeds 50%.

The Corrositivity ratio of the most water samples of the study area is less than 1 that means the water is safe for industrial use and it can be transported in metallic pipes.

From the analysis also reported Sample No 9 from Haldanwadi 4 area has the maximum values for parameters such as EC, Calcium, Magnesium, Sodium, Chlorine, Sulphate and TDS compared to all other samples from the study area not suitable for domestic, irrigation as well as industrial purpose. So we suggest that the well must be abandoned.

The comparison of the ground water chemistry of Bicholim area with the drinking water standards of WHO and ICMR have indicated that most of the water samples from study area are suitable for drinking purpose, but in practice only few are used for drinking purpose as the government of Goa provides good quality drinking and potable water to every house hold in the study area.

6. REFERENCES

[1]. Subramanian (1971) first systematic hydrogeological survey in the northern part of Goa. Published ministry of water resources. Govt. of India

[2]. Subramaniam, (1981), Surface and groundwater resources in the northern part of Goa: Proc: Earth resources for Goa's development, Panaji, Goa, pp. 9

[3]. Ghosh (1985) studied the rainfall contribution to groundwater recharge and evapotranspiration and surface runoff. Published by Govt. of India (CGWB).

[4]. Pathak (1981) the optimal design of groundwater structures together with proper selection of pumping unit in the territory to avoid hazards of seawater intrusion. Groundwater information booklet, Goa state published by Govt. of India (CGWB).

[5]. Adyalkar (1985) a systematic hydrogeological investigation in parts of Goa. Published by Govt. of India (CGWB).

[6]. Chachadi, A.G. (2002), Impact assessment and remediation of open-cast mine dewatering on rural drinking water supplies in Goa. Unpublished project report of the Rajeev Gandhi National Drinking Water Mission, Govt., of India, Department of Geology, Goa University.

[7]. Watson, K. (1989) Lineaments – A timely challenge or a waning illusion? *MemoirsGeological Society of India*, No.12, pp. 1659 – 1682.

[8]. Barreto M. A. (2001). Groundwater use estimation and sea water intrusion

mapping in the coastal Bardez Taluka, North Goa. Unpublished M.Sc. dissertation,

[9]. Fernandes M. (2002). Hydrogeology and groundwater recharge in Goa state. Unpublished M.Sc. dissertation, Department of Earth Science, Goa University, Goa.

[10]. Davangiri I. (2004). Hydrogeology and groundwater balance of a small watershed in the mining area of North Goa. Unpublished M.Sc. dissertation, Department of Earth Science, Goa University, Goa.

[11]. Kavlekar M. (2007). Hydro geological studies and morphometric analysis of Verna sub-watershed of Zuari river basin, South Goa. Unpublished M.Sc. dissertation, Department of Earth Science, Goa University, Goa.

[12]. Davis and Dewiest (1966) *Hydrogeology*. John Wiley and sons, New York.

[13]. Piper, A.M. (1944) A graphic procedure in the Geochemical interpretation of water analysis – ***Transactions - American Geophysical Union***, **25**, 914 -928.

[14]. Karanth KR (1987) (Ed.) Groundwater assessment, development and management. Tata McGraw-Hill Publ. Co.Ltd, New Delhi

[15]. Handa, B.K. (1964) Modified classification procedure for rating irrigation waters. ***Soil Science***, **98**, 313 - 314.

[16]. Wilcox, L.V., (1948) The quality of water for irrigation use. U.S Department of Agriculture Technical Bulletins - 962, Washington, D.C., 40 pp

[17]. Gibbs (1970) Mechanisms controlling world water chemistry. ***Science***, 170

[18]. Schoeller H (1967) Qualitative evaluation of ground water resource In: Methods and techniques of groundwater investigation and development. Water resources series - 33, UNESCO.