GROUND WATER QUALITY IN SHALLOW AQUIFER OF GOA STATE

Central Ground Water Board,
Department of Water Resources, River
Development and Ganga Rejuvenation
Ministry of Jal Shakti
2023

REPORT ON

GROUND WATER QUALITY IN SHALLOW AQUIFER OF GOA STATE

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Govt. of India
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1.0 INTRODUCTION

The quality of groundwater is a very sensitive issue. Groundwater is never pure and contains varying amounts of dissolved solids, the type and concentration depend on itssource, surface and sub-surface environment, rate of groundwater movement, the residence time, the solubility of minerals present and the amount of dissolved carbon dioxide. In addition to the natural changes, anthropogenic activities such as sewage disposal, agricultural practices, industrial pollution etc. also contribute significantly to changes in groundwater quality. Once the contaminants have entered to the sub-surface geological environment, they may remain concealed for many years and may get dispersed over wide areas. Weathering of rock and mineral solubility controls the major ion composition of groundwaters. With increasing anthropogenic activities, a substantial amount of dissolved matter is added to groundwater. The ground water resources are being utilized for drinking, irrigation and industrial purposes. However, due to rapid growth of population, urbanization, industrialization and agriculture activities, ground water resources are under stress. There is growing concern on the deterioration of ground water quality due to geogenic and anthropogenic activities.

India is a vast country with varied hydrogeological situations resulting from diversified geological, climatological and topographic settings. Water-bearing rock formations (aquifers), range in age from Archaean to Recent. The natural chemical composition of ground water is influenced predominantly by type & depth of soils and subsurface geological formations through which ground water passes. Ground water quality is also influenced by contribution from the atmosphere and surface water bodies. Quality of ground water is also influenced by anthropogenic factors. For example, overexploitation of ground water in coastal regions may result in sea water ingress and consequent increase in salinity of ground water, excessive use of fertilizers and pesticides in agriculture and improper disposal of urban/industrial waste can cause contamination of ground water resources.

A diverse range of dissolved inorganic compounds present in different concentrations characterizes groundwater. These compounds originate from the chemical and biochemical interactions between water and geological substances. Inorganic impurities such as salinity, chloride, fluoride, nitrate, iron, and arsenic play a crucial role in assessing the suitability of groundwater for drinking purposes.

1.1 LOCATION, EXTENT AND ACCESSIBILITY

Goa is the smallest State in India by area and the fourth smallest by population. It lies in the west coast of India between the Arabian Sea and the Western Ghats. It is bordered by Karnataka to the east and south, Maharashtra to the North and the Arabian Sea to its west (Fig 1). The Goa State is situated between North latitudes 14° 53′ 57″ and 15° 47′ 59″ and East longitudes 73° 40′ 35″ and 74° 20′ 11″. The geographical area of the State is 3702 sq.km and falls in the Survey of India toposheets Nos. 48E/13, 14,15,&16, 48I/2,3,4,5,& 6 and 48J/1.

The State is well connected by air, railway and road network to all metros in the country. National Highways (West Coast Highway (NH-17,17A) and the National Highway (NH4A) connecting Panaji and Belgaum) passes through the State. All the important villages are connected by metal roads and all the parts of State are easily approachable. The State has two distinct rail lines namely the South Western Railway and the Konkan Railway (Trivandrum-

Mumbai). Dabolim airport is Goa’s sole airport which serves as a military as well as civilian airport handling both domestic and international air lines. The excellent connectivity network has helped the growth of tourism in the State.

1.2 ADMINISTRATIVE SETUP AND DEMOGRAPHY

Administratively, the State has divided in to two districts viz., North and South Goa districts with headquarters at Panaji and Madgoa respectively. The North Goa district comprising six taluks has a total area of 1463.13 sq.km and South Goa comprising six taluks covers an area of 2238.87 sq.km. Total number of villages in the State is 654, out of which 338 are in North Goa and remaining in South Goa.

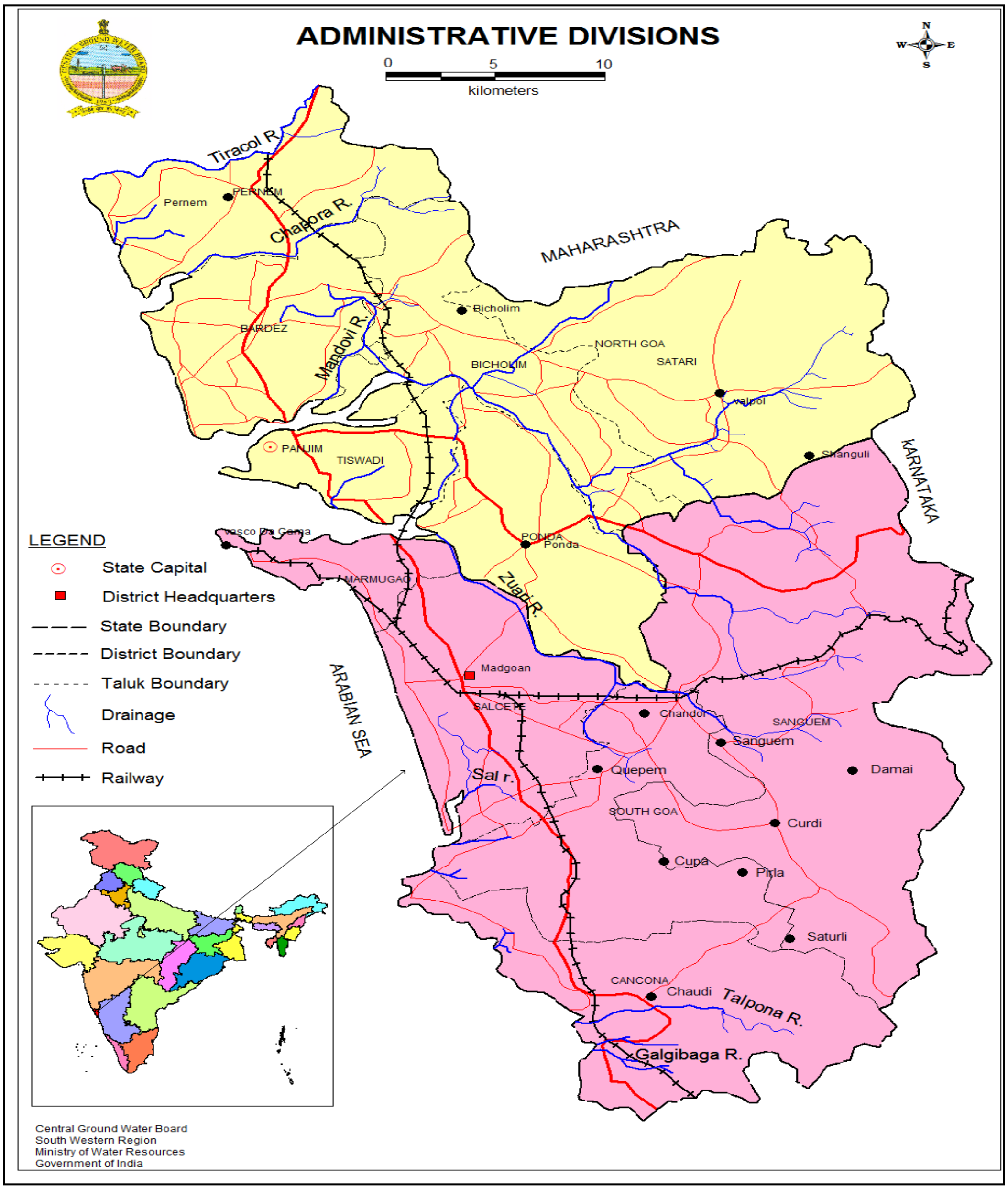

Fig. 1: Administrative Map of Goa State

1.3 AGRICULTURE AND CROPPING PATTERN

The State has been blessed with such soils and climatic conditions that favour growth of a variety of tropical crops. Agriculture is one of the important occupations of the people of Goa. Agriculture in Goa is quite commercialized in the sense that 36.63% of cultivated land is covered by cashew nut and 17.04% by coconuts. Gross Cropped Area of Goa State is 151957 ha (i.e. 42.08% of total geographical area). Rice is the principal crop which covers 38520 ha accounting for about 25.08% of the total cropped area. It is grown both in Kharif and Rabi seasons. Other main agricultural produce of Goa comprises of paddy, cashew nut, millet, coconut, sugarcane, pineapple, banana, mango etc. Gross cropped area under paddy is 38520 ha, out of which Salcete taluk has the largest area with 7530 ha. Cashew nuts are grown extensively in all the taluks of the State. The largest area under cashew nut is in Satari taluk (10803 ha). Other crops grown are cereals, millets, pulses & oil seeds, which constitute an area of 7077 ha (4.61%), Coconuts 26169 ha (17.04%) and areca nut 1836ha (1.10%).(Source:-Directorate of Agriculture, Govt. of Goa)

1.4 IRRIGATION

The geographical area of the State of Goa is 3.71 lakh hectares out of which net sown area is only 1.3 lakh hectares i.e 36%. Before liberation in 1961, total irrigation area was 7500 ha and after liberation a number of irrigation projects were constructed to promote irrigated agriculture. The water resources of the Goa State have been assessed at 8,570 MCM by the Central Water Commission (CWC). However, due to topographical, geological and other constraints the level of utilization of resources for irrigation is expected to be 1,465 m (1125 m surface + 340 m ground water). State government has constructed various storage structures for irrigation through major, medium and minor irrigation projects. (Source: Fourth Census of Minor Irrigation Schemes 2006-07)

2. HYDROGEOLOGY

The main source of ground water occurring in the state of Goa is mainly through precipitation and return flow from applied irrigation. The ground water occurrence and movement are controlled by the degree of weathering, fracturing and the geomorphological set up in the State.

2.1 WATER BEARING PROPERTIES OF THE ROCK FORMATIONS

The ground water availability depends upon the water bearing properties of the rock formations. The water bearing properties of metabasalt and metagreywacks and the associated rocks of Precambrian age are also dependent on the fracturing, jointing and foliation present in the rocks. The water bearing formations in the state of Goa are granite and granite gneiss, meta-volcanic & meta-sedimentaries, laterite and alluvium. Major Aquifer system and Hydrogeological set up of Goa state are presented in Fig.2 and Fig.3 respectively.

2.1.1 GRANITE AND GRANITE GNEISS

The granite and granitic gneiss vary widely in their water bearing properties. They do not have intergranular primary openings. Fresh crystalline rocks have less than one percent porosity and the permeability is negligible. Water bearing properties of the crystalline rocks depend upon the intensity of secondary porosity which occur in the form of weathered and fractured zones. The fracture porosity, degree of weathering and topographical setting play a dominant role in their productivity. The weathering processes increase the porosity and permeability of the granites and topographical setting controls the movement of water in the phreatic aquifer system

2.1.2 METAVOLCANICS & METASEDIMENTARIES

The water bearing properties of metabasalt and metagraywackes and the associated rocks of pre-cambrian age are also dependent on the fracturing, jointing and foliation present in the rocks.

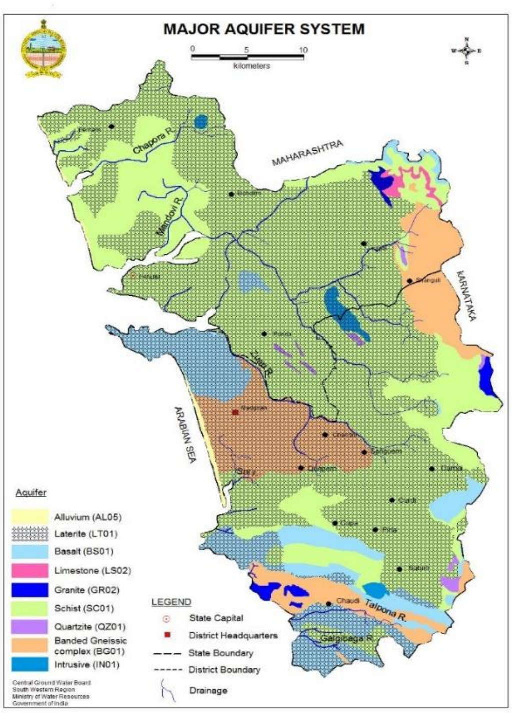

Figure. 2: Major Aquifer System of Goa

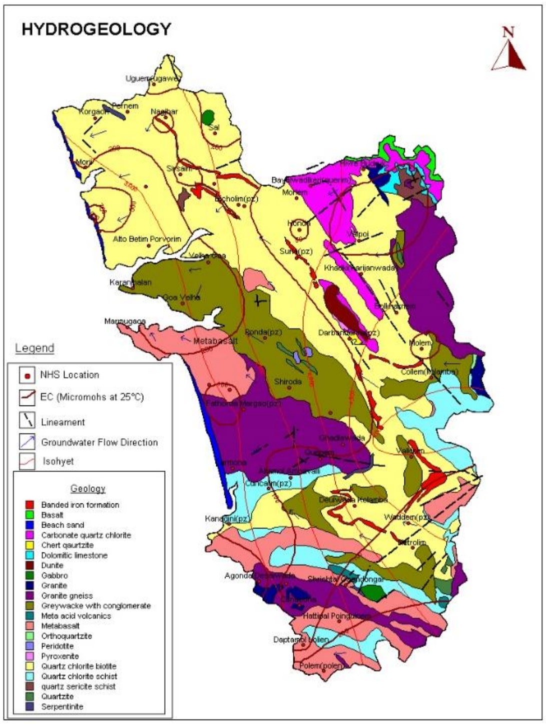

Figure. 3: Hydrogeological map of Goa

2.1.3 LATERITES

Laterites are the most important water-bearing formation covering over 60 percent of the state. The ground water occurs in laterites in their intricate network of sinuous conduits and in the weathered mantle. The lower section of the pallid zone, i.e., lithomarge serves as an effective aquiclude. The low-level secondary laterite of detrital origin offers an ideal venue for groundwater through its opening and loosely cemented zones. Besides the inherent porosity, the laterites are highly jointed and fractured which further enhances their water-bearing capacity. Like other formations, the degree of weathering and topographical setting of laterites have also a definite role to play in deciphering their ground water potential.

2.1.4 ALLUVIUM

The beach sands along the coast are characterised by their primary porosity. The groundwater occurs in the intergranular pore spaces of sands, gravels and pebbles with intercalated clays muds and silts serving as limited aquicludes. There are gravel beds occurring at different depths varying from 1 to 8 m bgl in the beach sand deposit and these are the most important water bearing horizons of the beach area.

2.2 OCCURRENCES OF GROUND WATER

In general, ground water occurs under water table conditions in shallow aquifer and semi-confined to confined conditions in deeper aquifer. The occurrence and movement of groundwater in the crystalline rock is along the weathered and fractured zones. In the upper portion the water moves through the permeable weathered rock and in the lower portion through fractures, joints and fissures. Fractured zones are followed by massive bedrock which acts as an aquiclude. In laterites, the movement of groundwater is through the network of conduits and along the joints and fractures right up to the basal portion, where lithomarge acts as an aquiclude. Further, there is an apparent hydraulic continuity between the water table aquifers in the laterites and the recent deposits of beach and alluvial sand.

2.2.1 GRANITE AND GRANITE GNEISS

Ground water occurs under unconfined, semi-confined and confined conditions in the weathered and fractured zones of granite and granitic gneiss. The laterites and the near surface weathered and jointed zones of granites and associated rocks together constitute the main water table aquifer. Depth to water level in these formations in irrigation wells varies from 3.8 to 6.25 m bgl and specific capacity between 14.4 and 77.3 m3/day/m. Exploratory boreholes drilled in granite and granite gneiss is in the depth range of 70.7 to 124 m bgl and discharges is recorded between 0.77 and 8.8 lps. Specific capacity of exploratory wells varies from 2.27 to 43 m3/day/m and transmissivity from 0.87 to 34.6 m2/day.

2.2.2 METAVOLCANICS & METASEDIMENTARIES

Semi-confined condition of groundwater has been observed in the weathered and fractured zones of granite, metagraywackes and metabasalts where they are mostly overlain by laterites with lithomarge serving as a confining layer. The aquifer characteristics of the meta-volcanics and meta-sedimentaries vary widely. Irrigation dug wells tap the weathered zones up to 9.25 m bgl. The diameter of dug wells vary from 2.2 to 6.1 m and depth to water level vary from 1.48 to 6.26 m bgl. Specific capacity varies from 10.6 to 228.7 m3/day/m.

2.2.3 LATERITES

In Laterites, the movement of ground water is through the network of conduits and along the joints and fractures right up to the basal portion where lithomarge acts as an aquiclude. The thickness of laterites extends up to 30 m. Irrigation dug wells tapping laterite ranges in depth from 2.85 m to 10.38 m and depth to water level varies from 1.3 to 6.5 mbgl. Ground water occurs under phreatic condition with specific capacities in the range of 1.73 to 3205 m3/day/m.

2.2.4 ALLUVIUM

The thickness of the coastal alluvium varies from 5 m to 22 m. Fine to coarse sands with intercalations of sandy loam, silt and clay occurring at depth range of 1.42 to 7.7 mbgl is tapped by dug wells. Depth to water levels in these formations varies from 1.4 to 5.85 m bgl. Specific capacity ranges between 72 to 297.85 m3/day/m.

2.3 GROUND WATER REGIME MONITORING

Ground water is a dynamic system. It always remains under the influence of time dependant recharging and discharges factors. Due to this continuous influence, water level of the aquifer system fluctuates and the range depends on the period of influence. Monitoring of ground water regime is an effort to obtain information on ground water levels and chemical quality through representative sampling. The important attributes of ground water regime monitoring are ground water level, ground water quality and temperature. The primary objective of establishing the ground water monitoring network stations is to record the response of ground regime to the natural and anthropogenic stresses of recharge and discharge parameters with reference to geology, climate, physiography, land use pattern and hydrologic characteristics. Central Ground Water Board has been started monitoring the ground water regime through all India National Hydrograph Network Stations from 1969 onwards. The density of observation wells was increased year after year.

Ground water monitoring was carried out earlier through a network of open wells in the Goa state tapping the shallow aquifer only. Recently piezometers tapping both shallow and deeper aquifers have been constructed under Hydrology Project-II.

At present the Ground water monitoring wells along with the piezometers are being monitored four times in a year (Jan, May, August and November). Ground water samples are being collected from these observation wells once a year during the month of May to obtain background information of ground water quality changes on regional scale. The database thus generated forms the basis for planning the ground water development and management programme. This data is used for assessment of ground water resources and changes in the regime consequent to various development and management activities.

The total number of hydrograph stations in the state of Goa is 152, out of these 152 stations, 103 are dug wells tapping shallow aquifer and 49 are the piezometers tapping shallow and deeper aquifers. The District-wise distribution of the ground water observation wells is given in Table- 2.3 and location map of National Hydrograph station is presented in Fig-4.

Table 2.3: District wise distribution of NHS

Sl.No	Districts	No of NHS		Total No of NHS
		Dug wells	Piezometers	
1	North Goa	54	28	82
2	South Goa	49	21	70
	Goa	**103**	**49**	**152**

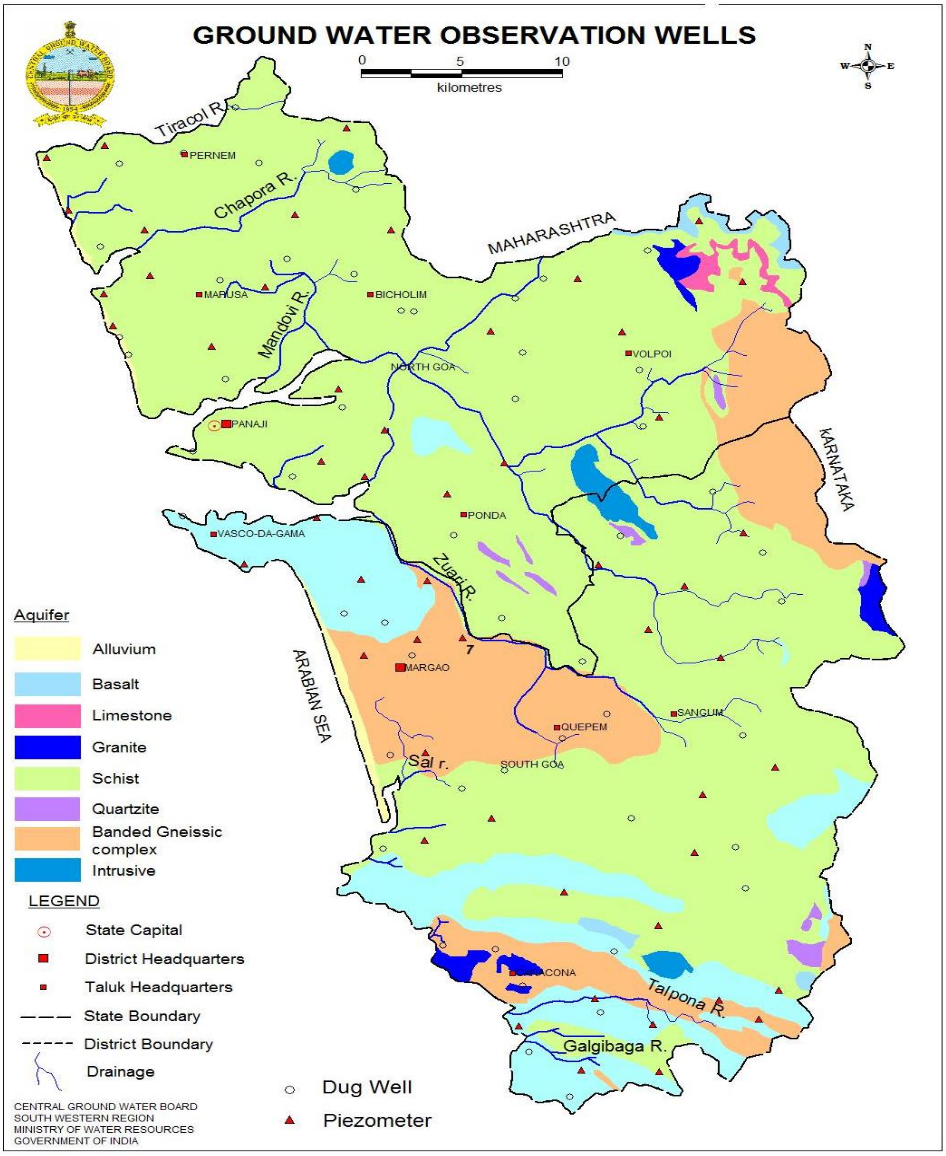

Figure. 4: Location of observation wells in Goa State

3.0 HYDROCHEMISTRY

Hydrochemistry is an interdisciplinary science that deals with the chemistry of water in the natural environment. Professional fields such as chemical hydrology, aqueous chemistry, hydrochemistry, water chemistry and hydro-geochemistry are all more or less synonyms. The classical use of chemical characteristics in chemical hydrology is to provide information about the regional distribution of water qualities. At the same time, hydrochemistry has a potential use for tracing the origin and history of water. The hydrochemistry can also be of immense help in yielding information about the environment through which water has circulated. Hydrochemistry can be helpful in knowing about residence times, flow paths and aquifer characteristics as the chemical reactions are time and space dependent. It is essential to study the entire system like atmospheric water (rainwater), surface water and ground water simultaneously in evaluating their hydrochemistry and pollution effect.

3.1 CHEMISTRY OF RAINWATER

The atmosphere is composed of water vapors, dust particles and various gaseous components such as N_2, O_2, CO_2, CH_4, CO, SO_4, NO_3 etc. Pollutants in the atmosphere can be transported long distances by the wind. These pollutants are mostly washed down by precipitation and partly as dry fall out. Composition of rainwater is determined by the source of water vapors and by the ion, which are taken up during transport through the atmosphere. In general, chemical composition of rainwater shows that rainwater is only slightly mineralized with specific electrical conductance (EC) generally below 50 μS/cm, chloride below 5 mg/l and HCO_3 below 10 mg/l. Among the cations, concentration of Ca, Mg, Na & K vary considerably but the total cations content is generally below 15 mg/l except in samples contaminated with dust. The concentration of sulphates and nitrates in rainwater may be high in areas near industrial hubs.

3.2 CHEMISTRY OF SURFACE WATER

Surface water is found extremely variable in its chemical composition due to variations in relative contributions of ground water and surface water sources. The mineral content in river water usually bears an inverse relationship to discharge. The mineral content of river water tends to increase from source to mouth, although the increase may not be continuous or uniform. Other factors like discharge of city wastewater, industrial waste and mixing of waters can also affect the nature and concentration of minerals in surface water. Among anions, bicarbonates are the most important and constitute over 50% of the total anions in terms of milli equivalent per liter (meq/l). In case of cations, alkaline earths or normally calcium predominates but with increasing salinity the hydrochemical facies tends to change to mixed cations or even to Na-HCO_3 type.

3.3 CHEMISTRY OF GROUND WATER

The downward percolating water is not inactive, and it is enriched in CO_2. It can also act as a strong weathering agent apart from general solution effect. Consequently, the chemical composition of ground water will vary depending upon several factors like frequency of rain, which will leach out the salts, time of stay of rain water in the root-zone and intermediate zone, presence of organic matter etc. It may also be pointed out that the water front does not move in a uniform manner as the soil strata are generally quite heterogeneous. The movement of percolating water through larger pores is much more rapid than through the finer pores. The overall effect of all these factors is that the composition of ground water varies from time to time and from place to place.

Before reaching the saturated zone, percolating water is charged with oxygen and carbon dioxide and is most aggressive in the initial stages. This water gradually loses its aggressiveness, as free CO_2 associated with the percolating water gets gradually exhausted through interaction of water with minerals.

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

$$H^+ + \text{Feldspar} + H_2O \longrightarrow \text{Clay} + H_4SiO_4 + \text{Cation}$$

The oxygen present in this water is used for the oxidation of organic matter that subsequently generates CO_2 to form H_2CO_3. This process goes on until oxygen is fully consumed.

$CH_2O + O_2 = CO_2 + H_2O$
(Organic matter)

Apart from these reactions, there are several other reactions including microbiological mediated reactions, which tend to alter the chemical composition of the percolating water. For example, the bicarbonate present in most waters is derived mostly from CO_2 that has been extracted from the air and liberated in the soil through biochemical activity. Some rocks serve as sources of chloride and sulphate through direct solution. The circulation of sulphur, however, may be greatly influenced by biologically mediated oxidation and reduction reactions. Chloride circulation may be a significant factor influencing the anion content in natural water.

4.0 WATER QUALITY CRITERIA

The available quality of groundwater is the resultant of all the processes and reactions, which taken place since the condensation of water in the atmosphere to the time it is retrieved in the form of groundwater from its source. The water has excellent capability to accumulate substances in soluble form as it moves over and into the land resource, from the biological processes and from human activities. Urbanization, agricultural development and discharges of municipal and industrial residues significantly alter characteristics of groundwater resource. The prevailing climatic conditions, topography, geological formations and use and abuse of this vital resource have significant effect on the characteristics of the water, because of which its quality varies with locations.

The definition of criteria and standards for water quality vary with the type of use. The characteristic of water required for human consumption, livestock, irrigation, industriesetc., have different water quality requirements. The term water quality criteria may be defined as the "Scientific data evaluated to derive recommendations for characteristics of water for specific use'. The term standard applies to any definite rule, principle or measure established by any statutory Authority. The distinction between criteria andstandards is important, as the two are neither interchangeable nor they become synonyms for the objective or goal. Realistic standards are dependent on criteria, designated uses and implementation as well as identification and monitoringprocedure. The changes in all these factors may provide a basis for alteration instandards. In formulation of water quality criteria, the selection of water quality parameters depends on its use. Sayers, et. al. (1976 as quoted in CGWB & CPCB2000) identified the key water quality parameters according to its various uses **(Table 4.0).**

Table 4.0: Water quality criteria parameters for various uses (Sayers et.al., 1976)

Public Water supply	Industrial Water supply	Agricultural water supply	Aquatic life & wild life water supply	Recreation and Aesthetics
Coliform bacteria Turbidity colour, Taste, Odour TDS, CI, F, SO_4 NO_3, CN, Trace Metals, Trace Organics Radioactive substances	**Processing** pH, Turbidity Colour, Alkalinity, Acidity, TDS, Suspended solids, Trace metals, Trace Organics **Cooling** PH, Temp, Silica, AI, Fe, Mg, Total hardness, Alkalinity / Acidity Suspended solids, Salinity	Farmstead Same as for public supply Live-stock Same as for public supply Irrigation TDS, EC, Na, Ca, Mg, K, B, CI and Trace metals	Temp, DO, pH, Alkalinity, Acidity, TDS Salinity, pH, DCOs, Turbidity Colour, Settleable materials, Toxic substances, Nutrients, Floating materials	Recreations Tem, Turbidity, Colour, Odour, Floating Materials, Settable Materials Nutrients, Coliforms Aesthetics Same as for Recreation and Substances adversely affecting wild life

4.1 WATER QUALITY CRITERIA FOR DRINKING PURPOSE

With the objective of safeguarding water from degradation and to establish a basis forimprovement in water quality, standards / guide lines / regulations have been laid downby various national and international organizations such as; Bureau of Indian Standards(BIS), World Health Organization (WHO), European Economic Community (EEC), Environmental Protection Agency (EPA), United States, and Inland Waters Directorate, Canada. The Bureau of Indian Standards (BIS) earlier known as Indian Standards Institutions (ISI) has laid down the standard specification for drinking water during 1983, which have been revised and updated from time to time. In order to enable the users, to exercise their discretion towards water quality criteria, the maximum permissible limit has been prescribed especially where no alternative sources are available. The national water quality standards describe essential and desirable characteristics required to be evaluated to assess suitability of water for drinking purposes. The important water quality characteristics as laid down in BIS standard (IS 10500: 2012) are summarized in **Table - 4.1**

Table 4.1: Drinking Water Characteristics (IS 10500: 2012)

S. No.	Parameters	Desirable Limits (mg/L)	Permissible limits (mg/L)
Essential Characteristics			
1	Colour Hazen Unit	5	15
2	Odour	Unobjectionable	-
3	Taste	Agreeable	-
4	Turbidity (NTU)	1	5
5	pH	6.5-8.5	No relaxation
6	Total Hardness, $CaCO_3$	200	600
7	Iron (Fe)	1.0	No relaxation
8	Chloride (Cl)	250	1000
9	Residual Free Chlorine	0.2	1
10	Fluoride (F)	1.0	1.5
Desirable Characteristics			
11	Dissolved Solids	500	2000
12	Calcium (Ca)	75	200
13	Magnesium (Mg)	30	100
14	Copper (Cu)	0.05	1.5
15	Manganese (Mn)	0.1	0.3
16	Sulphate (SO_4)	200	400
17	Nitrate (NO_3)	45	No relaxation
18	Phenolic Compounds	0.001	0.002
19	Mercury (Hg)	0.001	No relaxation
20	Cadmium (Cd)	0.003	No relaxation
21	Selenium (Se)	0.01	No relaxation

22	Arsenic (As)	0.01	No relaxation
23	Cyanide (CN)	0.05	No relaxation
24	Lead (Pb)	0.01	No relaxation
25	Zinc (Zn)	5.0	15
26	Hexavalent Chromium	0.05	No relaxation
27	Alkalinity	200	600
28	Aluminum (Al)	0.03	0.2
29	Boron (B)	0.5	2.4
30	Pesticides	Absent	0.001
31	Uranium	0.03	No relaxation

NTU- Nephelometric Turbidity Unit.

N.B. The fluoride limits vary with average annual temperature of the areas. Similarly, the limits for magnesium are based on sulphate contents of water. When sulphate content is 250 mg/L or above, the magnesium should be between 30 and 50 mg/L but ifsulphate is lower, higher content of magnesium is permissible.

4.2 WATER QUALITY CRITERIA FOR IRRIGATION PURPOSE

Water quality plays a significant role in irrigated agriculture. Many problems originate due to inefficient management of water for agriculture use, especially when it carries high salt loads. The effect of total dissolved salts in irrigation water (measured in terms of electrical conductance) on crop growth is extremely important. Soil water passes in to the plant through the root zone due to osmotic pressure and the plants root able to assimilate water and nutrients. Thus, the dissolved solid contents of the residual water in the root zone also have to be maintained within limits by proper leaching. These effects are visible in plants by their stunted growth, low yield, discoloration and even leaf burns at margin or top. The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are presented in **Table - 4.2.**

Table 4.2: Safe Limits for electrical conductivity for irrigation water (IS:11624-1986)

S. No.	Nature of soil	Crop Growth	Upper permissible safe limit of electrical conductivity in water µs/cm at 25°C
1	Deep black soil and alluvial soils having clay content more than 30%; soils that are fairly to moderately well Drained	Semi-tolerant	1500
		Tolerant	2000
2	Textured soils having clay contents of 20-30%; soils that are well drained internally and have good surface drainage system	Semi-tolerant	2000
		Tolerant	4000
3	Medium textured soils having clay 10-20%; internally very well drained and having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000

4	Light textured soils having clay lessthan 10%; soils that have excellent internal and surface drainage system.	Semi-tolerant	6000
		Tolerant	8000

In addition to problems caused by total amount of salts, some of the specific ions like sodium, boron and trace elements, if present in water in excess, also render it unsuitable for agricultural use.

4.2.1 SODIUM ADSORPTION RATIO (SAR) & RESIDUAL SODIUM CARBONATE (RSC)

The clay minerals in the soil adsorb divalent cations like calcium and magnesium ions from irrigation water. Whenever the exchange sites in clay are filled by divalent cations, the soil texture is conducive for plant growth. Sodium reacts with soil to reduce its permeability. In case the irrigation water is sodium dominant, the clay lattice is filled with sodium ions due to ion exchange. Such soils become impermeable and sticky and as such the cultivation becomes difficult to support plant growth. However, the cation exchange process is reversible and can be controlled either by adjusting the composition of water or by soil amendment by application of gypsum, which releases cations (Calcium) to occupy the exchange position. The tendency of water to replace adsorbed calcium and magnesium with sodium can be expressed by the Sodium Adsorption Ratio (SAR), where all the ion concentrations are in milli-equivalents per litre (meq/L).

$$\mathbf{SAR} = \frac{\mathbf{Na}}{\sqrt{}(\mathbf{Ca} + \mathbf{Mg})/\mathbf{2}}$$

When, water having high bicarbonates and low calcium and magnesium is used for irrigation purpose, precipitation of calcium and magnesium as carbonate takes place, changing the residual water to high sodium water with sodium bicarbonate in solution. It is termed as Residual Sodium Carbonate (RSC) which is expressed as;

$$\mathbf{RSC} = (\mathbf{HCO3} + \mathbf{CO3}) - \ (\mathbf{Ca} + \mathbf{Mg})$$

(Where all the ions' concentrations are in milli equivalents / litre).

PERCENTAGE SODIUM (%NA):

Percentage sodium (%Na) is an indication of the soluble sodium content of the groundwater and also used to evaluate Na hazard. In all natural waters, %Na is a common parameter to assess its suitability for irrigation purposes since sodium reacts with the soil to reduce permeability.

$$\%\mathbf{Na} = \frac{(\mathbf{Na} + \mathbf{K})}{(\mathbf{Ca} + \mathbf{Mg} + \mathbf{Na} + \mathbf{K})} * \mathbf{100}$$

The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. The recommended classification with respect to Electrical Conductivity, Sodium content, Sodium Adsorption Ratio, and Residual Sodium Carbonate, under customary irrigation conditions has been depicted in **Table - 4.2**

Table 4.2.1: Guidelines for evaluation of quality of irrigation water

Water Class	**Alkalinity hazards**		
	SAR IS:11624-1986	**RSC (meq/L) IS:11624-1986**	**%Na Wilcox**
Low	< 10	< 1.5	< 20
Medium	>10 – 18	1.5 – 3	20 - 60
High	>18 – 26	3 - 6	> 60
Very High	> 26	> 6	

4.3 EFFECTS OF WATER QUALITY PARAMETERS ON HUMAN HEALTH AND DISTRIBUTION FOR VARIOUS USERS

It is essential to ensure that various constituents are within prescribed limits in drinkingwater supplies to avoid impact on human health **(Table – 4.2.3)**. Man, life forms and domestic animals are affected by alteration in water quality due to natural or anthropogenic reasons. The effect of these substances depends on the quantity of water consumed per day and their concentration in water.

Table 4.2.3: Effects of water quality parameters on human health when used fordrinking Purpose

S. No.	**Parameters**	**Prescribed limits IS:10500, 2012**		**Probable Effects**
		Desirable Limit	**Permissible Limit**	
1	Colour (Hazen unit)	5	15	Makes water aesthetically undesirable
2	Odour	Essentially free from objectionable odour		Makes water aesthetically undesirable
3	Taste	Agreeable		Makes water aesthetically undesirable
4	Turbidity (NTU)	1	5	High turbidity indicates contamination / Pollution.
5	pH	6.5	8.5	Indicative of acidic or alkalinewaters, affects taste, corrosivity and the water supply system

S. No.	**Parameters**	**Prescribed limits IS:10500, 2012**		**Probable Effects**
		Desirable Limit	**Permissible Limit**	
6	Hardness as $CaCO_3$ (mg/L)	200	600	Affects water supply system (Scaling), Excessive soap consumption, and calcification of arteries. There is no conclusiveproof but it may cause urinary concretions, diseases of kidney or bladder and stomach disorder.
7	Iron (mg/L)	1.0	No relaxation	Gives bitter sweet astringenttaste, causes staining of laundry and porcelain. In traces it isessential for nutrition.
8	Chloride (mg/L)	250	1000	May be injurious to some people suffering from diseases of heart or kidneys. Taste, indigestion, corrosion and palatability are affected.
9	Residual Chlorine (mg/L) Only when water is Chlorinated	0.20	-	Excessive chlorination of drinking water may cause asthma,colitis and eczema.
10	Total Dissolved Solids-TDS (mg/L)	500	2000	Palatability decreases and may cause gastro intestinal irritation in human, may have laxative effect particularly upon transits and corrosion, may damage water system.
11	Calcium (Ca) (mg/L)	75	200	Causes encrustation in water supply system. While in sufficiency causes a severe type of rickets, excess causesconcretions in the body such as kidney or bladder stones and irritation in urinary passages.
12	Magnesium (mg) (mg/L)	30	100	Its salts are cathartics and diuretic. High concentration may have laxative effect particularly on new users. Magnesium deficiency is associated withstructural and functional changes.It is essential as an activator of many enzyme systems.
13	Copper (Cu) (mg/L)	0.5	1.50	Astringent taste but essential and beneficial element in human metabolism. Deficiency results in nutritional anemia in infants. Large amount may result in liver damage, cause central nervous system irritation and depression. In water supply it enhance corrosion of aluminum in particular

S. No.	**Parameters**	**Prescribed limits IS:10500, 2012** **Desirable Limit**	 **Permissible Limit**	**Probable Effects**
14	Sulphate (SO_4) (mg/L)	200	400	Causes gastro intestinal irritation along with Mg or Na, can have a cathartic effect on users, concentration more than 750 mg/L may have laxative effect along with Magnesium.
15	Nitrate (NO_3) (mg/L)	45	No relaxation	Cause infant methaemoglobinaemia (blue babies) at very high concentration, causes gastriccancer and affects adversely central nervous system and cardiovascular system.
16	Fluoride (F) (mg/L)	1.0	1.50	Reduce dental carries, very high concentration may cause crippling skeletal fluorosis.
17	Cadmium (Cd) (mg/L)	0.003	No relaxation	Acute toxicity may be associated with renal, arterial hypertension, itai-itai disease, (a bone disease).Cadmium salt causes cramps, nausea, vomiting and diarrhea.
18	Lead (Pb) (mg/L)	0.01	No relaxation	Toxic in both acute and chronic exposures. Burning in the mouth, severe inflammation of the gastro-intestinal tract withvomiting and diarrhoea, chronictoxicity produces nausea, severe abdominal pain, paralysis, mental confusion, visual disturbances, anaemia etc.
19	Zinc (Zn) (mg/L)	5	15	An essential and beneficial element in human metabolism. Taste threshold for Zn occurs at about 5 mg/L imparts astringent taste to water.
20	Chromium (Cr^6) (mg/L)	0.05	No relaxation	Hexavalent state of Chromium produces lung tumors can produce cutaneous and nasal mucous membrane ulcers and dermatitis.
21	Boron (B) (mg/L)	0.5	2.4	Affects central nervous system itssalt may cause nausea, cramps, convulsions, coma etc.
22	Alkalinity (mg/L) as $CaCO_3$	200	600	Impart distinctly unpleasant taste may be deleterious to human being in presence of high pH, hardness and total

S. No.	Parameters	Prescribed limits IS:10500, 2012		Probable Effects
		Desirable Limit	**Permissible Limit**	
				dissolved solids.
23	Pesticides: (m g/l)	Absent	0.001	Imparts toxicity and accumulated in different organs of human body affecting immune and nervous systems may be carcinogenic.
24	Phosphate (PO_4) (mg/L)	No guideline		High concentration may causevomiting and diarrhea, stimulate secondary hyperthyroidism andbone loss
25	Sodium (Na) (mg/L)	No guidelines		Harmful to persons suffering From cardiac, renal andcirculatory diseases.
26	Potassium (K) (mg/L)	No guidelines		An essential nutritional elementbut its excessive amounts is cathartic
27	Silica (SiO_2) (mg/L)	No guidelines		-
28	Nickel (Ni) (mg/L)	0.02		Non-toxic element but may becarcinogenic in animals, can react with DNA resulting in DNAdamage in animals.
29	Pathogens (a) Total coliform (per100ml) (b) Faecal Coliform (per 100ml)	nil		Cause water borne diseases like coliform Jaundice, Typhoid, Cholera etc. produce infections involving skin mucous membrane of eyes, ears and throat.
30	Arsenic	0.01	**No relaxation**	Various skin diseases, Carcinogenic
31	Uranium	0.03	**No relaxation**	Kidney disease, Carcinogenic

5.0 GROUND WATER QUALITY MONITORING

The International Standard Organization (ISO) has defined monitoring as," The programmed process of samplings, measurements and subsequent recording or signaling or both, of various water characteristics, often with the aim of assessing, conformity to specified objectives". A systematic plan for conducting water quality monitoring is called Monitoring Programme, which includes monitoring network design, preliminary survey, resource estimation, sampling, analysis, data management & reporting.

Monitoring of ground water quality is an effort to obtain information on chemical quality through representative sampling in different hydrogeological units. Ground Water is commonly tapped from phreatic aquifers through dugwells in a major part of the country and through springs and hand pumps in hilly areas. The main objective of ground water quality monitoring programme is to get information on the distribution of water quality on a regional scale as well as lattice is to create a background data bank of different chemical constituents in ground water.

One of the main objectives of the ground water quality monitoring is to assess the suitability of ground water for drinking purpose. The quality of drinking water is a powerful environmental determinant of the health of a community. The problem of the quality of water resources in general, and groundwater resources in particular, is becoming increasingly important in both industrialized and developing nation. In developing countries like India, the essential concerns as regards water resources are their quantity, availability, sustainability and suitability. Groundwater plays a leading role because it has of fundamental importance to all living beings.

Even though water is the most frequently occurring substance on earth, lack of safe drinking water is more prominent in the developing countries. Due to increasing world population, extraction of groundwater is also increasing for irrigations, industries, municipalities and urban and rural households' day by day. During dry season extensive withdrawal of groundwater for irrigation purpose is lowering the water table in the aquifer and also changing the chemical composition of water.

The physical and chemical quality of ground water is important in deciding its suitability for drinking purposes. Bureau of Indian Standards (BIS) formally known as Indian Standard Institute (ISI) vide its document IS: 10500:2012, Edition 3.2 (2012-15) has recommended the quality standards for drinking water. On this basis of classification, the natural ground water of India has been categorized as desirable, permissible and unfit for human consumption.

From the analytical results, it is seen that majority of water samples collected from observation / monitoring wells of CGWB in a major part of the country fall under desirable or permissible category and hence are suitable for drinking purposes.

5.1 DATA VALIDATION / DATA QUALITY CONTROL

Groundwater quality data validation is an essential step in ensuring the reliability and accuracy of the data. Here are some of the main steps for groundwater quality data validation.

a. Checking of Data Consistency: Checking of the data for consistency by comparing the measurements of a particular parameter over time. This will help identify any changes in the groundwater quality due to measurement methodology or equipment
b. Checking the correlation between EC and TDS:
    a. The relationship between the two parameters is often described by a constant (commonly between 0.55 and 0.95 for freshwaters).
    b. Thus: TDS (mg/l) ~ (0.55 to 0.95) x EC (mS/cm).
    c. The value of the constant varies according to the chemical composition of the water. For freshwaters, the normal range of TDS can be calculated from the following relationship:
    d. 0.55 conductivity (mS/cm) < TDS (mg/l) < 0.95 conductivity (mS/cm).
    e. Typically the constant is high for chloride rich waters and low for sulphate rich waters.

c. Checking the cation-anion balance

When a water quality sample has been analysed for the major ionic species, one of the most important validation tests can be conducted: the cation-anion balance.

$$\text{Sum of cations} = \text{sum of anions}$$

where:
cations = positively charged species in solution (meq/l)
anions = negatively charged species in solution (meq/l)

The Electronic charge balance is expressed as follows:

$$\text{Electronic Charge Balance (ECB \%)} = \frac{[\sum \text{cations} - \sum \text{anions}]}{[\sum \text{cations} + \sum \text{anions}]} \times 100$$

All concentrations should be in epm. Error charge balance has been computed for the chemical results of 2022-23 and analysis showing more than 10% ECB has not been accepted as it indicates that there has been an error made in at least one of the major cation/anion analyses.

6.0 GROUND WATER QUALITY SCENARIO IN GOA STATE

The quality of groundwater in Goa state has been evaluated by sampling and analysis of water samples collected from Groundwater Monitoring wells. About **72** Groundwater Monitoring wells were monitored for water quality during May 2022 representing pre-monsoon water quality. The state-wise chemical analysis data of the samples are given in the Annexure - IX. The summarized results of groundwater quality ranges are given in **Table - 6.0.**

Table - 6.0. Summarized results of groundwater quality ranges, (May 2022)

S. No	Parameters		Range	No. of sample	Percentage
1	Electrical Conductivity µs/cm at 25°c	Fresh	< 750	72	100
		Moderate	750- 2250	nil	nil
		Slightly mineralized	2251- 3000	nil	nil
		Highly mineralized	> 3000	nil	nil
2	Chloride mg/L	Desirable limit	< 250	72	100
		Permissible limit	251-1000	nil	nil
		Beyond permissible limit	> 1000	nil	nil
3	Fluoride mg/L	Desirable limit	< 1.0	72	100
		Permissible limit	1.0 - 1.5	nil	nil
		Beyond permissible limit	>1.5	nil	nil
4	Nitrate mg/L	Permissible limit	< 45	72	100
		Beyond permissible limit	> 45	nil	nil

The groundwater samples collected from dug wells and hand pumps tapping phreatic aquifers are analyzed for all the major inorganic parameters. Based on the results, it is found that ground water of the country is mostly of calcium bicarbonate ($Ca\text{-}HCO_3$) type when the total dissolved solids of water is below 500 mg/L (corresponding to electrical conductance of 750 µS/cm at 25^0C). They are of mixed cations and mixed anion type when the electrical conductance is between 750 and 3000 µS/cm and waters with electrical conductance above 3000 µS/cm are of sodium chloride (Na-Cl) type. However, other types of water are also found among these general classifications, which may be due to the local variations in hydro-chemical environments due to anthropogenic activities. Nevertheless, occurrence of high concentrations of some water quality parameters such as salinity, chloride, fluoride, iron, arsenic and nitrate have been observed in some pockets in few states of the country.

6.1 ELECTRICAL CONDUCTIVITY

Conductivity measurements are used routinely in many industrial and environmental applications as a fast, inexpensive and reliable way of measuring the ionic content in a solution. For example, the measurement of product conductivity is a typical way to monitor and continuously trend the performance of water purification systems. In many cases, conductivity is linked directly to the total dissolved solids (TDS).

Salinity is the saltiness or dissolved salt contents of a water body. Salt content is an important factor in water use. Salinity can be technically defined as the total mass in grams of all the dissolved substances per Kilogram of water. Different substances dissolve in water giving it taste and odour. In fact, humans and other animals have developed senses which are, to a degree, able to evaluate the potability of water, avoiding water that is too salty or putrid.

Salinity always exists in ground water but in variable amounts. It is mostly influenced by aquifer material, solubility of minerals, duration of contact and factors such as the permeability of soil, drainage facilities, and quantity of rainfall and above all, the climate of the area. The salinity of groundwater in coastal areas in addition to the above may be due to air borne salts originating from air water interface over the sea and also due to over pumping of fresh water which overlays saline water in coastal aquifer systems.

BIS has recommended a drinking water standard for total dissolved solids a limit of 500 mg/L (corresponding to EC of about 750 µS/cm at 250C) that can be extended to a TDS of 2000 mg/L (corresponding to EC of about 3000 µS/cm at 250C) in case of no alternate source. Water having TDS more than 2000 mg/L is not suitable for drinking purpose. The Distribution of Electrical conductivity is shown in Fig 6.1. In general, the ground water quality of the Goa state is fresh in all the Ground Water Monitoring wells as indicated by the EC value less than 750 µs/cm at 25° C. The highest value 720 µS/cm at 25° C was observed in Hasapur, North Goa district (Table 6.1).

Table 6.1 District-wise percentage of samples having EC >3000 µS/cm

Sr. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (EC >3000 µS/cm)	(%) Samples (EC >3000 µS/cm)
1	North Goa	36	NIL	NIL
2	South Goa	36	NIL	NIL

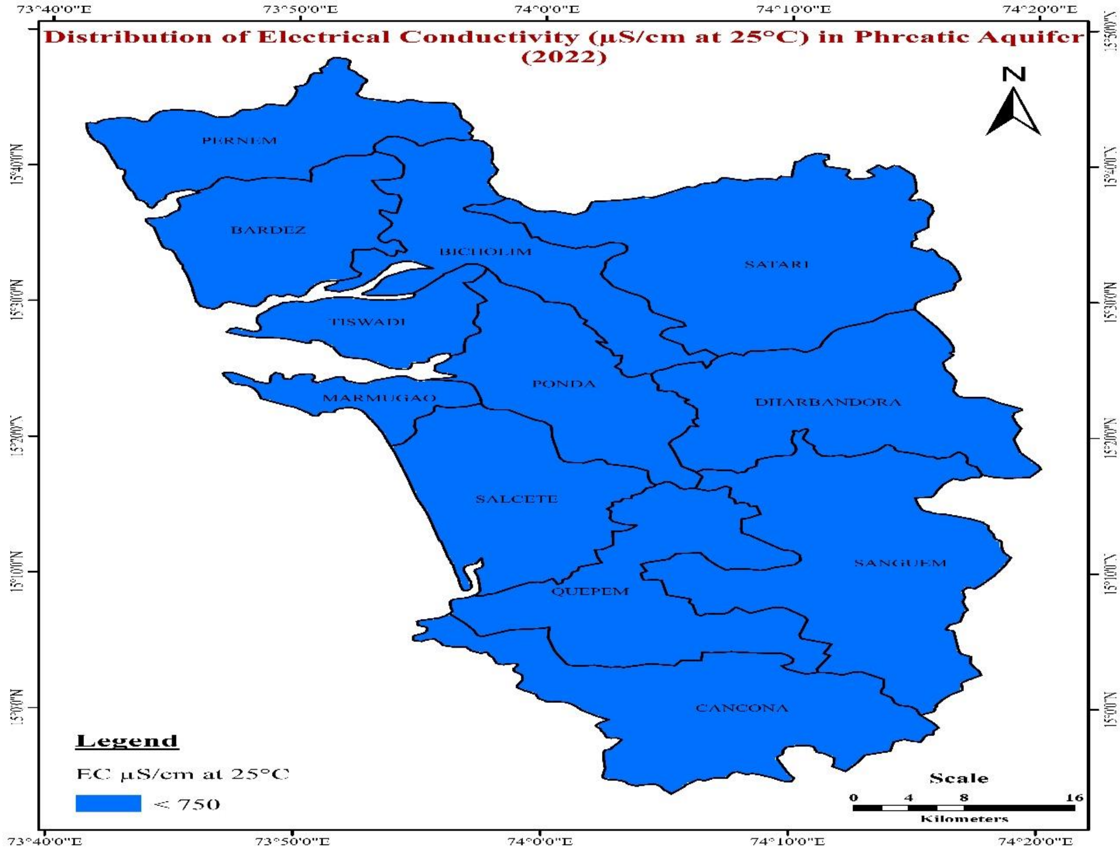

Figure. 6.1: Distribution of Electrical conductivity in phreatic aquifer of Goa-2022

6.2 CHLORIDE

Chloride is present in all-natural waters, mostly at low concentrations. It is highly soluble in water and moves freely with water through soil and rock. In ground water the chloride content is mostly below 250 mg/L except in cases where inland salinity is prevalent and in coastal areas.

BIS (Bureau of Indian Standard) have recommended a desirable limit of 250 mg /L of chloride in drinking water; this concentration limit can be extended to 1000 mg/L of chloride in case no alternative source of water with desirable concentration is available. However, ground water having concentration of chloride more than 1000 mg /L are not suitable for drinking purposes.

Distribution of Chloride is shown in Fig 6.2. The chloride content is less than 250 mg/L in all the ground water samples. The highest value of 85 mg/L was observed in Calangate, North Goa district (Table 6.2).

Table 6.2 State-wise percentage of samples having Chloride >1000mg/L

Sr. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (Cl >1000 mg/l)	(%) Samples (Cl >1000 mg/l))
1	North Goa	36	NIL	NIL
2	South Goa	36	NIL	NIL

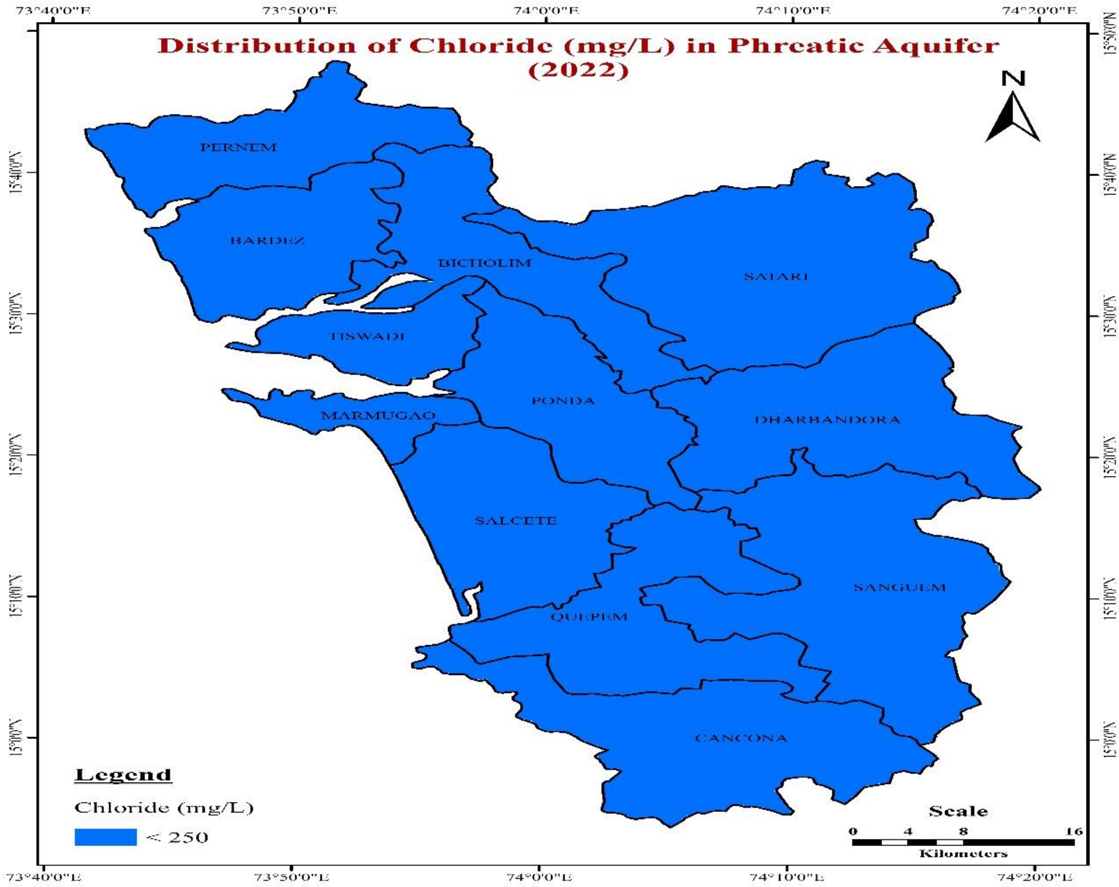

Figure. 6.2: Distribution of Chloride in phreatic aquifer of Goa during 2022

TECHNIQUES AVAILABLE FOR REMOVAL OF SALINITY

Traditionally, distillation has been the method used for desalting water for human consumption or other use. Membrane methods have emerged through the last 50 years and now predominate among the desalination practices. The following describes each of the various methods used for water desalination treatment.

1. Distillation Methods

There are several variations in distillation technology used in desalination. They are all based on the vapourization of liquid water when brought to its boiling point. The nearly pure water vapour produced is condensed and collected for use, while dissolved salts remain behind in the remaining liquid feed water. Some of the methods by which distillation is practiced are as follows:

- Multi-stage flash;
- Multiple effect;
- Vapour compression;
- Membrane distillation; and
- Solar humidification.

2. Membrane Technologies

Membrane processes involve passing of impaired feed water through a semi-permeable material which can filter out unwanted dissolved or undissolved constituents, depending on the size and treatment of the openings. Membrane technologies identified include:

- Reverse Osmosis;
- Microfiltration/Ultrafiltration/Nanofiltration;
- Electrodialysis Reversal; and
- Forward Osmosis.

3. **Hybrid Technology:** A method of reducing overall costs of desalination can be the use of hybrid systems using both RO and distillation processes. Such a system could provide a more suitable match between power and water development needs.

6.3 FLUORIDE

Fluorine is a fairly common element but it does not occur in the elemental state in nature because of its high reactivity. Fluorine is the most electronegative and reactive of all elements that occur naturally within many types of rock. It exists in the form of fluorides in a number of minerals of which fluorspar, cryolite, fluorite and fluorapatite are the most common. Fluorite (CaF_2) is a common fluoride mineral.

Most of the fluoride found in groundwater is naturally occurring from the breakdown of rocks and soils or weathering and deposition of atmospheric particles. Most of the fluorides are sparingly soluble and are present in ground water in small amounts. The occurrence of fluoride in natural water is affected by the type of rocks, climatic conditions, nature of hydrogeological strata and time of contact between rock and the circulating ground water. Presence of other ions, particularly bicarbonate and calcium ions also affect the concentration of fluoride in ground water.

It is well known that small amounts of fluoride (less than 1.0 mg/L) have proven to be beneficial in reducing tooth decay. Community water supplies commonly are treated with NaF or fluorosilicates to maintain fluoride levels ranging from 0.8 to 1.2 mg/L to reduce the incidence of *dental carries*. However, high concentrations such as 1.5 mg/L of F and above have resulted in staining of tooth enamel while at still higher levels of fluoride ranging between 5.0 and 10 mg/L, further pathological changes such as stiffness of the back and difficulty in performing natural movements may take place.

BIS has recommended an upper desirable limit of 1.0 mg/L of F^- as desirable concentration of fluoride in drinking water, which can be extended to 1.5 mg/L of F in case no alternative source of water is available. Water having fluoride concentration of more than 1.5 mg/L are not suitable for drinking purposes.

The distribution of Fluoride content in Goa state is less than 1.5 mg/L in 100% of the samples from Ground Water Monitoring wells. The highest fluoride content of 0.41 mg/L was observed in Pirna, North Goa district (Table 6.3). Concentration of fluoride is given in Fig. 6.3.

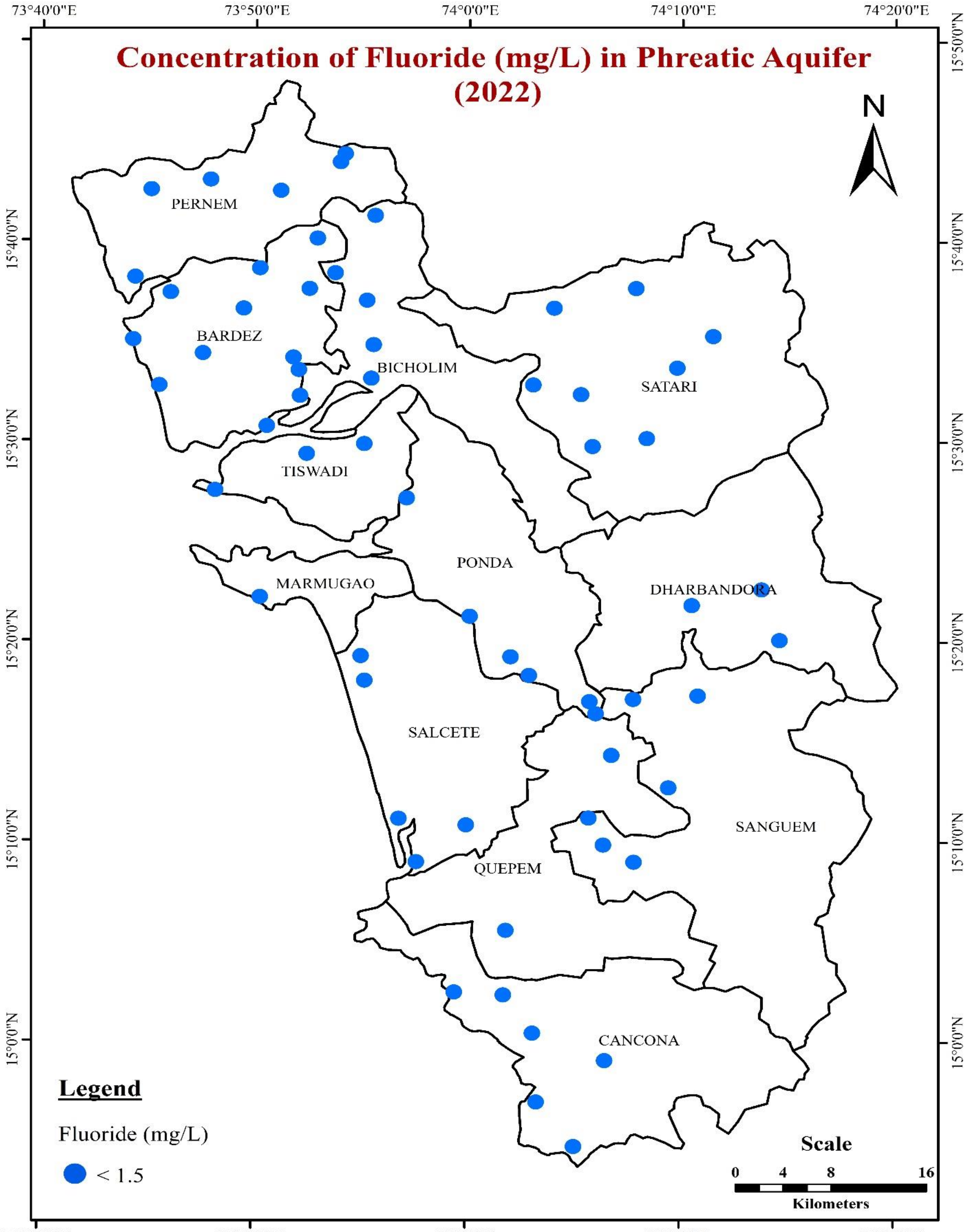

Figure. 6.3: Concentration of Fluoride in phreatic aquifer of Goa during 2022

Table 6.3 District-wise percentage of wells having fluoride >1.5mg/L

S. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (F >1.5 mg/l)	% of Samples (F >1.5 mg/l)
1	North Goa	36	NIL	NIL
2	South Goa	36	NIL	NIL

REMEDIAL MEASURES FOR FLUORIDE

The fluoride remedial measures broadly adopted are ex-situ techniques. They can be classified into three major categories.

(a) Adsorption and ion exchange

This technique functions on the adsorption of fluoride ions onto the surface of an active agent such as activated alumina, red mud, bone char, brick pieces column, mud pot and natural adsorbents where fluoride is removed by ion exchange or surface chemical reaction with the solid bed matrix.

Activated alumina: Activated alumina is a highly porous aluminum oxide exhibiting high surface area. Alumina has a high preference for fluoride compared to other anionic species, and hence is an attractive adsorbent. The crystal structure of alumina contains cation lattice discontinuities giving rise to localized areas of positive charge which makes it attract various anionic species. It also does not shrink, swell, soften nor disintegrate when immersed in water. The maximum absorption capacity of activated alumina for fluoride is found to be 3.6 mg F/g of alumina.

Ion-Exchange resins: Synthetic chemicals, namely, anion and cation exchange resins have been used for fluoride removal. Some of these are Polyanion (NCL), Tul-sion A - 27, Deacedite FF (IP), Amberllte IRA 400, LewatitMIH - 59, and AmberliteXE - 75. These resins have been used in chloride and hydroxy form. The fluoride exchange capacity of these resins depends upon the ratio of fluoride to total anions in water.

(b) Coagulation-precipitation

Precipitation methods are based on the addition of chemicals (coagulants and coagulant aids) and the subsequent precipitation of a sparingly soluble fluoride salt as insoluble. Fluoride removal is accomplished with separation of solids from liquid. Aluminium salts (eg. Alum), lime, Poly Aluminium Chloride, Poly Aluminium Hydroxy sulphate and Brushite are some of the frequently used materials in defluoridation by precipitation technique. The best example for this technique is the famous Nalgonda technique.

Nalgonda Technique

Nalgonda technique involves addition of Aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation, sedimentation, filtration and disinfection. It is opined that this technique is preferable at all levels because of the low price and ease of handling, is highly versatile and can be used in various scales from household level to community scale water supply.

The Nalgonda technique can be used for raw water having fluoride concentration between 1.5 and 20 mg/L and the total dissolved solids should be <1500 mg/L, and total hardness < 600 mg/L. The alkalinity of the water to be treated must be sufficient to ensure complete hydrolysis of alum added to it and to retain a minimum residual alkalinity of 1 - 2 meq/L in the treated water to achieve a pH of 6.5 - 8.5 in treated water. Several researchers have attempted to improve the technique by increasing the removal efficiency of fluoride using Poly Aluminium Chloride (PAC) and Poly Aluminium Hydroxy Sulphate (PAHS).

(c) Membrane techniques

Reverse osmosis, nanofiltration, dialysis and electro dialysis are physical methods that have been tested for defluoridation of water. Though they are effective in removing fluoride salts from water, however, there are certain procedural disadvantages that limit their usage on a large scale.

6.4 NITRATE

Nitrate is a naturally occurring compound that is formed in the soil when nitrogen and oxygen combine. The primary source of all nitrates is atmospheric nitrogen gas. This is converted into organic nitrogen by some plants by a process called nitrogen fixation. Dissolved Nitrogen in the form of Nitrate is the most common contaminant of ground water. Nitrate in groundwater generally originates from non-point sources such as leaching of chemical fertilizers & animal manure, groundwater pollution from septic and sewage discharges etc. It is difficult to identify the natural and man-made sources of nitrogen contamination of ground water. Some chemical and micro-biological processes such as nitrification and denitrification also influence the nitrate concentration in ground water.

As per the BIS Standard for drinking water the maximum desirable limit of Nitrate concentration in ground water is 45 mg/L with no relaxation. Though, Nitrate is considered relatively non-toxic, a high nitrate concentration in drinking water is an environmental health concern arising from increased risks of methemoglobinemia particularly to infants. Adults can tolerate little higher concentrations. The specified limits are not to be exceeded in public water supply. If the limit is exceeded, water is considered to be unfit for human consumption.

The Nitrate content is less than 45 mg/L in all the 72 ground water samples collected during May-2022. The highest value of 43 mg/L was observed in Calangate, North Goa district (Table 6.4). The Concentration of Nitrate is depicted in Fig 6.4.

Table 6.4: District-wise percentage of wells having Nitrate > 45 mg/L

S. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (NO_3 > 45 mg/L)	(%) Samples (NO_3 > 45mg/L)
1	North Goa	36	NIL	NIL
2	South Goa	36	NIL	NIL

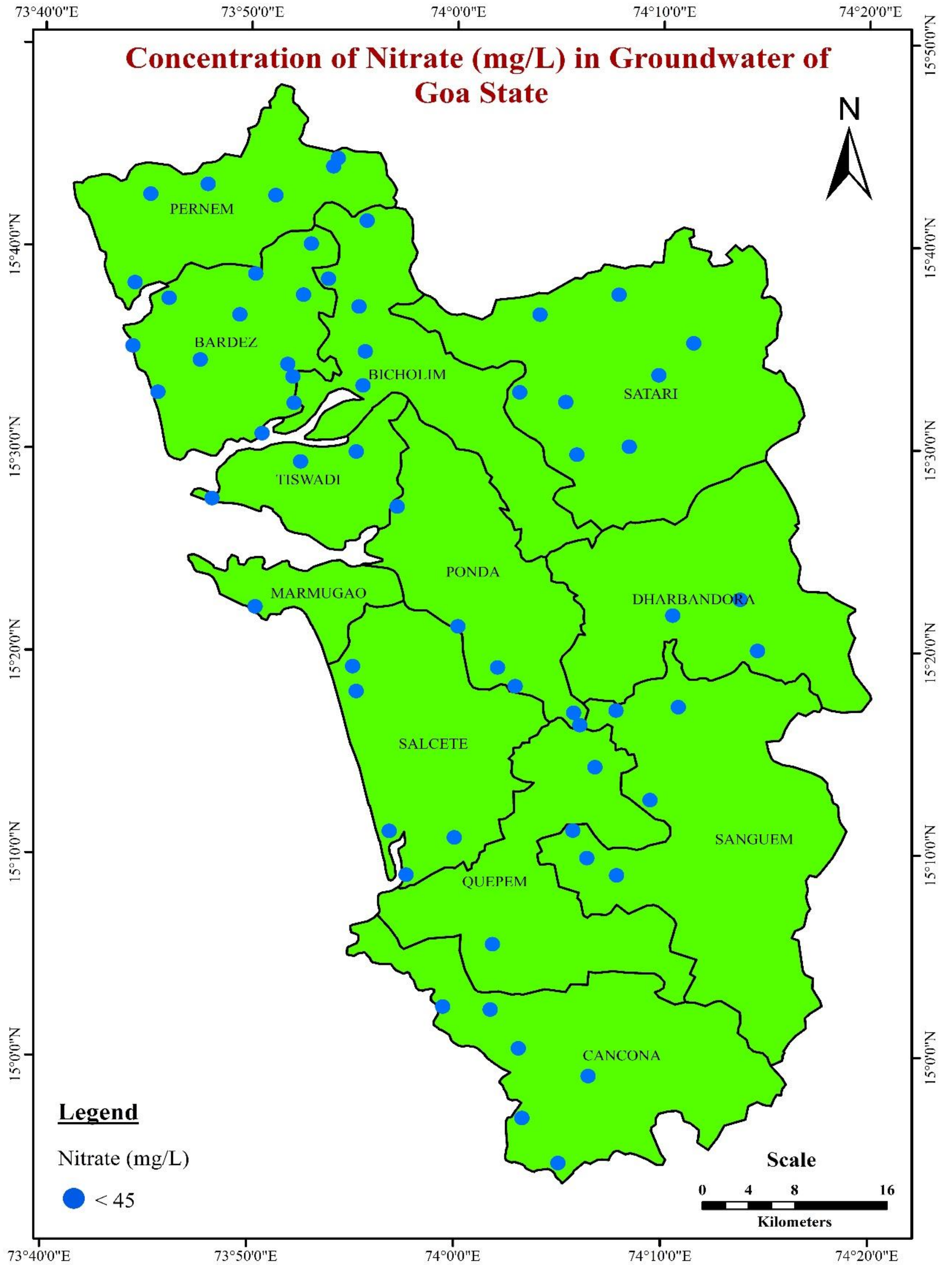

Figure. 6.4: Concentration of Nitrate in phreatic aquifer of Goa during 2022

REMEDIAL MEASURES FOR NITRATE

For removal of nitrate both non-treatment techniques like blending and treatment processes such as ion-exchange, reverse osmosis, biological denitrification and chemical reduction are useful. The most important thing is that neither of these methods is completely effective in removing all the nitrogen from the water.

a) Methods involving no treatment: In order to use any of these options the nitrate problem must be local-scale. Common methods are –

- Raw water source substitution
- Blending with low nitrate waters

This greatly reduces expenses and helps to provide safer drinking water to larger numbers of people.

b) Methods involving Treatment:

They are as follows

- Adsorption/Ion Exchange
- Reverse Osmosis
- Electrodialysis
- Bio-chemical Denitrification **(**By using denitrifying bacteria and microbes)
- Catalytic Reduction/Denitrification (using hydrogen gas)

The mechanism of nitrate pollution in subsurface porous unconfined/confined aquifer is governed by complex biogeochemical processes. Apart from recharge conditions, groundwater chemistry may be impacted by the mineral kinetics of water-rock interactions. Consequently, suitable nitrate removal technologies should be selected. Nitrate is a very soluble ion with limited potential for co-precipitation or adsorption. This makes it difficult such as chemical coagulation, lime softening and filtration which are commonly used for removing most of the chemical pollutants such as fluoride, arsenic and heavy metals. According to King et al., 2012 nitrate treatment technologies can be classified in two categories in two categories, i.e. nitrate reduction and nitrate removal options. Nitrate removal technologies involve physical processes that does not necessarily involve any alteration of the chemical state of nitrate ions. Bio-chemical reduction options aim to reduce nitrate ions to other states of nitrogen, e.g. ammonia, or a more innocuous form as nitrogen gas. In-situ bioremediation is also effectively used in used in nitrate treatment of contaminated groundwater. Reverse Osmosis, catalytic reduction and blending are effective methods for nitrate removal from groundwater. For nitrate removal, operating trans-membrane pressure of RO unit generally ranges from 20 to 100 bar.

6.5 HEAVY METALS AND URANIUM

Sampling for Heavy metal analysis was not done during the period of May, 2022. Uranium occurs naturally in groundwater and surface water. Being a radioactive mineral, high uranium concentration can cause impact on water, soil and health. Uranium has both natural and anthropogenic source that could lead to the aquifer. These sources include leaching from natural deposits, release in mill tailings, and emissions from the nuclear industry, combustion of coal and other fuels and the use of phosphate fertilizers that contains uranium and contribute to ground water pollution. Uranium enters in human tissues mainly through drinking water, food, air and other occupational and accidental exposures. Intake of uranium through air and water is normally low, but in circumstances in which uranium is present in a drinking water source, the majority of intake can be through drinking water.

Water with uranium concentration above the recommended maximum permissible concentration of 30 ppb (BIS,10500:2012) is not safe for drinking purposes as it can cause damage to internal organs, on continuous intake. Elevated uranium concentrations in drinking water have been associated with many epidemiological studies such as urinary track cancer as well as kidney toxicity. A recent study, found a strong correlation between uranium concentration in drinking water and uranium in bone, suggesting that bones are good indicators of uranium exposed via ingestion of drinking water. Therefore, such studies trigger further assessment of uranium's adverse health effects on humans and/or the environment for countries where elevated uranium concentration in drinking water has been observed. Hence, it becomes important to study the level of uranium in drinking water for health risk assessment.

Uranium concentration in the shallow ground water varies primarily due to recharge and discharge, which would have dissolved or leached the uranium from the weathered soil to groundwater zone. High uranium concentrations observed in groundwater may be due to local geology, anthropogenic activities, urbanization and use of phosphate fertilizers in huge quantity for agriculture purpose. Studies have shown that phosphate fertilizer possess uranium concentration ranging from 1 mg/kg to 68.5 mg/kg (Brindha K et al., 2011). Hence, the phosphate fertilizers manufactured from phosphate rocks may also contribute uranium to ground water in agriculture region. In ores, uranium is found as uranite (UO_2^{2+}) and pitchblende ($U_3O_8^{2+}$) or in the form of secondary minerals (complex oxides, silicates, phosphates, vanadates).

Table 6.5 Summary of uranium concentrations in different types of rocks

Rocks	Range(mg/kg)
Granite	3.4
Limestone/dolomite	2.2
Argillaceous shale	3.7
Sediments	1.4-53
Phosphates	30-100

Table 6.5.1 Standards and guidelines for uranium in drinking water in various countries.

Sl. No	Country / agency	guideline value (µg/L)	Reference
1	Australia	GV 17	NHMRC, Australia (2011)
2	Bulgaria	ML 60	European Food Safety Authority (2009)
3	Canada	MAC 20	Health Canada (2019)
4	Finland	RV 100	European Food Safety Authority (2009)
5	India	RBL 60	AERB, India (2004)
6	India	PL 30	BIS,2012
7	Malaysia	MAV 2	Ministry of Health Malaysia (2004)
8	USA	MCL 30	USEPA (2011)
9	WHO	PGV 30	WHO 2011

GV, Guideline value; ML, Maximum limit; MAC, Most acceptable concentration; RV, Recommended value; RBL, Radiological based limit; PL, Permissible Limit; MAV, Maximum acceptable value; MCL, Maximum contaminant level; PGV, Provisional guideline value

To assess the Uranium concentration and distribution in the ground water, Central Ground Water Board (CGWB) had decided to carry out Uranium sampling of its National Hydrograph Network Stations (NHNS) in Goa state during Pre-monsoon monitoring (May,2022). The sample collection and storage were done according to the standard protocols prescribed by APHA (2017). The groundwater samples were collected in plastic bottles after having been filtered through 0.45-µm filter paper. For the cations and uranium analyses, groundwater samples were immediately acidified below pH 2 by adding nitric acid to prevent precipitation and adsorption to the container walls. Uranium (U) was detected using LED Fluorimeter. In addition, a trace element standard reference material was examined. A total of 72 samples were analysed for Uranium in Goa State and uranium content was not detected in all the samples of the state (Table 6.5.2).

Table 6.5.2: District-wise percentage of wells having Uranium > 30 µg/L

S. No	District	No. of Samples collected (NHS 2022-23)	No. of Samples (U > 30 µg/L)	(%) Samples (U > 30 µg/L)
1	North Goa	36	NIL	NIL
2	South Goa	36	NIL	NIL

REMEDIAL MEASURES

Finding a remedy for the uranium contaminated groundwater effectively and thoroughly, has become need of day. Remediation technologies can be classified into physical, chemical and biological methods. Bioremediation is divided into plant and microorganism methods. Each method consists of both advantages and disadvantages and the appropriate mitigation techniques should be need based.

Adsorption has a high removal efficiency, but costs are also higher. The coagulation process is simple and comparatively economical, but the standard effluent concentration is hard to reach, so there is a need for follow-up treatment. Combined with adsorption, coagulation can remove 99% of U. The extraction process can remove effluent U concentrations of less than 0.05mg / L, but it will produce a lot of sludge. Reverse osmosis is referred as a best technology, but due to its high cost it can not be used on community scale. The evaporation method is simple and effective, the removal rate is high, but there are high costs and sludge needs that must be dealt with. A review of various treatment technologies for Uranium removal from water and their technical achievability as reported by various researchers are given below in Table 6.5.3.

6.5.3 Comparison of treatment methods for removal of Uranium.

Treatment Method	Technical Achievability (%)
Coagulation/filtration at high pH (10+)	> 95
Lime softening	85-99
Anion exchange	99
Reverse osmosis	>95
Activated alumina	90
Coagulation/filtration	80-89

(Source: Hand Book for Drinking Water Treatment, JJM, Ministry of Jal Shakti, Gov. of India).

6.6 TOTAL HARDNESS

Total hardness is predominantly caused by cations such as calcium and magnesium and anion such as bicarbonate and sulphate. Total hardness is defined as the sum of calcium and magnesium both expressed as $CaCO_3$ in mg/L. Hardness represents the soap-consuming capacity of water. Species that form insoluble compounds with soap Ca, Mg, Organic compounds etc.Total hardness is sum of Ca and Mg and expresses as CaC03 mg/l. EDTA titration. The two kind of hardness observed in water.

- Temporary hardness is due to Carbonate.
- Permanent hardness is due to Sulphate, Chloride or Nitrate.

The hardness in water is derived largely from contact with the soil and rock formations. Rain water as it falls upon the earth is in capable of dissolving the tremendous amount of solids found in many natural waters. People with kidney and bladder stones should avoid high content of calcium and magnesium in water (K. R. Karanth, 1997). The BIS permissible limit of hardness is 200 – 600 mg/L. The total hardness in all the samples of Goa state was found to be within the permissible limit.

REMOVAL OF TOTAL HARDNESS

A few methods to remove hardness from water are,

- Chemical Process of Boiling Hard Water.
- Adding Slaked Lime (Clark's Process)
- Adding Washing Soda.
- Calgon Process.
- Ion Exchange Process.
- Using Ion Exchange Resins.

CARBONATE (TEMPORARY) HARDNESS also known as Ca Bicarbonate

$Ca(HCO_3)_2$ + Mg Bicarbonate $Mg(HCO_3)_2$. Removal by Boiling or adding Lime

NON-CARBONATE (PERMANENT) HARDNESS

Calcium Sulfate $CaSO_4$ + Magnesium Sulfate $MgSO_4$ & Calcium Chloride $CaCl_2$ + Magnesium Chloride $MgCl_2$

Removal by Lime-soda, Zeolite or Demineralization Processes

7.0 SUITABILITY OF GROUNDWATER FOR IRRIGATION PURPOSE

The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation purposes. Plants grown by irrigation absorb and transpire water but leave nearly all the salts behind in the soil, where they accumulate and eventually prevent plant growth. Excessive concentrations of solute interfere with the osmotic process by which plant root membranes are able to assimilate water and nutrients. In areas where natural drainage is inadequate, the irrigation water infiltrating the root zone will cause water table to rise excessively. In addition to problems caused by excessive concentration of dissolved solids, certain constituents in irrigation water are especially undesirable and some may be damaging even when present in small concentrations. Irrigation indices viz. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) have been evaluated to assess the suitability of ground water for irrigation purposes.

7.1 ALKALI HAZARD

In the irrigation water, it is characterized by absolute and relative concentrations of cations. If the sodium concentrations are high, the alkali hazard is high and if the calcium & magnesium levels are high, this hazard is low. The alkali soils are formed by the accumulation of exchangeable sodium and are characterized by poor tilt and low permeability. The U.S. Salinity laboratory has recommended the use of sodium adsorption ratio (SAR) as it is closely related to adsorption of sodium by the soil.

SAR is derived by the following equation:

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

The water with regard to SAR is classified into four categories

- **S_1 – Low Sodium Water** (SAR <10)

Such waters can be used on practically all kinds of soils without any risk or increase in exchangeable sodium.

- **S_2 – Medium Sodium Water** (SAR 10-18)

Such waters may produce an appreciable sodium hazard in fine textured soil having high cation exchange capacity under low leaching.

- **S_3 – High Sodium Water** (SAR >18-26)

Such waters indicate harmful concentrations of exchangeable sodium in most of the soil and would require special management, good drainage, high leaching and addition of organic matter to the soil. If such waters are used on gypsiferrous soils the exchangeable sodium could not produce harmful effects.

- **S_4 – Very High Sodium Waters** (SAR >26)

Generally, such waters are unsatisfactory for irrigation purposes except at low or perhaps at medium salinity where the solution of calcium from the soil or addition of gypsum or other amendments makes the use of such waters feasible.

The computed SAR values of Goa state ranges from 0.13 to 9.44. All the samples were classified as good category (S_1) for irrigation use (Fig 7.1).

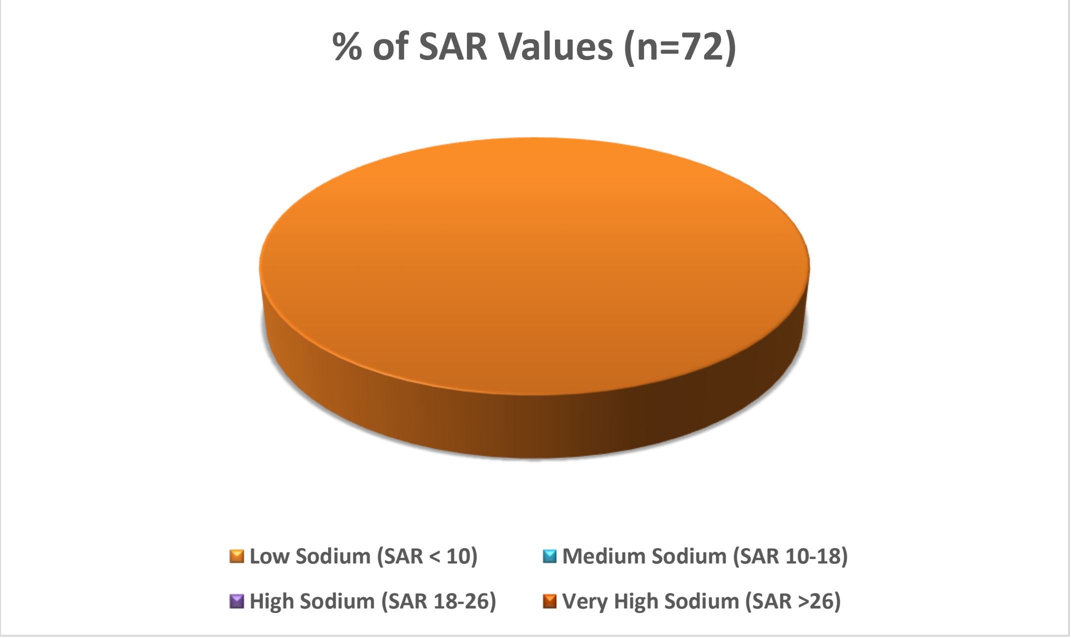

Fig 7.1: Percentage of groundwater samples according to SAR classifications (n=72).

7.2 RESIDUAL SODIUM CARBONATE (RSC)

If the enriched carbonate (residual) concentration becomes relatively high, carbonates get together with calcium and magnesium to form precipitates. The relative abundance of sodium in comparison to alkaline earths and the quantity of bicarbonate and carbonate in excess of alkaline earths also influences the suitability of water for irrigation. This excess is represented in terms of “Residual Sodium Carbonate” (RSC). The highly soluble sodium carbonate known as residual sodium carbonate (RSC) is defined as;

$$\boldsymbol{RSC} = (\boldsymbol{HCO_3^-} + \boldsymbol{CO_3^-}) - (\boldsymbol{Ca^{2+}} + \boldsymbol{Mg^{2+}})$$

Waters with high RSC produces harmful effects on plant development and is not suitable for irrigation. Waters associated with RSC < 1.25 are of excellent irrigation quality and can be safely applied for irrigation for almost all crops without the risks associated with residual sodium carbonate (Wilcox et al.,1954). If the RSC values lie between 1.25 and 2.5, the water is of an acceptable quality for irrigation. Waters associated with RSC values higher than 2.5 are not acceptable for irrigation. In fig. it can be seen that in India 85.77% collected water samples are associated with RSC values less than 1.25 and are safe for use in irrigation practices. Only 7.69% water samples are associated with RSC values more than 2.5 and are unsuitable for irrigation. The water with high RSC values if applied for irrigation causes soil to become infertile owing to deposition of sodium. According to RSC classification all water samples of Goa state falls in very safe category with RSC values less than 1.25 (Fig 7.2).

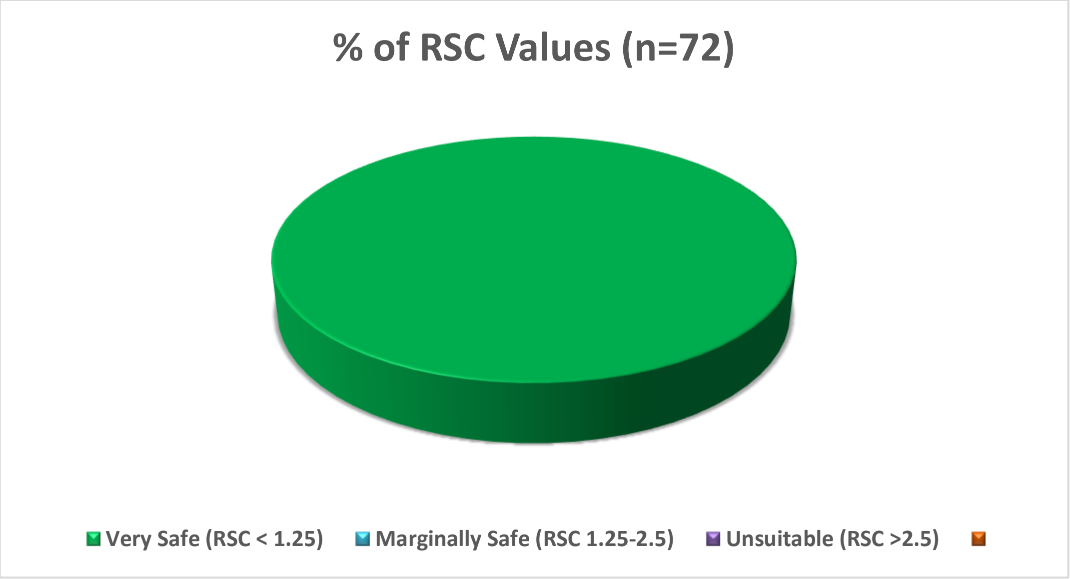

Fig 7.2: Percentage of groundwater samples according to SAR classifications (n=72) (Wilcox *et al.*, 1954)

8.0 Piper Diagram:

Piper diagram (Piper 1944) describes the process responsible for the evolution of hydrogeochemical parameter in groundwater. Based on the major cation and major anion content in the water samples and plotting them in the trilinear diagram, hydrochemical facies could be identified. Hydro-chemical facies are very useful in investigating diagnostic chemical character of water in hydrologic systems. Different types of facies within the same group formations are due to characteristic ground water flow through the aquifer system and effect of local recharge. The types of facies are inter-linked with the geology of the area and distribution of facies with the hydrogeological controls. Hydrochemical facies are delineated by plotting percentage reacting value of major ions on tri-linear diagrams know as Piper Diagram.

The facies mapping shows (Fig. 8.1) that Mg-HCO_3 is the dominant hydrogeochemical facies followed by Na-Cl and mixed chemical character of hydrogeochemical facies.

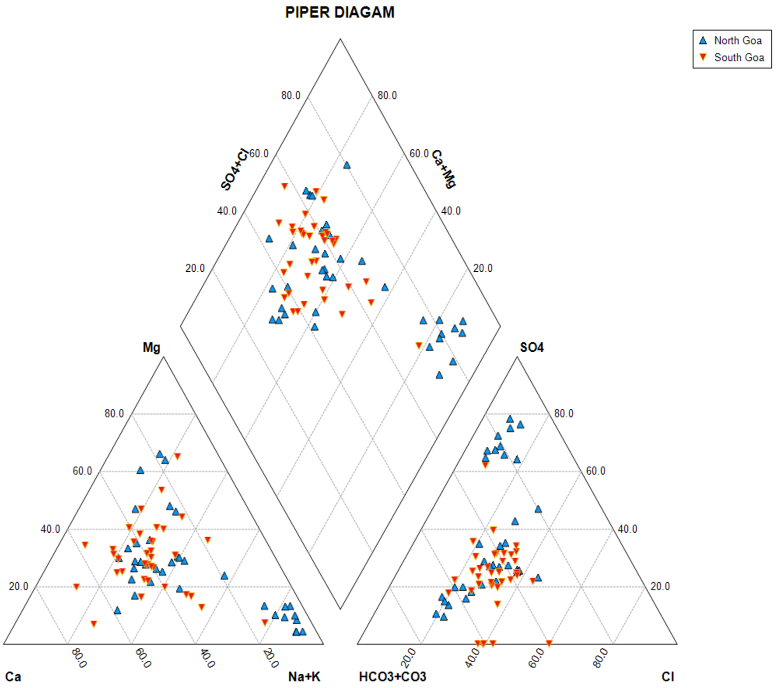

Fig 8.1: Piper diagram of groundwater of Goa

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Annexure I

Water quality data of NHS 2022-23 for basic parameters for Goa State

Sl. No .	**Location**	**Taluk**	**District**	**Latitude**	**Longitude**	**pH (6.5-8.5)**	**EC in m S/cm**	**TH (600)**	**Ca (200)**	**Mg (100)**	**Na**	**K**	**CO_3**	**HCO_3**	**Cl (1000)**	**SO_4 (400)**	**NO_3 (45)**	**F (1.5)**	**U (30 ppb)**	**TDS (2000)**	**TA (600)**
1	Parra	Mapusa	North Goa	15.5729	73.7927	7.47	365	145	36	13	14	6.8	0	119	39	38	0	0.23	0.00	220	98
2	Calangate	Mapusa	North Goa	15.5461	73.7587	7.79	640	170	44	15	59	9.7	0	104	85	59	43	0.20	0.00	378	85
3	Anjuna Beach	Mapusa	North Goa	15.5842	73.7382	7.06	179	50	10	6	15	2.3	0	61	16	13	6	0.36	0.00	106	50
4	Shivoli	Mapusa	North Goa	15.6236	73.7672	7.67	363	140	34	13	20	5.3	0	123	25	32	15	0.25	0.06	220	101
5	Morji	Pernem	North Goa	15.6363	73.7396	7.12	156	55	14	5	9	1.8	0	68	11	8	1	0.20	0.00	90	56
6	Kargaon	Pernem	North Goa	15.7092	73.7519	6.88	88	30	10	1	4	2.5	0	37	7	4	1	0.23	0.00	52	30
7	Pernem	Pernem	North Goa	15.7175	73.7982	7.22	142	50	12	5	7	4.1	0	56	10	10	5	0.22	0.00	87	46
8	Amberem	Pernem	North Goa			6.82	129	40	8	5	7	8.8	0	43	12	11	8	0.15	0.00	85	35
9	Nagjhar	Pernem	North Goa	15.7085	73.8531	6.36	84	35	8	4	4	1.1	0	31	6	5	13	0.13	0.00	59	25
10	Cha0El	Pernem	North Goa	15.7325	73.8997	6.54	60	25	6	2	5	0.7	0	31	5	6	0	0.17	0.00	43	25
11	Hasapur	Pernem	North Goa	15.7392	73.9033	7.36	720	70	14	8	120	14.1	0	67	39	189	14	0.39	0.00	440	55
12	Pirna	Mapusa	North Goa	15.6688	73.8819	6.82	476	20	4	2	97	1.4	0	61	18	158	0	0.41	0.00	318	50
13	Adavapal	Dicholi	North Goa	15.6400	73.8959	6.41	86	35	6	5	3	0.2	0	18	11	10	5	0.20	0.00	52	15
14	Sal	Dicholi	North Goa	15.6879	73.9269	7.08	159	50	12	5	7	11.2	0	43	18	16	3	0.34	0.00	98	35
15	Gwakawada Narve	Dicholi	North Goa	15.5523	73.9243	6.55	162	70	6	13	6	0.0	0	37	21	20	5	0.27	0.00	94	30
16	Mayam	Dicholi	North Goa	15.5803	73.9260	6.75	71	30	6	4	5	1.2	0	20	10	11	2	0.27	0.00	51	16
17	Mulgaon Shivalkherwad	Dicholi	North Goa	15.6172	73.9207	6.80	82	30	4	5	5	0.8	0	18	11	10	5	0.19	0.00	52	15
18	Colvol	Mapusa	North Goa	15.6439	73.8371	7.17	258	95	26	7	15	4.0	0	65	18	40	25	0.05	0.00	175	53
19	Mapusa	Mapusa	North Goa	15.6103	73.8245	6.57	224	45	8	6	26	3.4	0	31	17	35	32	0.00	0.00	145	25
20	Sirsaim	Mapusa	North Goa	15.6268	73.8759	6.94	492	30	4	5	96	1.6	0	31	21	170	2	0.26	0.00	318	25
21	Ho0A	Valpoi	North Goa	15.5471	74.0509	7.04	490	25	6	2	96	0.9	0	37	14	173	2	0.29	0.00	316	30

22	Bhuipal	Valpoi	North Goa	15.5392	74.0882	7.24	676	85	16	11	116	0.7	0	89	21	205	2	0.27	0.00	427	73
23	Charawne	Valpoi	North Goa	15.6278	74.1309	7.45	164	65	14	7	8	1.9	0	18	18	34	5	0.27	0.00	100	15
24	Amberem	Valpoi	North Goa	15.5616	74.1633	6.92	479	25	6	2	98	0.0	0	85	14	158	0	0.38	0.00	330	70
25	Bamber	Valpoi	North Goa	15.5880	74.1913	7.40	548	45	4	8	101	0.0	0	61	14	176	1	0.40	0.00	342	50
26	Khadki	Valpoi	North Goa	15.5028	74.1397	6.81	542	50	6	9	103	0.4	0	88	14	181	1	0.33	0.00	368	72
27	Kotaden		North Goa			7.64	521	45	8	6	102	0.3	0	66	24	162	1	0.39	0.00	344	54
28	Dhat-Wado-Vante	Valpoi	North Goa	15.4960	74.0973	6.96	513	35	4	6	100	0.4	0	43	18	173	0	0.00	0.00	328	35
29	Olauim	Mapusa	North Goa	15.5696	73.8634	6.65	68	20	4	2	5	0.8	0	18	7	9	1	0.23	0.00	41	15
30	Pomburpa-Palmar	Mapusa	North Goa	15.5593	73.8676	6.84	189	70	6	13	7	1.2	0	37	17	28	8	0.20	0.00	102	30
31	Salwardhar Dumun	Mapusa	North Goa	15.5377	73.8687	6.65	52	20	6	1	4	0.5	0	14	6	7	4	0.20	0.15	37	11
32	Bitthon-Virloswade	Mapusa	North Goa	15.5126	73.8429	8.45	150	65	8	11	4	0.4	12	31	13	15	0	0.23	0.00	77	45
33	Aivao-Panjim	Panji	North Goa	15.4590	73.8029	6.90	220	65	14	7	16	5.2	0	43	18	30	28	0.14	0.00	145	35
34	Shiroda	Po0a	North Goa	15.3206	74.0340	6.95	123	45	12	4	10	2.1	0	36	13	17	9	0.00	0.00	89	30
35	Bori	Po0a	North Goa	15.3543	74.0020	7.33	282	100	24	10	20	8.4	0	79	26	39	10	0.02	0.00	185	65
36	Keri-Sattari	Valpoi	North Goa	15.6112	74.0671	6.90	137	45	6	7	8	1.3	0	31	18	16	6	0.00	0.00	81	25
37	Gavalebhat	Panji	South Goa	15.4894	73.8742	6.67	79	25	6	2	5	1.4	0	16	9	10	5	0.22	0.00	48	13
38	Ella- Old Goa (Icar)	Panji	South Goa	15.4978	73.9191	7.95	237	110	34	6	7	1.1	0	80	21	31	4	0.37	0.00	154	66
39	Ku0Ai Dasoolwada	Panji	South Goa	15.4527	73.9524	6.65	157	60	4	12	8	0.3	0	43	10	26	6	0.12	0.00	91	35
40	Suktolim	Sanguem	South Goa	15.3638	74.1753	6.46	65	25	6	2	2	0.7	0	18	7	6	2	0.22	0.00	37	15
41	Bolkharnem		South Goa			6.87	78	30	6	4	2	1.4	0	16	12	8	1	0.10	0.00	44	13
42	Molem	Sanguem	South Goa	15.3771	74.2297	6.90	121	55	20	7	3	1.0	0	33	14	15	3	0.22	0.00	84	27
43	Collem(Kolamba)	Sanguem	South Goa	15.3349	74.2438	6.51	40	15	4	1	3	0.8	0	17	6	0	1	0.26	0.00	26	14
44	Kalay	Sanguem	South Goa	15.2884	74.1801	6.13	61	15	4	1	6	1.2	0	12	7	9	2	0.03	0.00	39	10

45	Paik	Sanguem	South Goa	15.2120	74.1576	6.92	102	40	10	4	4	0.9	0	31	11	14	1	0.01	0.00	63	25
46	Ghadiawada (Kakoda)/Dhadiawada	Quepem	South Goa	15.2388	74.1130	6.65	104	30	8	2	9	6.4	0	37	14	13	1	0.01	0.00	76	30
47	Gudemal	Sanguem	South Goa	15.2856	74.1298	6.85	100	30	8	2	9	1.3	0	33	10	12	1	0.07	0.00	64	27
48	Kapsa	Po0a	South Goa	15.2734	74.1007	6.72	169	45	6	7	16	2.5	0	43	17	26	4	0.08	0.00	104	35
49	Panchiwada	Po0a	South Goa	15.2836	74.0957	6.35	69	20	6	1	4	1.0	0	21	9	0	2	0.00	0.00	36	17
50	Mankem	Po0a	South Goa	15.3052	74.0484	7.00	118	45	10	5	7	3.1	0	31	14	20	1	0.00	0.00	79	25
51	Jambavali	Quepem	South Goa	15.1866	74.0953	6.48	74	25	6	2	5	0.4	0	21	9	7	2	0.00	0.00	45	17
52	Revona	Sanguem	South Goa	15.1640	74.1068	6.89	150	50	12	5	9	3.4	0	34	12	28	8	0.00	0.00	99	28
53	Deulwada Kolamba	Sanguem	South Goa	15.1499	74.1307	7.09	141	60	10	8	5	2.2	0	39	15	23	6	0.00	0.00	94	32
54	Vinchurdem	Sanguem	South Goa			6.45	45	15	4	1	3	0.4	0	16	6	0	1	0.00	0.00	26	13
55	Vaddem/Waddem	Sanguem	South Goa			6.08	60	20	4	2	3	0.5	0	12	11	0	3	0.00	0.00	31	10
56	Bhati	Sanguem	South Goa			6.36	55	20	4	2	3	0.3	0	21	8	0	1	0.00	0.00	31	17
57	Netrolim	Sanguem	South Goa			6.82	141	65	16	6	4	5.0	0	47	14	20	4	0.00	0.00	98	39
58	Shrishtal Gao0Ongar	Sanguem	South Goa			6.86	107	35	6	5	6	1.4	0	30	8	15	2	0.01	0.00	62	25
59	Yedda	Sanguem	South Goa			7.17	165	65	14	7	7	2.6	0	31	18	25	6	0.01	0.00	99	25
60	Hattipal Poinguinem	Chauri	South Goa	14.9845	74.1085	6.76	88	30	8	2	4	0.5	0	21	11	9	2	0.00	0.00	50	17
61	Depot	Chauri	South Goa	14.9499	74.0553	6.35	62	20	4	2	6	0.3	0	18	8	4	1	0.00	0.00	37	15
62	Polem(Polen)	Chauri	South Goa	14.9129	74.0845	7.72	233	125	22	17	19	4.8	0	135	25	30	2	0.02	0.00	202	111
63	Canacona/Canconna	Chauri	South Goa	15.0072	74.0521	7.25	183	60	8	10	13	2.2	0	43	25	22	3	0.01	0.00	109	35
64	Ago0A Desaiwada	Chauri	South Goa	15.0413	73.9911	7.21	210	75	18	7	11	6.1	0	55	25	31	6	0.00	0.00	138	45
65	Gulem Velipwada	Chauri	South Goa	15.0390	74.0293	6.39	162	65	8	11	8	1.5	0	47	18	20	3	0.00	0.00	97	39
66	Padi	Quepem	South Goa	15.0928	74.0310	6.93	94	40	8	5	5	0.5	0	38	11	10	1	0.00	0.00	63	31

67	Cunculium	Madgaon	South Goa	15.1806	73.9998	7.35	203	80	18	8	15	2.0	0	79	25	25	1	0.00	0.00	143	65
68	Kavaselium/Cavelossim	Madgaon	South Goa	15.1857	73.9473	7.79	394	155	42	12	19	4.0	0	147	28	44	12	0.02	0.00	251	120
69	Baradi (Velim)	Madgaon	South Goa	15.1497	73.9610	6.93	145	55	20	1	8	0.6	0	39	18	15	5	0.00	0.00	92	32
70	Betalbatti/Betalbatim	Madgaon	South Goa	15.3007	73.9201	7.52	575	60	16	5	97	2.7	0	97	18	164	1	0.00	0.00	362	80
71	Majorda Bpada Curilo	Madgaon	South Goa	15.3212	73.9171	7.05	302	70	20	5	33	12.4	0	61	32	41	36	0.00	0.00	216	50
72	V.P. Chicolna-Bogmalo	Sambaji	South Goa	15.3700	73.8381	6.72	153	65	14	7	12	1.9	0	43	25	21	8	0.00	0.00	115	35