Hydrochemical characterization of groundwater in the coastal stretch of South Goa

A Dissertation Report for

GEO 651: Dissertation

Credits: 16

Submitted in partial fulfillment of

Master of Science

In

Applied Geology

By

AARON ALERT PEREIRA

Seat Number: 22P0450001

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Under the Supervision of

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GOA UNIVERSITY

April 2024

SEOAS, GOA UNIVERSITY TALEIGAO PLATEAU GOA

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Seal of the School

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I hereby declare that the data presented in this Dissertation report entitled, **"Hydrochemical characterization of groundwater in the coastal stretch of South Goa"** is based on the results of investigations carried out by me in the Master of Science Degree in Applied Geology at the School of Earth Ocean and Atmospheric Sciences, Goa University under the Supervision of Professor Mr. Mahesh Mayekar and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understandthat Goa University or its authorities will not be responsible for the correctness of observationsor other findings given in the dissertation.

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Date: 2|5|24

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This is to certify that the dissertation "**Hydrochemical Characterization of groundwater in the Coastal stretch of south Goa**" is a bonafide work carried out by Mr. Aaron Alert Pereira under my supervision in partial fulfilment ofthe requirements for the award of the degree of Master of Science in Applied Geology at the School of Earth Ocean and Atmospheric Sciences, Goa University.

Mr. Mahesh Mayekar

Assistant professor

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Date: 02/05/2024

Senior Prof. Sanjeev C Ghadi

Dean

School of Earth Ocean and Atmospheric

SciencesDate:

Place: Goa University

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Preface

Water is an indispensable resource vital for sustaining life and supporting various socio-economic activities. As global populations continue to grow and urbanization accelerates, the demand for water resources escalates, placing increased pressure on water availability and quality. In the face of these challenges, understanding the dynamics of groundwater systems and ensuring the sustainable management of aquifers are imperative for safeguarding water security and promoting environmental resilience.

This dissertation endeavors to contribute to our understanding of groundwater quality and hydrogeological processes in a specific study area during both pre-monsoon and post-monsoon periods. Through comprehensive analysis of physicochemical parameters and hydrogeological characteristics, this study aims to elucidate the intricate interactions between groundwater dynamics, geological formations, and anthropogenic activities.

The research presented herein encompasses a wide array of analytical techniques and methodologies, ranging from field measurements and sample collection to laboratory analyses and data interpretation. By meticulously examining parameters such as pH, electrical conductivity, total dissolved solids, dissolved oxygen, and ion concentrations, among others, this study seeks to delineate the spatial and temporal variations in groundwater quality and its suitability for both drinking and irrigation purposes.

Moreover, the investigation delves into the hydrogeological dynamics of the study area, utilizing flow net mapping techniques to elucidate groundwater flow patterns and hydraulic gradients. Through the integration of geospatial analyses and hydrological modeling, this research aims to provide insights into the factors influencing groundwater movement and recharge processes, particularly in coastal regions characterized by complex geological formations and hydrological interactions.

It is my sincere hope that this dissertation will serve as a valuable resource for researchers, policymakers, and stakeholders involved in water resources management, environmental conservation, and sustainable development initiatives. By advancing our knowledge of groundwater systems and promoting evidence-based decision-making, we can work towards ensuring the long-term sustainability and resilience of our water resources for future generations.

May this work contribute to the collective efforts aimed at addressing the challenges of water scarcity, pollution, and climate change, and pave the way towards a more sustainable and equitable water future.

Acknowledgment

I would like to express my sincere gratitude to all those who have contributed to the completionof my dissertation.

Firstly, I would like to thank my guide, Mr. Mahesh Mayekar, Assistant Professor, School of Earth, Ocean & Atmospheric Sciences for his guidance, patience, and support throughout my research journey. I am grateful for his insights, feedback, and encouragement that have helpedme to develop my ideas and refine my arguments.

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A special thanks to Dr. Maheshwar R. Nasnodkar, Program Director of the Marine Science Department, for granting me permission to utilize the instruments in the marine science laboratory.

I am especially thankful and grateful to my Parents for their assistance, patience and supportduring the entire duration of my dissertation.

Furthermore, I would like to acknowledge the support and encouragement of my friends, especially Yash Bagkar, Snevio Fernandes, Shawn Fernandes and Kaushiki Kamat who have been a constant source of motivation and inspiration.

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Abstract

Access to safe drinking water is a fundamental requirement for maintaining good health. Groundwater suitability for both drinking and irrigation purposes is widely recognized. In the coastal region of Goa, there is a significant concentration of population and active economic activities. This coastal area is rapidly transforming into residential zones, with substantial and unregulated infrastructure development in recent years. Consequently, these activities have had detrimental effects on the environment and have placed considerable stress on available resources. Especially in coastal areas, there is a noticeable decline in groundwater quality due to the intrusion of saline water. Although the issue of seawater intrusion hasn't reached a critical stage yet, it holds the potential to become a serious concern in the near future if appropriate corrective and preventive measures are not put in place.

This study offers an examination of the hydro-chemical characteristics of groundwater, aiming to understand the spatial and temporal quality of drinking water along South Goa's coastal region from Pale to Varca.

Chapter 1

Introduction

General

Water, an indispensable asset crucial for the sustenance and prosperity of all life forms on our planet, is dispersed through diverse reservoirs. Predominantly housed in oceans, constituting approximately 97.5% of the Earth's water, with the remaining 2.5% existing as freshwater. This freshwater is largely trapped within glaciers and ice caps, while a notable portion lies as groundwater beneath the Earth's surface. Lakes, rivers, and wetlands harbor a minor share of freshwater, while atmospheric water vapor holds the remainder. This distribution undergoes constant flux as water perpetually cycles through various reservoirs via evaporation, precipitation, and runoff processes, ensuring a steady supply of freshwater for both ecosystems and human activities. Nonetheless, the escalating impacts of climate change and human interventions present formidable hurdles to this intricate equilibrium, adversely affecting the accessibility and purity of water resources across different global regions.

The state of Goa boasts a coastline that spans approximately 102 kilometers. Goa's coastline, which is well known for its pristine sandy beaches, is a major attraction for tourists from around the world. With the increasing tourism industry, there is a corresponding rise in demand for essential resources such as water. This heightened demand is putting considerable pressure on the coastal aquifers, which may lead to seawater infiltrating into these aquifers as groundwater levels decline. The excessive utilization of groundwater is adversely affecting both its quality and quantity. Moreover, the future effects of climate change, including rising sea levels, are expected to further compound this vulnerability.

Sea water has a larger density than freshwater, which helps to preserve the interface between the two types of water. Freshwater usually prevents sea water from entering aquifers. In the dispersion zone, seawater and freshwater mix together (Barlow 2013). Excessive extraction of groundwater can cause a drop in the freshwater table, and the intrusion of seawater into aquifers is becoming a growing concern. This phenomenon can severely impact the quality of freshwater resources due to the high salinity of seawater, making it unsuitable for drinking or irrigation. Moreover, seawater intrusion can result in the loss of agricultural land and harm coastal ecosystems. The objective of the present study is to assess the patterns of groundwater flow in coastal communities and ascertain whether seawater intrusion has adverse effects on the quality of groundwater.

1.1.1 Study Area

1.1.1a. Location

The study area is situated on the coastal stretch of South Goa. The villages of Pale, Velsao, Cansaulim, Utorda, Betalbatim, Colva and Varca make up the study area. The study area is covered under the Survey of India toposheets 48E15-SE-A1, 48E15-SE-B1, 48E15-SE-B2, scale 1:50,000. Due to its proximity to the sea, the area is vulnerable to seawater intrusion. Beaches like Velsao beach, Cansaulim beach, Colva beach, Benaulim beach, Varca Beach are some of the beaches lie on the Arabian sea coast on the western part of the study area. The highest elevation in the study area is present in Cuelim which is 112m above mean sea Level (MSL) which lies in the north eastern part of the study area.

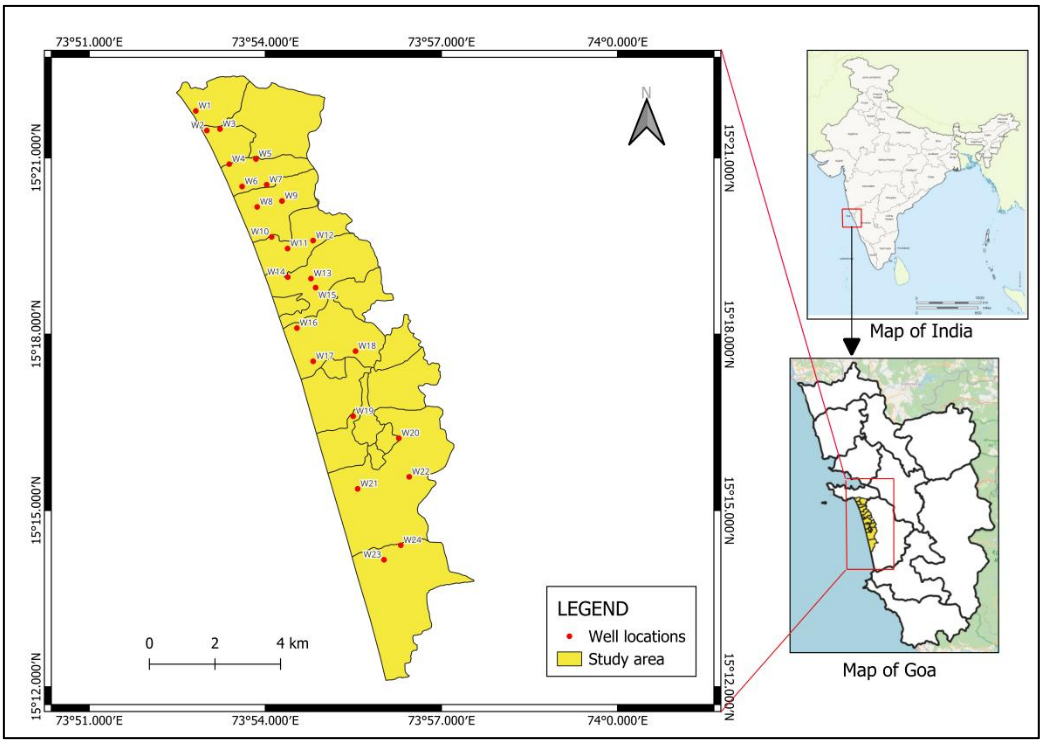


Figure 1.1: Map of study area

1.1.2 Topography:

The study area consists of coastal plains and elevated topography. There is a plateau region in the north which is indicative of an elevated area. Furthermore, the low lying areas are flat plains with a scattered regions of higher elevation which is distributed along the central region throughout the coastal stretch. The topography gradually reduces to almost flat plains as it approaches the coastline.

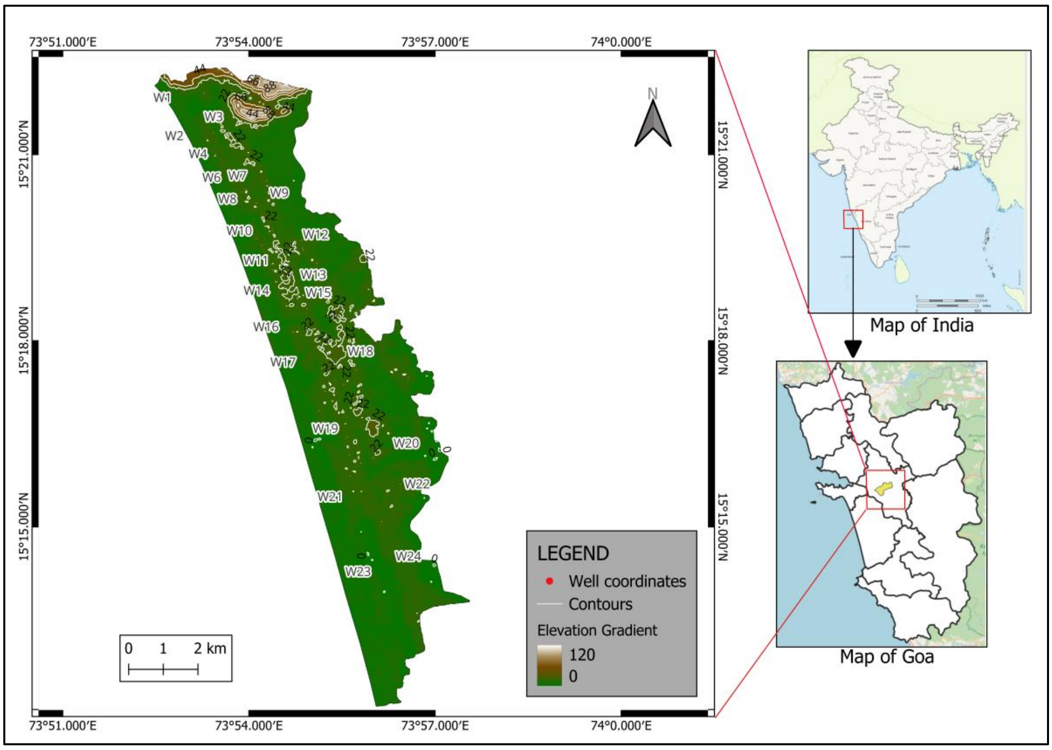


Figure 1.2: topography map of study area

1.1.3 Geology

The rocks in the study area are of Archaen age. It has crystalline and metamorphic rocks mainly, Metabasalts in the Northern region and the Chandranath granite gneiss in the southern region of the study area. The Chandranath granite gneiss is a grey granitic gneiss which is folliated and petrographically similar to the TTG gneisses. This younger granitic gneiss is intrusive into the metasediments according to Gokul et al.(1985). The metabasalts belong to the Barcem formation under the Dharwar supergroup. Metabasalt is pale green to green, hard and compact and at places schistose. Its mineral constituents are actinolite, amphibole, plagioclase and epidote suggesting good degree of alteration. There is fine grain sand found throughout the coastline in the Western part of the study area.

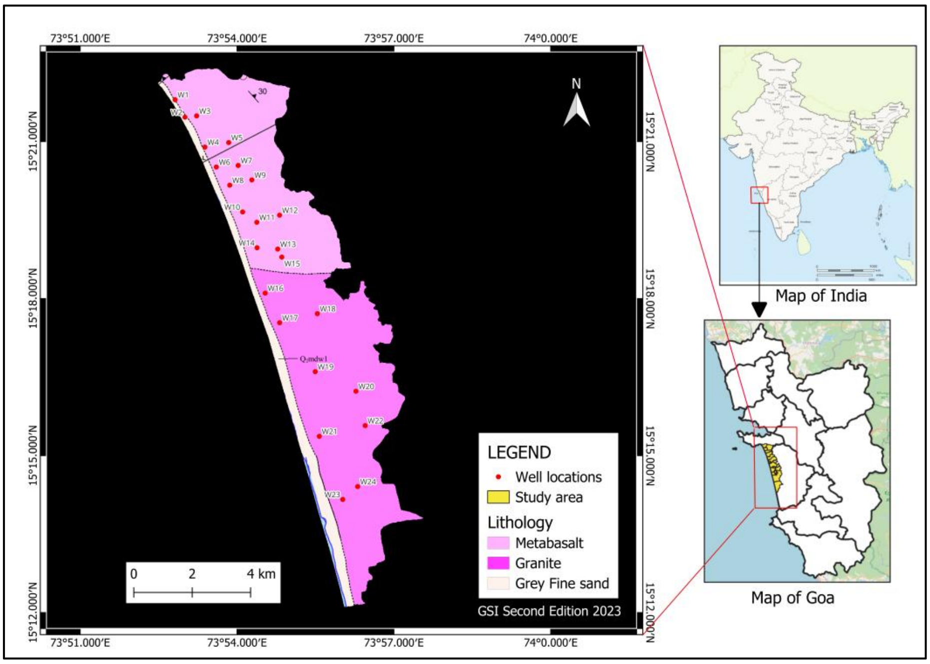


Figure1.3: Lithology map of study area

1.1.4 Climate and rainfall:

As Goa is located on the southwestern coast of India, it experiences a tropical monsoon climate with distinct wet and dry seasons. The maximum temperature ranges from 28°C to 33°C throughout the year, while minimum temperatures range from 19°C-26°C. Due to maritime climate, the diurnal variation in temperature is not yet pronounced. Since the state is close to the Arabian sea, the humidity is high throughout the year. The monsoon season typically lasts from June to September, bringing heavy rainfall and high humidity. During this period, Goa receives the majority of its annual rainfall, with the Western Ghats contributing to the region's lush greenery. The average annual relative humidity in Goa is 75.90%. The pre-monsoon and post-monsoon months, from October to May, constitute the dry season when the weather is generally sunny and less humid.

Goa experiences an average rainfall of about 330 centimeters annually, However rainfall is more in the areas which are nearer to the Western Ghats in east parts of Goa. July is the wettest month of the year with more than 995 mm of rainfall. Over 90% rainfall occurs during the monsoon months while the remaining 10% is received during the non monsoon months.

1.1.5 Drainage:

In the Eastern part of the study area there is the Sal river which flows south and drains into the Arabian sea. There are minor streams located on the western region of the study area. The surface runoff is from higher elevated areas, which flow into the sea. The major streams are located in Pale, Gonsua, Betalbatim, Colva, Benaulim and Varca. Apart from the ones depicted on the map, there are several other minor streams that contribute to the drainage pattern.

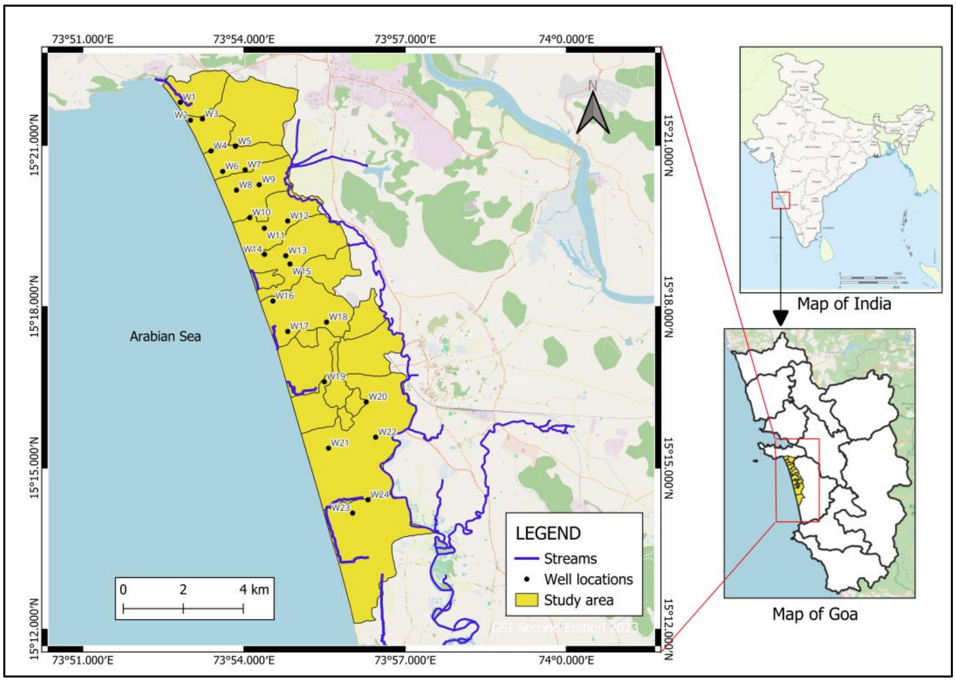


Figure 1.4: Drainage map of study area

1.1.6 Land use pattern

Majority of the study area is occupied as settlement area, which are present on the low lying regions.The coastline is densely populated due to tourism activities. As a result of the frequent rainfall in this region, a significant amount of the study area is covered by trees and plants. There is agricultural land in the plains of Cuelim, Cansaulim, Arossim, Utorda, Majorda, Benaulim and Varca. There is a plateau region in the north of the study area where natural vegetation and trees are present.

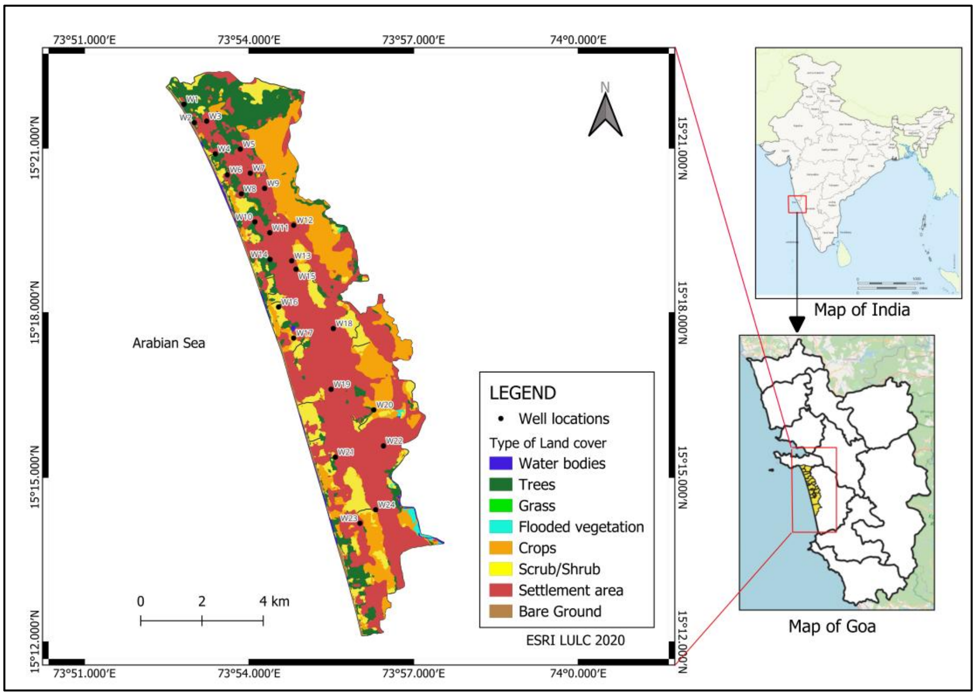


Figure 1.5: Land use map of study area

1.1.7 Soils

Lateritic soil makes up the majority of the study area's soil. When temperatures are high and there is a lot of precipitation, the underlying rock formations are severely weathered, which results in the creation of lateritic soils. These soils are frequently distinguished by their high levels of iron and aluminium, which give them a recognisable reddish appearance. These iron-rich soils are formed by the weathering of rocks under high temperatures and alternating wet and dry seasons. Coastal alluvial soils, well-suited for agriculture due to their good drainage and presence of nutrients, are also present. These soils, mainly composed of sand particles, drain quickly and have low fertility, and are found along beaches and sand dunes. There are also marshy soils present in the the study area. These waterlogged soils are found in low-lying areas with poor drainage. They are rich in organic matter and can be productive for crops like rice if managed properly.

1.2 Aims and objectives

1. To assess the concentration of major cations and anions in the water samples.
2. To check seasonal variation in the groundwater levels, to prepare flownets and deduce the groundwater flow direction.
3. To assess the presence of seawater intrusion in the study area (if any).

Chapter 2

Literature Review

A. K. Haritash et al. did the Hydrochemical characterization and suitability assessment of groundwater in Baga–Calangute stretch of Goa, India in 2017. The study conducted in the Baga–Calangute stretch of Goa represents the first comprehensive assessment of groundwater suitability for drinking and irrigation in the area. Findings indicate that while 90% of groundwater samples are suitable for drinking, elevated levels of hardness, chlorides, and nitrates were observed. However, parameters relevant to irrigation met prescribed limits. Silicate weathering emerged as a significant factor influencing groundwater chemistry, with a predominant Ca–Na–SO4 composition noted, except for one sample exhibiting Na–Cl composition. Evidence suggests that land use activities, particularly agriculture, may impact groundwater quality, with potential seawater intrusion identified in one sample. Shallow dug wells, prevalent in the area, are susceptible to contamination from land use activities. With increasing demand for groundwater due to tourism and population growth, there's a likelihood of rising abstraction rates, posing future challenges to groundwater quality.

M. Thabrez, S. Parimalarenganayaki has done Assessment of Hydrogeochemical Characteristics and Seawater Intrusion in Coastal Parts of Mangaluru City, Karnataka, India in 2023. The study conducted in the coastal region of Mangaluru city, Karnataka, aimed to assess groundwater quality and seawater intrusion using various hydrogeochemical indicators and groundwater level measurements. The study area was divided into six zones, and 35 groundwater samples were collected during post-monsoon and pre-monsoon seasons. Analysis revealed that while potential indicators of seawater intrusion such as salinity, chloride, and electrical conductivity (EC) were not significantly elevated, moderately high EC values were observed in samples near the coastline (up to zone 2). The hydrochemistry of the samples was primarily influenced by rock-water interaction, as indicated by Gibbs plot and modified Piper diagram. Ionic ratio analysis suggested seawater intrusion up to zone 4, with negative BEX index values corroborating intrusion up to zone 2 and 4. Graphical approaches, including EC v/s Cl plot and HFE diagram, further confirmed seawater intrusion up to zone 2, with some samples in the mixing zone. Groundwater level measurements in zone 1 wells were below mean sea level, supporting evidence of seawater intrusion. The study concludes that while seawater intrusion was identified up to zone 2 using some indicators and up to zone 4 using others, the integration of multiple approaches provided more reliable results. Overall, groundwater quality up to 1 km from the coastline is highly susceptible to seawater contamination, with the likelihood of seawater mixing up to 2 km during non-monsoon seasons. However, beyond 2 km, no strong evidence of seawater intrusion was observed. Geological characteristics and annual groundwater recharge influence the severity of seawater intrusion in the study area, suggesting the need for suitable mitigation measures to prevent further ingression.

P. J. Sajil Kumar et al. has done Assessment of hydrochemistry and groundwater quality in the coastal area of South Chennai, India in 2013 The assessment of water quality in the fast-growing coastal area of South Chennai revealed several key findings. Groundwater in the region exhibited alkaline properties with pH ranging from 7.2 to 8.2. Elevated levels of sodium (Na) and chloride (Cl) were positively correlated with electrical conductivity (EC), particularly near the coastal regions, indicating potential seawater intrusion. The dominant water type identified by Piper diagram was Na–Cl, with evidence of Ca–Cl facies suggesting ion exchange reactions in the aquifer. High molar ratios of Cl/HCO3 and Mg/Ca (>1) further confirmed the influence of seawater intrusion on water quality. The Water Quality Index (WQI) ranged from 8 to 116, with the highest values recorded in Thiruvanmiyur and the lowest in Muttukkadu. Notably, 64% of samples exhibited hard or very hard total hardness. However, indices such as Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), and

Permeability Index (PI) indicated suitability for irrigation in the majority of samples. Spatial distribution maps revealed significant deterioration of groundwater quality in the northern Thiruvanmiyur region due to urbanization and overexploitation, while the southern Muttukkadu area exhibited better water quality. Overall, the study highlights the significant impact of urbanization and seawater intrusion on groundwater quality in the South Chennai coastal area, with implications for both drinking water and agricultural use.

Md. Mezbaul Bahar, Md. Salim Reza did a study in 2010 on the Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of Southwest Bangladesh. The study conducted in the coastal region of Khulna, southwest Bangladesh, evaluated the hydrochemical characteristics of shallow groundwater for drinking and irrigation purposes. Analysis of water samples from 26 boreholes revealed varying chemical compositions, with most groundwater slightly alkaline and exhibiting a wide range of electrical conductivity (EC), from 962 to 9,370 µS/cm. Two major hydrochemical facies were identified: Na^+–K^+–Cl^-–SO_4^{2-} and Na^+–K^+–HCO_3^-. However, salinity, total hardness (TH), and sodium percentage (Na%) indicated that the majority of samples were unsuitable for irrigation and domestic use, falling short of drinking water standards. The brackish nature of groundwater was attributed to seawater intrusion and hydrogeochemical processes. Additionally, high levels of EC and Na% rendered the groundwater unsuitable for irrigation despite acceptable sodium adsorption ratio (SAR) values. Approximately 50% of samples exceeded recommended total dissolved solids (TDS) limits, while TH was generally high, rendering three-fourths of the sample locations unsuitable for drinking. These findings underscore the challenges posed by seawater intrusion and highlight the need for careful management of groundwater resources in the region.

Chapter 3

Methodology

3.1 Field work

The study area boundaries were delineated using topographic sheets indicating well locations in the coastal region. This data was overlaid onto Google Earth, where placemarks denoting the well positions were added, and their coordinates were recorded accordingly. These coordinates were subsequently inputted into Google Maps, facilitating on-site navigation during fieldwork. Additionally, Google Maps served to verify the accuracy of these coordinates while in the field. Samples were collected sequentially from the coastline extending towards the west to assess the impact of seawater on wells in close proximity to the shore compared to those situated further inland.

3.2 Field visit

Two field visits were conducted to gather necessary data, one during May (premonsoon)and the other during postmonsoon. Wells were selected with a minimum separation of 400 meters. A total of 24 wells were selected for examination. Coordinates for these wells were confirmed on-site during visits and subsequently entered into an Excel spreadsheet.

In-situ measurements were taken for electrical conductivity (EC meter), pH and dissolved oxygen using the FiveGo-Mettler Toledo pH and DO meter.

Table 3.1: Coordinates of well located

Well. No.	Latitude	Longitude
W1	15.3633243	73.8802594
W2	15.3577653	73.8834055
W3	15.3581904	73.8871344
W4	15.3482475	73.8897655
W5	15.3496944	73.8973556
W6	15.3418889	73.8934056
W7	15.3423972	73.9003778
W8	15.3361111	73.8976833
W9	15.3377833	73.9047333
W10	15.3275944	73.9018
W11	15.3243028	73.9063167
W12	15.3265605	73.9135654
W13	15.3157722	73.9129626
W14	15.3161944	73.9063889
W15	15.3132211	73.9142819
W16	15.3017421	73.9089825
W17	15.2923083	73.913575
W18	15.2952	73.9256083
W19	15.2767354	73.9249303
W20	15.2704912	73.9379095
W21	15.256141	73.9262251
W22	15.2595509	73.9408465
W23	15.2360379	73.9337071
W24	15.2401466	73.938463

pH and DO values were determined by the following steps-

Procedure:

1. Electrode was taken out of solution (KCl) and rinsed with distilled water

2. Immerse the electrode in the water sample and switch on the meter and press read. The screen will start showing readings

3. Once the reading is stable the meter produces a beep sound, that reading should be noted.

4. Once the reading is taken, the meter must be put off and the electrode must be rinsed with distilled water before putting it back into the KCl solution.

Electrical conductivity was measured using the EC meter. The EC meter has a measuring tape which is attached to an electrode which is coiled around the meter.

The EC values were determined using the following steps-

Procedure:

1. Press and hold the start button till the meter makes a beep sound indicating that it is turned on and note down the reading and then press and hold the start button till the EC meter is turned off.
2. The knob on the EC meter is loosened and the electrode is decended into the well till the electrode touches the water surface.
3. The EC meter is turned on by pressing and holding the start button and the readings are noted.
4. The meter is then switched off and the electrode is pulled back to the surface where it is rinsed with distilled water before placing it back in the meter.

The static water level was measured in meters with the help of a measuring tape. The static water table varies depending on rainwater recharge, type of aquifer and human activities like frequent pumping of water.

Premonsoon survey was done in the month of May 2023 and post monsoon survey was done in February 2024.

TDS values were calculated from EC values using the formula,

TDS(mg/l) = EC x ke (Taylor, 2018)

ke = 0.65, where ke is a constant of proportionality.

3.3 Chemical parameters:

3.3.1 Total Hardness

The total hardness was calculated titrimetically (S.A.P., May 1999) as follows.

Requirements: Beaker, Conical flask – 250mL, Eriochrome black- T indicator, 0.02NEDTA solution, Ammonium chloride buffer solution, Distilled water, Glass rod, Burette, etc.

Preparation of Reagents:

1. Preparation of 0.02N EDTA titrant- take 3.273g of EDTA powder and dissolve it in 1000mL of distilled water.

2. Preparation of Ammonium Buffer- To prepare the Ammonia buffer solution. Dissolve 16.9g ammonium chloride (NH_4Cl) in 143 ml concentrated ammonium hydroxide (NH_4OH). Add 1.25g magnesium salt of EDTA and dilute to 250 ml with distilled water. If magnesium salt of EDTA is not available, dissolve 1.179g disodium salt of EDTA (AR) grade and 780 mg $MgSO_4.7H_2O$ or 644 mg $MgCl_2.6h_2O$ in 50 ml distilled water. Add this to above solution of NH_4Cl in NH_4OH and dilute to250ml.

3. Preparation of Eriochrome Black T indicator- Dissolve 0.5g of Eriochrome black T indicator in 80mL of 90% ethanol and make up to 100mL with 95% ethanol.

Procedure:

1. Rinse and fill the burette with 0.02N EDTA solution.

2. Rinse and pipette out 25mL of water sample in a clean 250mL conical flask and add 1mL Ammonium buffer.

3. Now add one drop of Eriochrome black T indicator into the flask and titrate it against 0.02N

EDTA solution.

4. The end point is determined by colour change from wine red to blue.

Calculation:

$$\textbf{Hardness} = \frac{\text{ml of the EDTA titrant} \times 1 \times 1000}{\text{ml of sample taken for titration}}$$

3.3.2 Estimation of Calcium Hardness

Titrimetric analysis (S.A.P., May 1999) was used to determine calcium hardness.

Requirements: Beaker, Conical flask – 250mL, Murexide indicator powder, 1N Sodium hydroxide solution, 0.02N EDTA sol., Distilled water, Glass rod, Burette, etc.

Preparation of Reagents:

1. Preparation of 0.02N EDTA titrant- take 3.273g of EDTA powder and dissolve it in 1000mL
of distilled water.

2. Preparation of 1N Sodium Hydroxide Solution: Weigh 4.5g of sodium hydroxide in 100mL distilled water and allow it to cool.

Procedure:

1. Rinse and fill the burette with 0.02N EDTA solution.

2. Rinse and pipette out 25mL of water sample in a clean 250mL conical flask and add 2mL NaOH solution.

3. Now add a pinch of Murexide indicator powder to the sample solution and titrate it against 0.02N EDTA solution.

4. The endpoint is determined by the change in colour from pink to purple.

Calculation:

$$\text{Calcium (as Ca) Mg/L} = \frac{\text{ml of the EDTA titrant} \times 1 \times 100 \times 0.40}{\text{ml of sample taken for titration}}$$

3.3.3. Estimation of Magnesium Hardness

Magnesium hardness was determined by using the below formula (S.A.P., May 1999):

Mg in mg/L = (TH as MgCaCO3/L− Calcium Hardness as CaCO3/L) × 0.243

Where; TH = Total Hardness, MgCaCO3/L

3.3.4. Estimation of Chloride:

Mohr's method was used to evaluate chloride levels in water samples.

Requirements: Burette, Pipette, measuring cylinder, Conical flasks, Acid or alkali for adjusting pH.

Preparation of Reagents:

1. Standard silver Nitrate solution (0.0141N): Dissolve 2.395g of $AgNO_3$ in distilled water and dilute it to 1L.

2. Potassium Chromate Indicator: Dissolve 5g potassium Chromate in a little distilled water. Add silver nitrate solution till a definite red precipitate is formed. Let stand for 12 hours. Filter and dilute the filtrate to 1L with distilled water

Procedure:

1. Take 25mL water sample and dilute it with 50mL distilled water.

2. pH of the sample is checked using pH meter. (pH should be within the range of 7-8 if not pH is adjusted using acid or alkali).

3. Now add 0.5mL potassium Chromate indicator and titrate it against 0.0141N standard silver nitrate solution.

4. End point is determined by formation of reddish-brown precipitate.

Calculation:

$$\text{Chloride (as Cl) Mg/L} = \frac{\text{ml of the AgNO3 titrant} - 0.2 \times 500}{\text{ml of sample taken for titration}}$$

3.3.5 Sodium and Potassium

The analysis of Sodium and Potassium were obtained by using the Flame Photometric Method.

Procedure:

1. Switch on the flame photometer and the air compressor.
2. Turn on the gas and ignite the flame.
3. Click on Analysis -> "G-" -> Batch number -> g-na-k and click next.
4. Pour some distilled water in a beaker and aspirate it through the tube for cleaning and click next.
5. Pour the water sample in another beaker and aspirate it through the tube and click next.
6. The instrument will start analysing the water sample for sodium and potassium and will display the readings in ppm and meq after analysis.
7. Note down the readings and repeat the procedure from step 4 for each sample.

3.3.6 Nitrite

The determination of Nitrite is based on the method of Strickland and Parsons (1968). Nitrite reacts with sulfanilamide in an acid solution resulting in a diazonium compound. This is then coupled with N-(1-Naphthyl)-ethylenediamine dihydrochloride to form a colored azo dye, the extinction of which can be measured spectrophotometrically at the wavelength of 540 nm.

Procedure

1. 0 (Blank), 1, 2, 3, 4, and 5 ml of the working solution (NaNO 2) are taken in 50 ml graduated tubes and diluted to the marks with distilled water.

2. 50 ml of the water sample is taken in the graduated tubes.
3. 1 ml of sulfanilamide and 1 ml of diamine is added and shaken well.
4. The absorbance of this is measured after 20 minutes in a spectrophotometer at the wavelength of 540 nm.

Note: The dye should not be exposed to sunlight.

Calculation:

$$\text{Concentration of Nitrite } (\mu \text{ mol / L}) = \text{Average Factor} \times \text{Optical Density}$$

3.3.7 Phosphate

For the analysis of Phosphate, Murphy and Riley's Molybdenum blue method forms the basis of most methods. It involves the reaction of orthophosphate with ammonium molybdate under conditions to form 12-molybdophosphate, a yellow- coloured complex. This complex is reduced by either ascorbic acid or Stannous chloride in the presence of antimony to a blue colour complex (molybdenum blue). The light absorption of this is measured in a spectrophotometer at the wavelength of 880 nm.

Procedure

1. Blank (0), 2, 4, 6, 8, 10, and 12 ml of working solution (Potassium dihydrogen phosphate) are taken in 50 ml graduated tubes and diluted to the marks with distilled water and 50 ml of the water sample is taken in the graduated tubes.

2. 1 ml of the Mixed reagent and 1 ml of ascorbic acid is added and mixed well.

After 30 minutes the absorbance is measured at the wavelength of 880 nm.

3. A calibration curve is constructed using known concentration of the phosphate against absorbance

Calculation:

$$\text{Concentration of phosphate } (\mu \text{ mol / L}) = \text{Average Factor} \times \text{Optical Density}$$

Chapter 4

Groundwater quality assessment

4.1: Physical parameters:

Various types of impurities enter into groundwater which could be due to soil water interactions, weathering of rocks, leaching of soils, aerosol particles and from human activities.

The physical parameters pH, EC, TDS and DO were estimated for all 24 water samples from the wells in the study area. This was done to check the variation of values for each parameter in the water samples during pre-monsoon and post-monsoon periods.

4.1.1: pH

pH serves as a crucial indicator of groundwater quality, influenced by local geology, human activities, soil composition through which water permeates, and potential contaminant sources. It quantifies the concentration of hydrogen ions within a liquid, thereby characterizing its acidic or basic properties. Solutions with a pH exceeding 7 are considered basic, while those below 7 are acidic. Typically, groundwater exhibits a pH range of 6 to 8.5, categorized as slightly acidic, neutral, or slightly alkaline. According to WHO, the permissible range for pH is from 6.5 to 8.5.

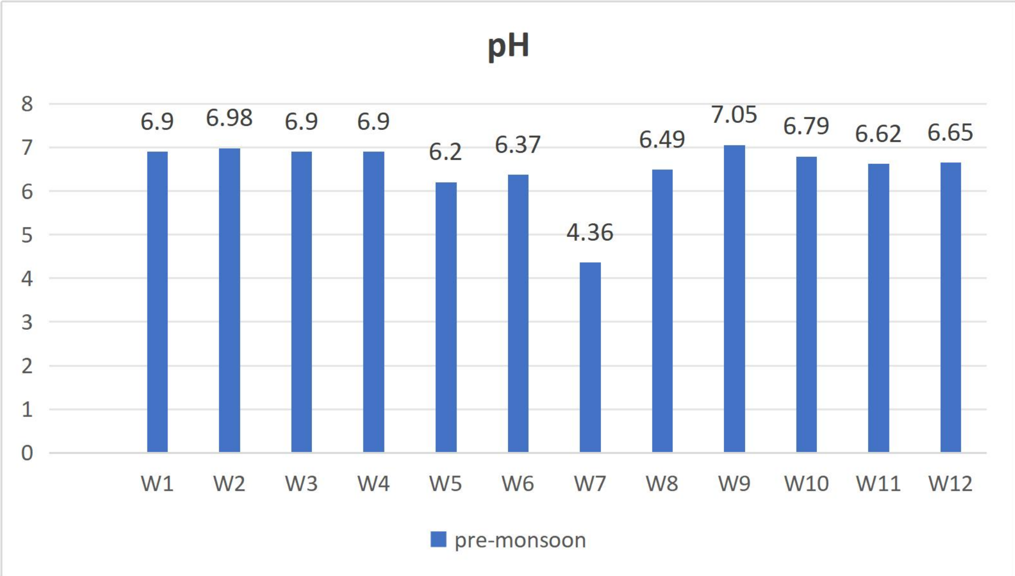
4.1.1.a: Observations

During pre-monsoon, pH levels for water samples ranged from 5.36 to 7.41. The majority of wells exhibited slightly acidic pH. The lowest pH value recorded was 5.36 for well W7, while the highest pH value was 7.41 for well W23. On average, the pH value during pre-monsoon was 6.77.

During the pre-monsoon period, 21 out of the 24 wells surveyed exhibited pH levels within the permissible drinking water limit (6.5-8.5) as defined by the Bureau of Indian Standards (BIS) in 2012.

Table 4.1: pH measurements of observed wells

Well. No.	Latitude	Longitude	pH
			pre-monsoon
W1	15.3633243	73.8802594	6.9
W2	15.3577653	73.8834055	6.98
W3	15.3581904	73.8871344	6.9
W4	15.3482475	73.8897655	6.9
W5	15.3496944	73.8973556	6.2
W6	15.3418889	73.8934056	6.37
W7	15.3423972	73.9003778	4.36
W8	15.3361111	73.8976833	6.49
W9	15.3377833	73.9047333	7.05
W10	15.3275944	73.9018	6.79
W11	15.3243028	73.9063167	6.62
W12	15.3265605	73.9135654	6.65
W13	15.3157722	73.9129626	6.55
W14	15.3161944	73.9063889	7.33
W15	15.3132211	73.9142819	6.53
W16	15.3017421	73.9089825	6.67
W17	15.2923083	73.913575	6.74
W18	15.2952	73.9256083	6.86
W19	15.2767354	73.9249303	6.97
W20	15.2704912	73.9379095	7.25
W21	15.256141	73.9262251	7.35
W22	15.2595509	73.9408465	7.38
W23	15.2360379	73.9337071	7.41
W24	15.2401466	73.938463	7.3



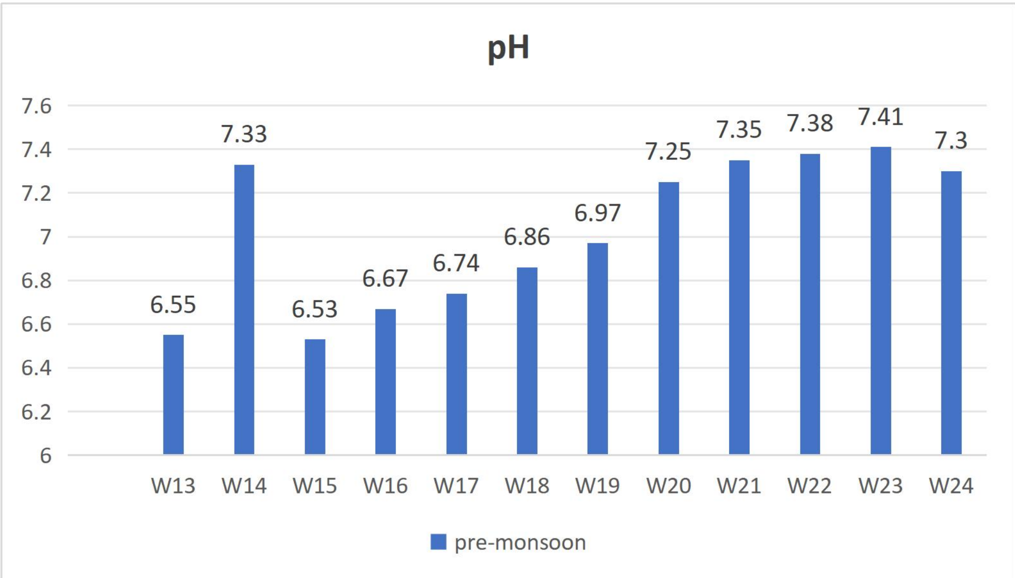


Figure 4.1: premonsoon pH graphs

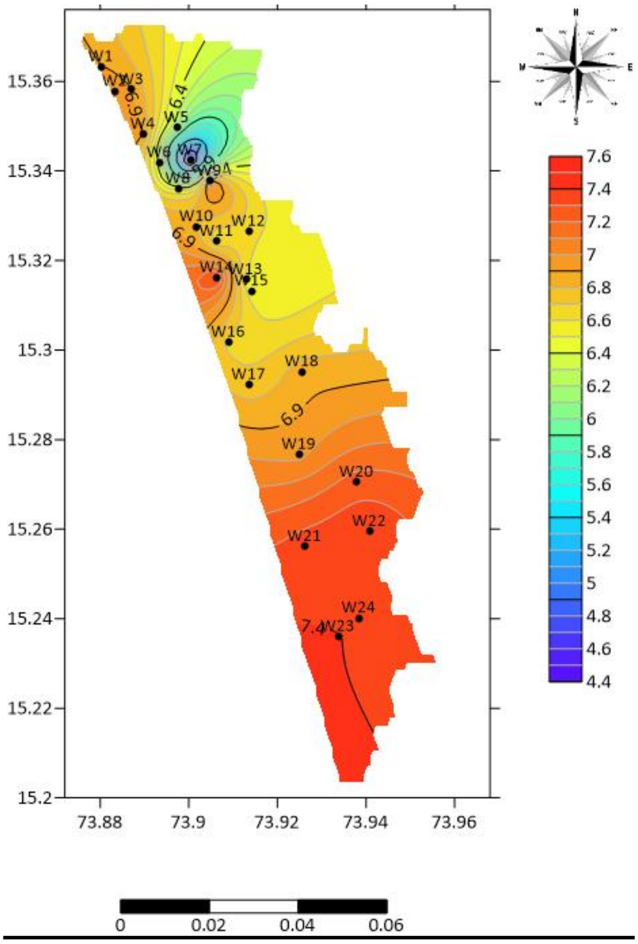


Figure 4.2: Premonsoon pH contour map

4.1.2 Electrical Conductivity (EC):

Electrical conductivity serves as an essential indicator of the dissolved ion concentration in water, providing valuable insights into its overall composition. High EC values may indicate elevated levels of dissolved salts, which can affect the taste and palatability of water. Moreover, elevated EC levels may suggest the presence of contaminants, such as industrial pollutants, agricultural runoff, or sewage, which can pose significant health risks if present in drinking water above permissible limits. Changes in EC values can indicate the presence of pollutants, such as heavy metals, nutrients, pesticides, and organic contaminants, which may originate from industrial discharges, agricultural runoff, urban development, or natural sources.

4.1.2. a Observations:

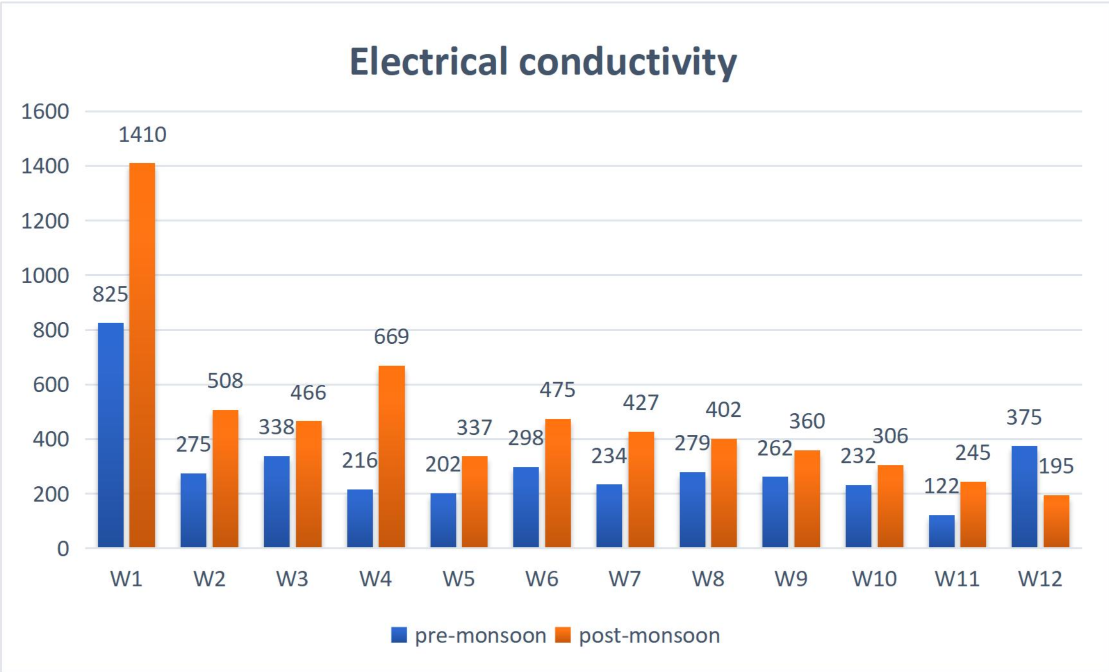
EC measurements were conducted in all 24 wells during both pre-monsoon and post-monsoon periods. The highest EC recorded during pre-monsoon was 833µS/cm in well W13, while the lowest was 122µS/cm observed in well W11. Conversely, during post-monsoon, the highest EC measured was 1410µS/cm in W1, with the lowest at 120µS/cm in W22. EC values range from 112-833µS/cm during premonsoon and 120-1410µS/cm during postmonsoon. The average EC value during pre-monsoon was 323.29µS/cm, slightly lower than the 383µS/cm recorded during post-monsoon.

Analysis of the data indicates that 58% of the samples exhibit higher EC levels during post-monsoon compared to pre-monsoon. Graphical representations illustrate that the majority of wells show minimal fluctuation between their pre-monsoon and post-monsoon EC values. However, wells W1, W2, W4, W12, W13, W16, W18, W19, and W24 displayed notable fluctuations in their EC values between the two seasons.

The increase in electrical conductivity observed post-monsoon can be attributed to several contributing factors such as the proximity to the sea, tidal variations, and the possibility of saltwater intrusion, contribute to the variability observed in groundwater electrical conductivity (EC) levels. The substantial rainfall experienced during the monsoon period often leads to heightened surface runoff, transporting dissolved solids like salts, minerals, and organic matter into nearby groundwater reservoirs. Moreover, the porous nature of laterite rock facilitates the percolation of these dissolved solids along with rainwater, infiltrating into the groundwater aquifers. As a result, the influx of these solid salts during runoff events contributes to an increase in the levels of dissolved solids within the groundwater, consequently elevating the electrical conductivity readings post-monsoon.

Table 4.2: EC measurements of observed wells

Well No.	Latitude	Longitude	Electrical Conductivity	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	825	1410
W2	15.3577653	73.8834055	275	508
W3	15.3581904	73.8871344	338	466
W4	15.3482475	73.8897655	216	669
W5	15.3496944	73.8973556	202	337
W6	15.3418889	73.8934056	298	475
W7	15.3423972	73.9003778	234	427
W8	15.3361111	73.8976833	279	402
W9	15.3377833	73.9047333	262	360
W10	15.3275944	73.9018	232	306
W11	15.3243028	73.9063167	122	245
W12	15.3265605	73.9135654	375	195
W13	15.3157722	73.9129626	833	600
W14	15.3161944	73.9063889	294	272
W15	15.3132211	73.9142819	240	280
W16	15.3017421	73.9089825	545	251
W17	15.2923083	73.913575	177	159
W18	15.2952	73.9256083	206	394
W19	15.2767354	73.9249303	348	213
W20	15.2704912	73.9379095	311	323
W21	15.256141	73.9262251	379	333
W22	15.2595509	73.9408465	124	120
W23	15.2360379	73.9337071	301	260
W24	15.2401466	73.938463	343	187



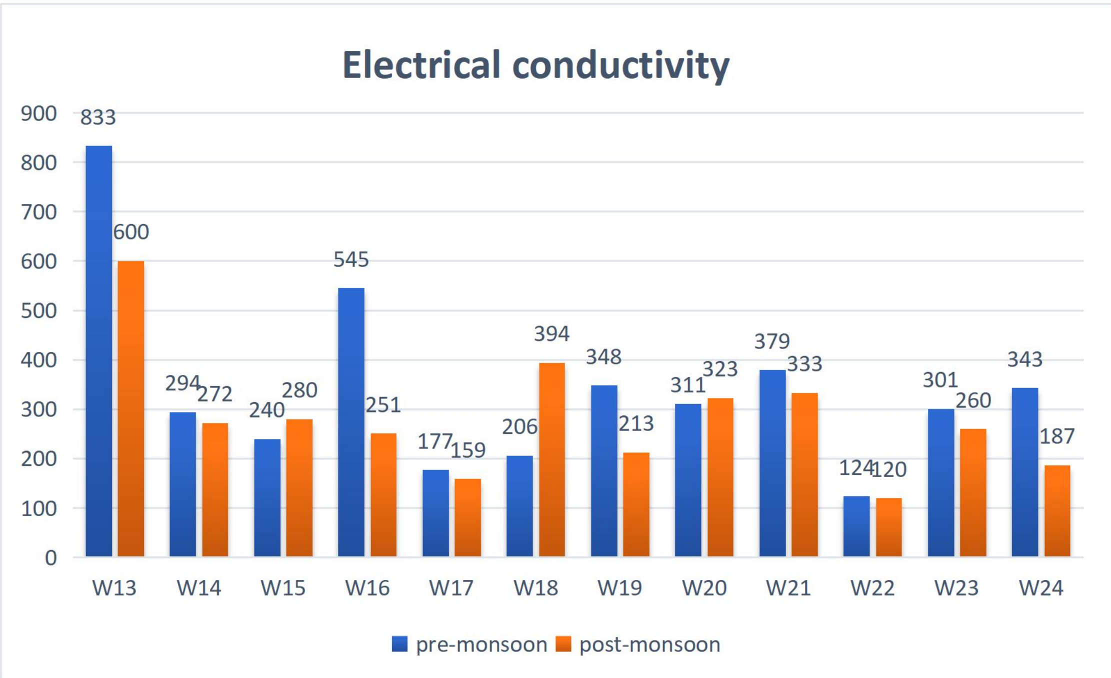


Figure 4.3: EC measurement graph

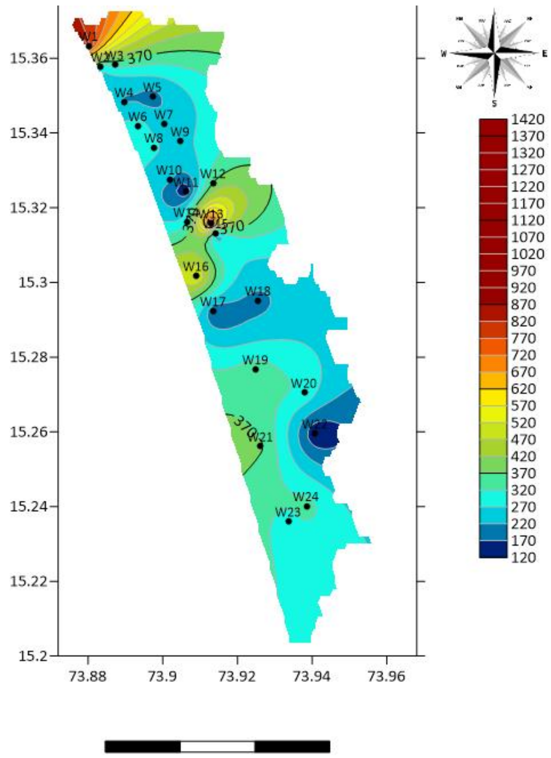


Figure 4.4: Premonsoon EC contour map

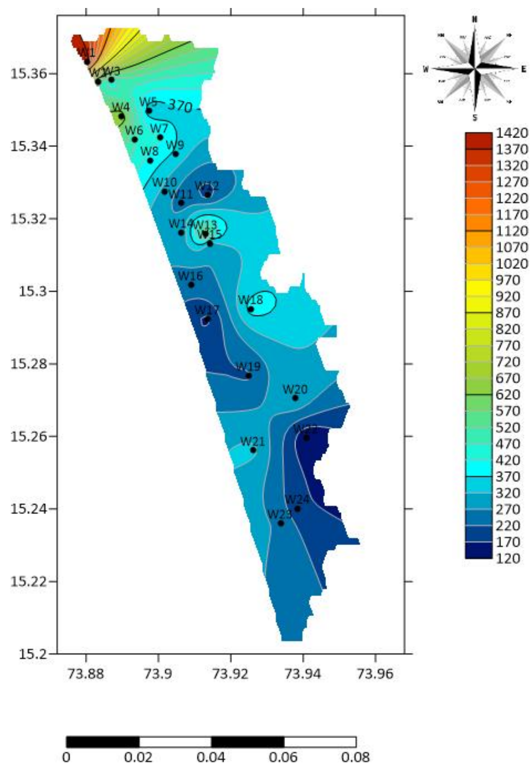


Figure 4.5: Postmonsoon EC contour map

4.1.3 Total Dissolved Solids (TDS):

Total Dissolved Solids (TDS) represent the combined content of all inorganic and organic substances dissolved in water. High levels of TDS can impact the taste, odor, and overall acceptability of drinking water. Additionally, certain dissolved substances, such as heavy metals and organic compounds, can pose health risks if present in concentrations above regulatory limits.

Elevated Total Dissolved Solids (TDS) levels can introduce a discernible taste or odor to water, potentially rendering it unappealing to consumers. Such high TDS concentrations often signal the presence of dissolved pollutants like heavy metals, salts, and organic compounds, posing health hazards when consumed beyond acceptable thresholds. Chronic exposure to certain contaminants found in elevated TDS water, such as arsenic, lead, or fluoride, can lead to adverse health effects ranging from gastrointestinal discomfort to neurological disorders and developmental delays, particularly in vulnerable populations such as infants, children, and pregnant women.

Monitoring TDS helps ensure that drinking water meets health-based standards and is safe for consumption. While high TDS values may not necessarily indicate harmful contaminants, they can suggest the presence of dissolved minerals, salts, and other substances that may affect water usability and treatment requirements. By monitoring TDS, water providers can identify potential sources of contamination and implement appropriate treatment measures to maintain water quality within acceptable limits.

4.1.3.a Observations:

The TDS values were derived from EC measurements across all 24 wells in the study area during both pre-monsoon and post-monsoon periods. The highest TDS reading during pre-monsoon was 541.45 ppm in well W13, while the lowest was 79.3 ppm observed in well W11. Conversely, during post-monsoon, the highest TDS value reached 916.5 ppm in W1, with the lowest recorded at 78 ppm in W22. TDS values range from 79.3-541.45 ppm during premonsoon and 78-916.5 ppm. On average, TDS levels were 210.13 ppm during pre-monsoon and 248.95 ppm during post-monsoon.

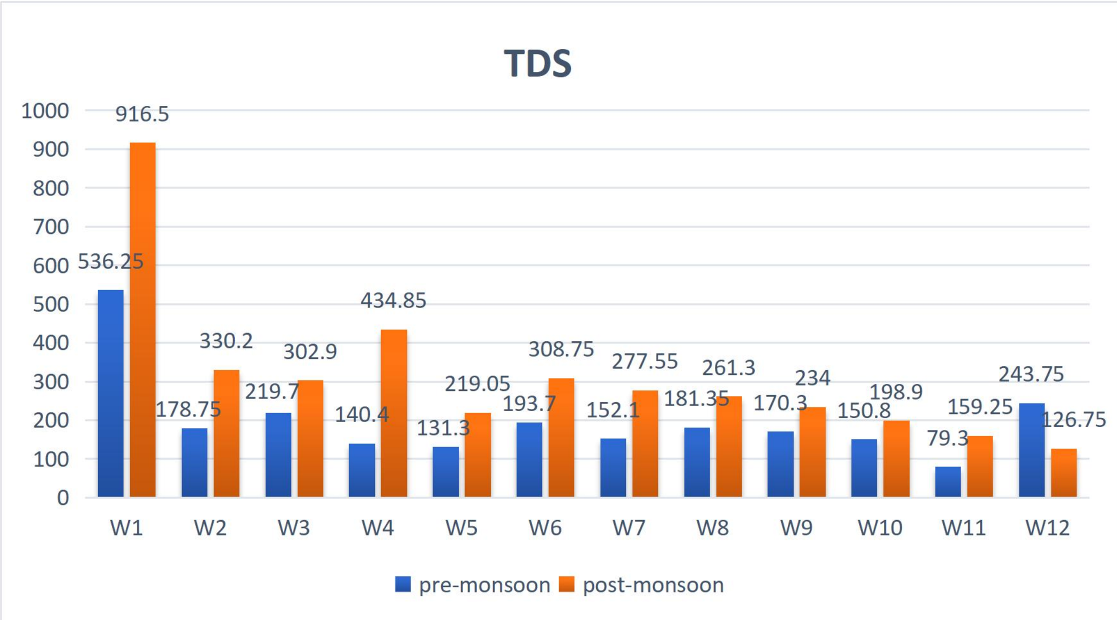
Similar to EC measurements, 58% of the wells exhibited higher TDS values during post-monsoon compared to pre-monsoon. The observed phenomenon is probably due to rainfall facilitating the process of leaching organic matter, minerals, and salts from the soil into the groundwater. As rainwater percolates through the soil, it can dissolve minerals and salts, thus raising the concentration of Total Dissolved Solids in the groundwater.

Visual inspection of graphs revealed that most wells displayed minimal fluctuations in TDS values between pre-monsoon and post-monsoon periods. However, wells W1, W2, W4, W12, W13, 13a, W16, W18, and W24 exhibited notable variations in TDS levels between these two periods.

According to BIS standards, 22 out of 24 wells demonstrated TDS values within acceptable limits (below 300 mg/L) during pre-monsoon. Exceptions were noted in wells W1 and W13, which exceeded the acceptable drinking limit with TDS concentrations of 536.25 mg/L and 541.45 mg/L, respectively. During the post-monsoon period, 23 out of 24 wells remained within acceptable TDS limits. However, W1 surpassed the acceptable limit for drinking with a TDS concentration of 916.5 mg/L, as per BIS (2012) guidelines.

Table 1.3: TDS measurements for observed wells

Well. No.	Latitude	Longitude	Total dissolved solids	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	536.25	916.5
W2	15.3577653	73.8834055	178.75	330.2
W3	15.3581904	73.8871344	219.7	302.9
W4	15.3482475	73.8897655	140.4	434.85
W5	15.3496944	73.8973556	131.3	219.05
W6	15.3418889	73.8934056	193.7	308.75
W7	15.3423972	73.9003778	152.1	277.55
W8	15.3361111	73.8976833	181.35	261.3
W9	15.3377833	73.9047333	170.3	234
W10	15.3275944	73.9018	150.8	198.9
W11	15.3243028	73.9063167	79.3	159.25
W12	15.3265605	73.9135654	243.75	126.75
W13	15.3157722	73.9129626	541.45	390
W14	15.3161944	73.9063889	191.1	176.8
W15	15.3132211	73.9142819	156	182
W16	15.3017421	73.9089825	354.25	163.15
W17	15.2923083	73.913575	115.05	103.35
W18	15.2952	73.9256083	133.9	256.1
W19	15.2767354	73.9249303	226.2	138.45
W20	15.2704912	73.9379095	202.15	209.95
W21	15.256141	73.9262251	246.35	216.45
W22	15.2595509	73.9408465	80.6	78
W23	15.2360379	73.9337071	195.65	169
W24	15.2401466	73.938463	222.95	121.55



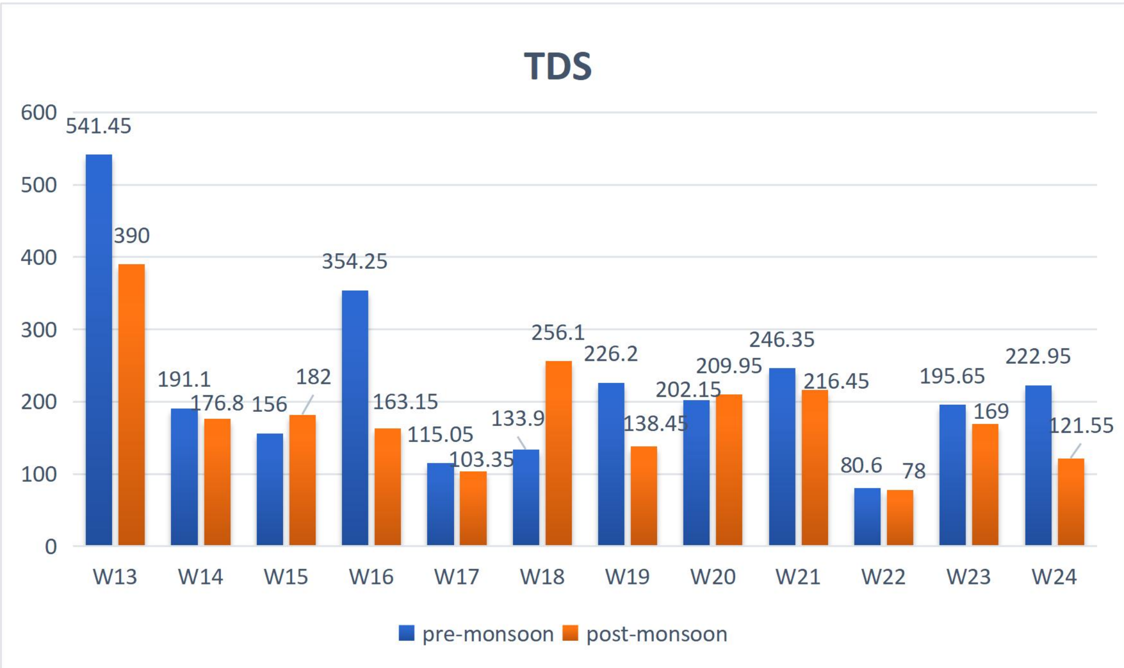


Figure 4.6: TDS measurement graph

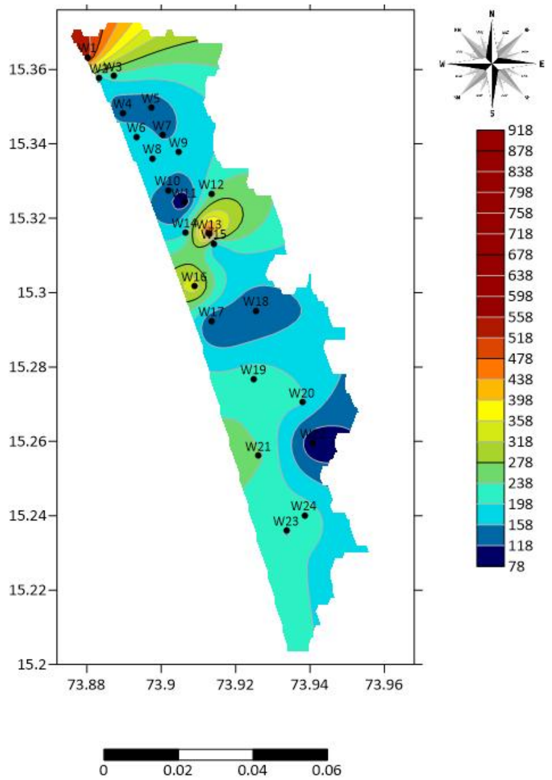


Figure 4.7: premonsoon TDS contour map

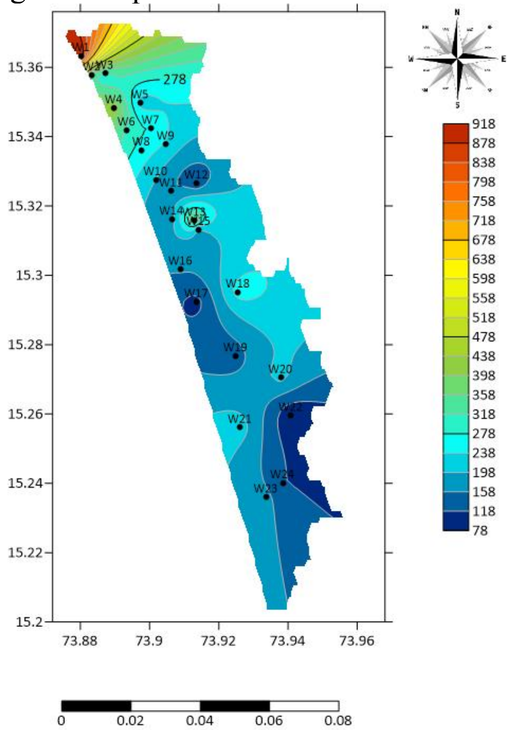


Figure 4.8: Postmonsoon TDS contour map

4.1.4 Dissolved Oxygen (DO):

Dissolved oxygen (DO) is a critical parameter in testing water for drinking purposes, as it directly impacts the health of aquatic ecosystems and the safety of drinking water supplies. The importance of DO in drinking water analysis is underscored by its role in supporting aquatic life, regulating chemical reactions, and indicating water quality. Adequate DO concentrations are essential for sustaining aquatic organisms, such as fish and other aquatic fauna, which serve as indicators of ecosystem health. Insufficient DO levels in drinking water can lead to hypoxia (low oxygen levels), which may result in fish kills, habitat degradation, and impaired water quality. Elevated DO concentrations may indicate excessive aeration or turbulence, which can lead to gas supersaturation and harm aquatic organisms, particularly fish and invertebrates. Furthermore, high DO levels may promote the growth of algae and other aquatic plants, leading to algal blooms, taste and odor issues, and potential health hazards associated with algal toxins.

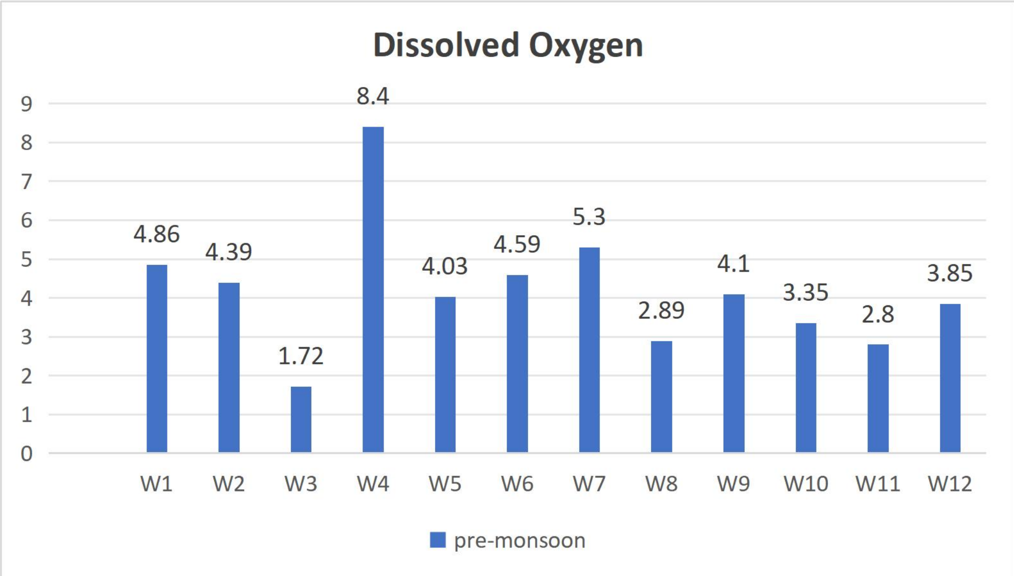
4.1.4.a Observations:

The measured DO of both premonsoon and postmonsoon are given in table 1.4. DO for water samples ranged from 1.72 - 13.35 during premonsoon. The Lowest DO value is 1.72 shown by W3 during premonsoon. The highest DO value is 13.35 shown by W16 during premonsoon. The average DO value during pre-moonsoon is 5.22.

The desirable limit for dissolved oxygen is 5mg/L according to Bureau of Indian Standard (2016). 13 out of the 24 wells showed dissolved oxygen values within the acceptable limits (below 5mg/L) during the pre-monsoon. W4, W7, W15-W23 had dissolved oxygen values above the acceptable limit for drinking.

Table 4.4: Dissolved oxygen measurements for observed wells

Well. No.	Latitude	Longitude	Dissolved Oxygen
			pre-monsoon
W1	15.3633243	73.8802594	4.86
W2	15.3577653	73.8834055	4.39
W3	15.3581904	73.8871344	1.72
W4	15.3482475	73.8897655	8.4
W5	15.3496944	73.8973556	4.03
W6	15.3418889	73.8934056	4.59
W7	15.3423972	73.9003778	5.3
W8	15.3361111	73.8976833	2.89
W9	15.3377833	73.9047333	4.1
W10	15.3275944	73.9018	3.35
W11	15.3243028	73.9063167	2.8
W12	15.3265605	73.9135654	3.85
W13	15.3157722	73.9129626	2.93
W14	15.3161944	73.9063889	3.64
W15	15.3132211	73.9142819	5.3
W16	15.3017421	73.9089825	13.35
W17	15.2923083	73.913575	5.61
W18	15.2952	73.9256083	5.41
W19	15.2767354	73.9249303	7.64
W20	15.2704912	73.9379095	6.75
W21	15.256141	73.9262251	7.56
W22	15.2595509	73.9408465	6.2
W23	15.2360379	73.9337071	5.85
W24	15.2401466	73.938463	4.75



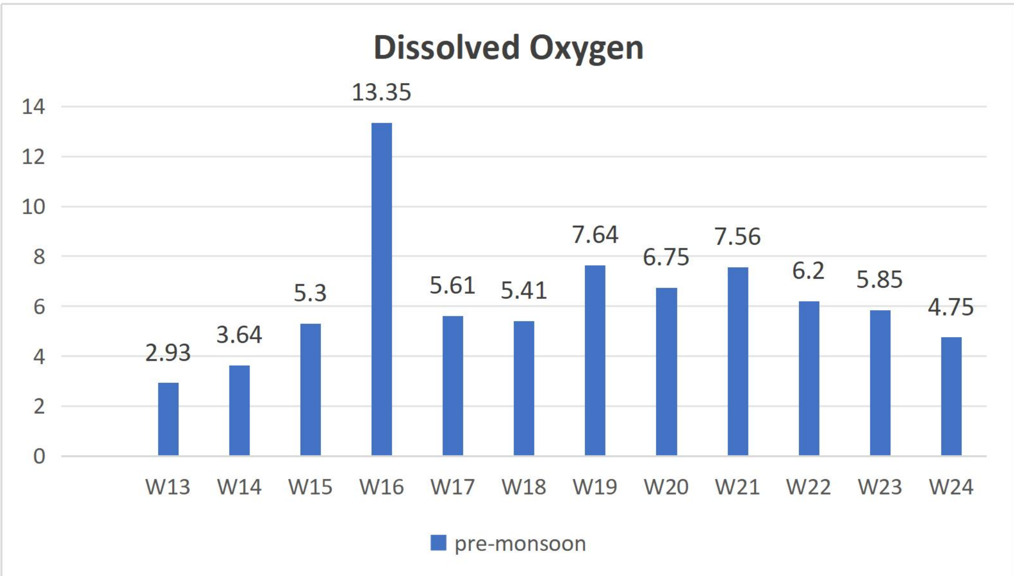


Figure 4.9: DO measurement graph

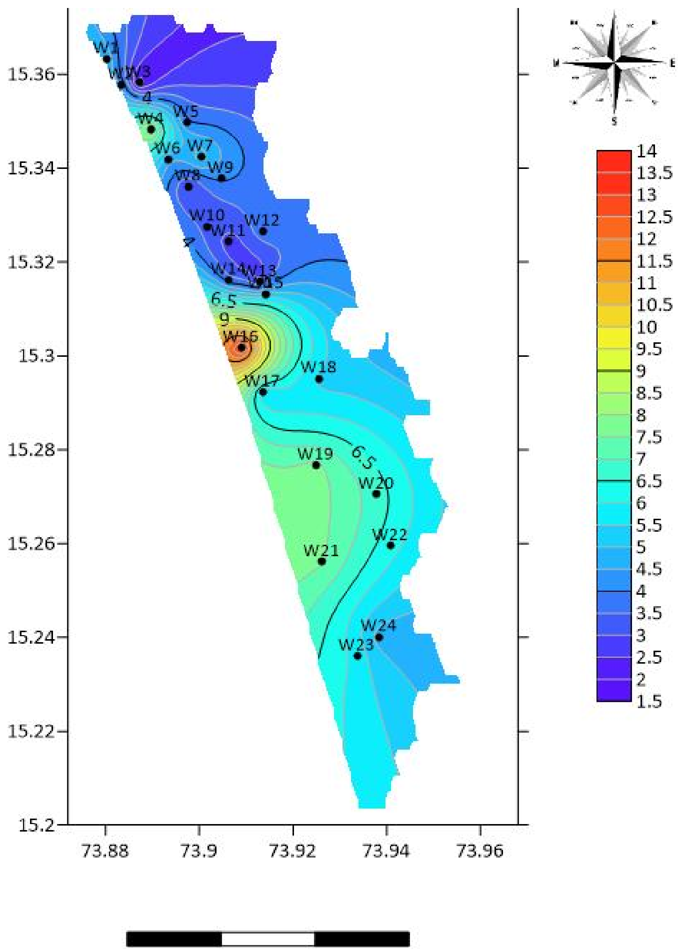


Figure 4.10: Premonsoon DO contour map

4.2 Chemical Parameters:

Water contains various types of impurities such as inorganic compounds, dissolved gases, organic compounds, microorganisms and suspended solids that can influence the chemistry of water, hence it is essential to assess the quality of water before it is used for drinking, irrigation, commercial and non commercial purpose. The increase or the decrease of the concentration of the ions in groundwater below or above the permissible limit can cause various health hazards and since groundwater is prone to various contaminants and their sources such as industrial waste, fertilizers, landfill leachate, saltwater intrusion, oil and gas contamination etc it becomes essential to check not only the physical but also the chemical parameters of the groundwater.

Chemical analyses were conducted on the well water samples from the study area to assess various parameters, including Total Hardness, Calcium, Magnesium, Chloride, Sodium, Potassium, Nitrite, Nitrate, Phosphate, and Sulphates.

4.2.1 Calcium:

Calcium is a naturally abundant alkaline earth element which is the most common cation found in groundwater systems. The concentration of Calcium content present in groundwater is largely dependent on the solubility of calcium carbonate, sulphate and rarely chloride. Calcium is a major contributor to water hardness, which refers to the concentration of dissolved minerals, particularly calcium and magnesium ions, in water. Calcium can affect the taste and appearance of drinking water. High levels of calcium may impart a slightly mineral taste to the water. Calcium is essential for maintaining healthy bones and teeth, muscle function, nerve transmission, and blood clotting. Adequate intake of calcium is particularly important during childhood and adolescence for bone development and in adulthood to prevent osteoporosis.

The acceptable limit of calcium concentrations for drinking water is specified as 75mg/L and permissible upto 200mg/L (BIS,2012).

4.2.1.a Observations:

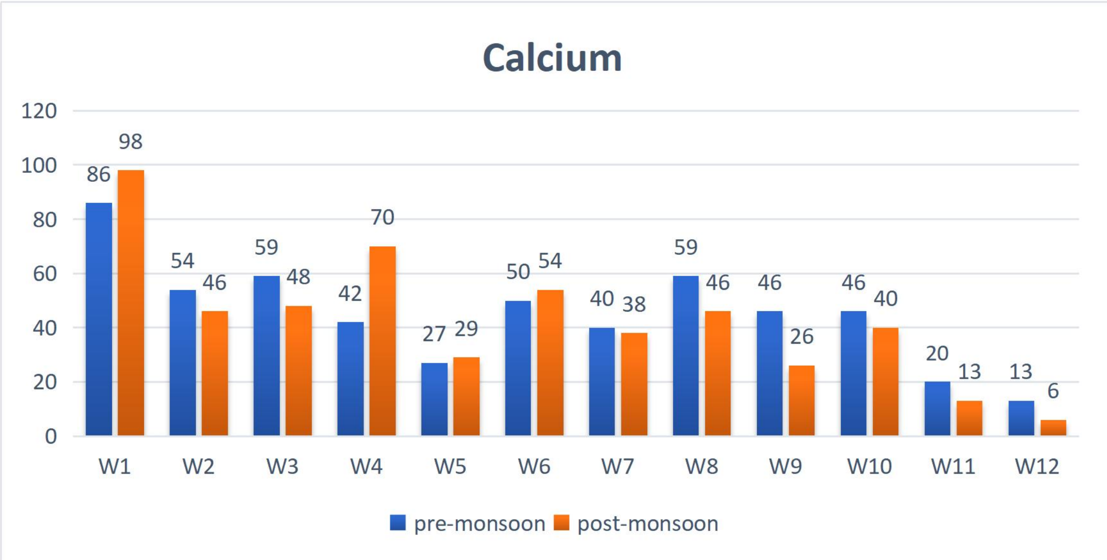
The Calcium values in the water samples ranges from 14.4-86.41 mg/L during pre-monsoon and 4.8-97.62mg/L during post-monsoon. The highest value of Calcium during pre-monsoon is 86.41mg/L shown by W1 and the lowest value is 14.4mg/L shown by W22. During post-monsoon, the highest value of Calcium is 97.62mg/L shown by W1 and the lowest value is 4.8mg/L shown by W22. The Average value of Calcium is 38.47mg/L during pre-monsoon and 31.47mg/L during post-monsoon.

Analysis of the data indicates that 79% of the samples exhibit lower calcium levels during post-monsoon compared to pre-monsoon. During periods of heavy monsoon rainfall, there is a likelihood of increased groundwater recharge, which could result in elevated water levels in wells. This influx of water may lead to a dilution effect on the concentration of calcium in groundwater, resulting in decreased calcium levels post-monsoon. Furthermore, the intense rainfall may have a flushing effect, causing the removal of calcium-rich minerals from the groundwater, thereby contributing to the subsequent decrease in calcium levels in wells.

According to BIS standards, the majority of the samples, specifically 23 out of 24 samples, exhibit calcium concentrations within permissible limits during both premonsoon and postmonsoon periods. However, well W1 stands out with the highest calcium values, measuring 86.41 mg/L during the premonsoon and 97.62 mg/L during the postmonsoon period, thereby exceeding the acceptable limits for drinking water.

Table 4.5: Calcium measurement of observed wells

Well. No.	Latitude	Longitude	Calcium	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	86.41728	97.61952
W2	15.3577653	73.8834055	54.41088	46.40928
W3	15.3581904	73.8871344	59.21184	48.0096
W4	15.3482475	73.8897655	41.60832	70.41408
W5	15.3496944	73.8973556	27.20544	28.80576
W6	15.3418889	73.8934056	49.60992	54.41088
W7	15.3423972	73.9003778	40.008	38.40768
W8	15.3361111	73.8976833	59.21184	46.40928
W9	15.3377833	73.9047333	46.40928	25.60512
W10	15.3275944	73.9018	46.40928	40.008
W11	15.3243028	73.9063167	20.80416	12.80256
W12	15.3265605	73.9135654	12.80256	6.40128
W13	15.3157722	73.9129626	43.20864	40.008
W14	15.3161944	73.9063889	62.41248	36.80736
W15	15.3132211	73.9142819	30.40608	14.40288
W16	15.3017421	73.9089825	41.60832	16.0032
W17	15.2923083	73.913575	17.60352	19.20384
W18	15.2952	73.9256083	40.008	35.20704
W19	15.2767354	73.9249303	28.80576	11.20224
W20	15.2704912	73.9379095	33.60672	28.80576
W21	15.256141	73.9262251	22.40448	12.80256
W22	15.2595509	73.9408465	14.40288	4.80096
W23	15.2360379	73.9337071	25.60512	14.40288
W24	15.2401466	73.938463	19.20384	6.40128



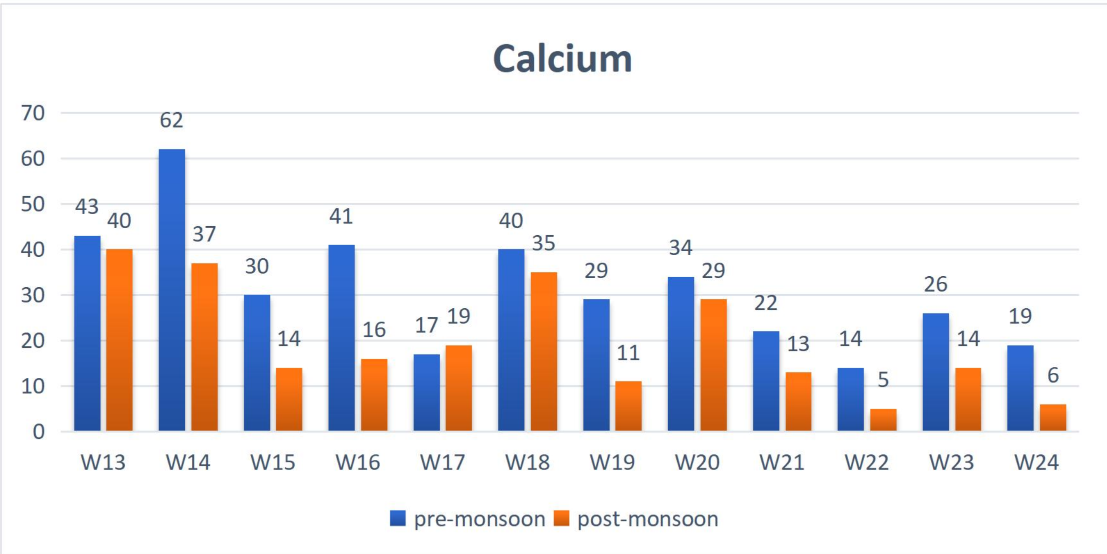


Figure 4.11: Calcium measurement graphs

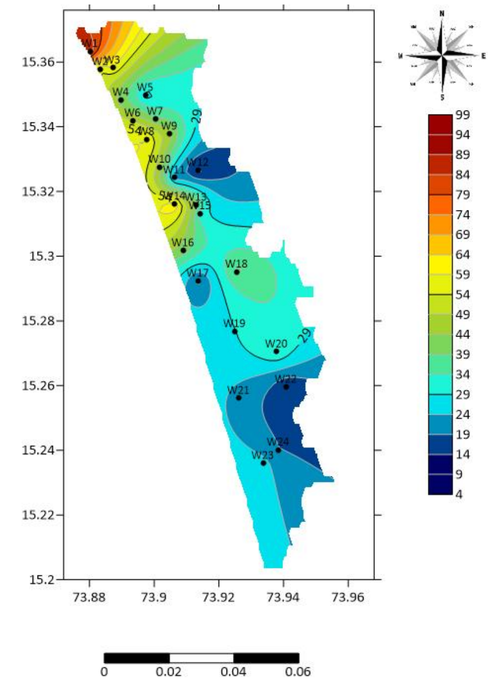


Figure 4.12: Premonsoon Calcium contour map

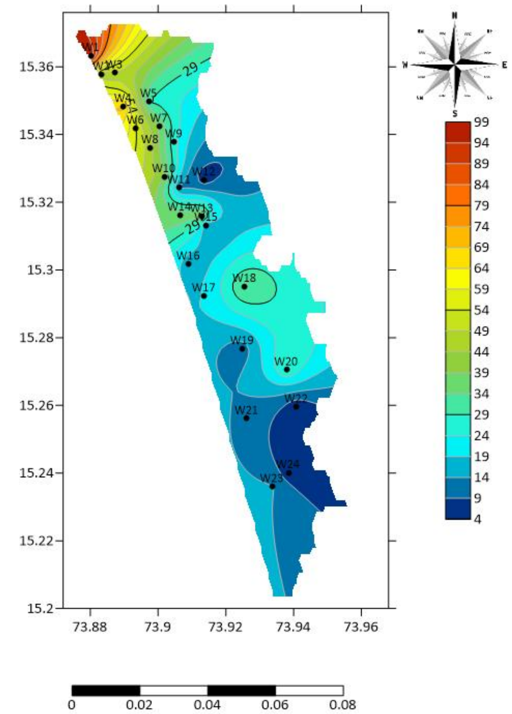


Figure 4.13: Postmonsoon calcium contour map

4.2.2 Magnesium:

Magnesium (Mg) is a naturally occurring element found in many geological formations, including aquifers that serve as sources of groundwater. It dissolves into water primarily through the weathering of magnesium-rich minerals such as dolomite and magnesite. Magnesium, along with calcium, contributes to water hardness. Magnesium is an essential mineral for human health, involved in various biological processes such as muscle function, nerve transmission, and bone development. High concentrations of magnesium can impart a bitter taste to drinking water. Excessive intake of magnesium through drinking water may cause digestive discomfort such as diarrhea or abdominal cramping in sensitive individuals.

According to BIS, the acceptable limits for Magnesium concentrations is specified as 30mg/L and permissible upto 100mg/L.(BIS,2012)

4.2.2.a Observations:

The magnesium levels in the water samples exhibit a range of 7.96-60.64 mg/L during the pre-monsoon period and 9.14-58.9 mg/L during the post-monsoon period. Notably, well W1 records the highest magnesium concentration during both pre-monsoon (60.64 mg/L) and post-monsoon (58.9 mg/L), while well W24 demonstrates the lowest values with 7.96 mg/L during pre-monsoon and 9.14 mg/L during post-monsoon. On average, the magnesium content is measured at 20 mg/L during the pre-monsoon and slightly higher at 20.54 mg/L during the post-monsoon period.

Analysis of the data indicates that 45.8% of the samples exhibit lower magnesium levels during post-monsoon compared to pre-monsoon while 54% of the samples show higher magnesium levels during postmonsoon as compared to premonsoon.

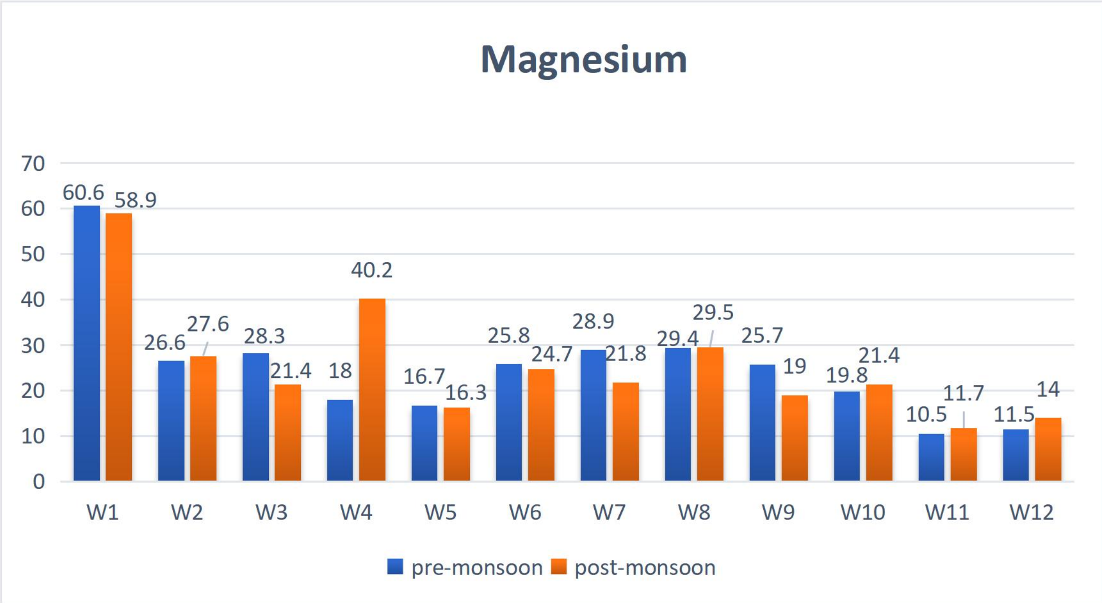
The variation in magnesium levels between pre-monsoon and post-monsoon periods can be attributed to several factors. During the pre-monsoon phase, there is typically limited rainfall and groundwater recharge, leading to the accumulation of dissolved minerals, including magnesium, in the groundwater. Additionally, elevated evapotranspiration rates during this period can further concentrate salts, contributing to higher magnesium levels. Geological factors, such as the composition of aquifers and surrounding rocks, also play a role, with certain rock types releasing magnesium-rich minerals into the groundwater. Anthropogenic activities like agricultural practices and industrial discharge may introduce pollutants, affecting magnesium concentrations.

In contrast, the post-monsoon period sees increased groundwater recharge and flushing effects from heavy rainfall, resulting in diluted magnesium levels due to enhanced groundwater replenishment and the removal of dissolved salts. Surface runoff and biological activity further influence magnesium dynamics in groundwater during this phase. Additionally, the proximity to the sea in the coastal area of Goa can influence magnesium levels, with potential inputs of marine-derived minerals affecting groundwater chemistry.

Majority of the samples ie. 23 out of 24 samples are in the acceptable limits for drinking according to BIS (30mg/L) except for W1 which has magnesium value of 60.64mg/L during premonsoon and 58.9mg/L during postmonsoon which exceeds the acceptable limit for drinking.

Table 4.6: Magnesium measurements for observed wells

Well. No.	Latitude	Longitude	Magnesium	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	60.64860096	58.89845664
W2	15.3577653	73.8834055	26.63015616	27.60254496
W3	15.3581904	73.8871344	28.37952288	21.3816672
W4	15.3482475	73.8897655	18.07717824	40.23737856
W5	15.3496944	73.8973556	16.71707808	16.32820032
W6	15.3418889	73.8934056	25.85278944	24.68615616
W7	15.3423972	73.9003778	28.186056	21.77093376
W8	15.3361111	73.8976833	29.35152288	29.54654496
W9	15.3377833	73.9047333	25.65854496	19.04995584
W10	15.3275944	73.9018	19.82654496	21.382056
W11	15.3243028	73.9063167	10.49658912	11.46897792
W12	15.3265605	73.9135654	11.46897792	13.99648896
W13	15.3157722	73.9129626	24.49230048	28.186056
W14	15.3161944	73.9063889	24.68576736	21.18781152
W15	15.3132211	73.9142819	16.91132256	11.08010016
W16	15.3017421	73.9089825	16.13317824	14.5792224
W17	15.2923083	73.913575	14.19034464	15.74546688
W18	15.2952	73.9256083	19.438056	22.54868928
W19	15.2767354	73.9249303	9.52420032	10.88585568
W20	15.2704912	73.9379095	8.35756704	18.27220032
W21	15.256141	73.9262251	16.91171136	13.41297792
W22	15.2595509	73.9408465	10.10810016	9.52536672
W23	15.2360379	73.9337071	10.30195584	12.05210016
W24	15.2401466	73.938463	7.96946688	9.13648896



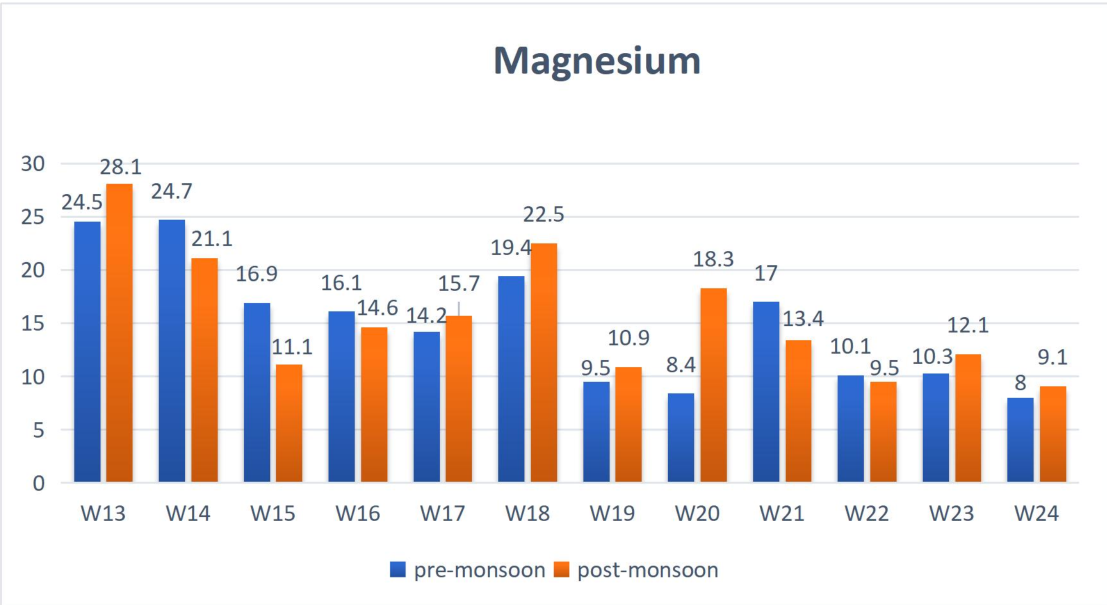


Figure 4.14: Magnesium measurement graph

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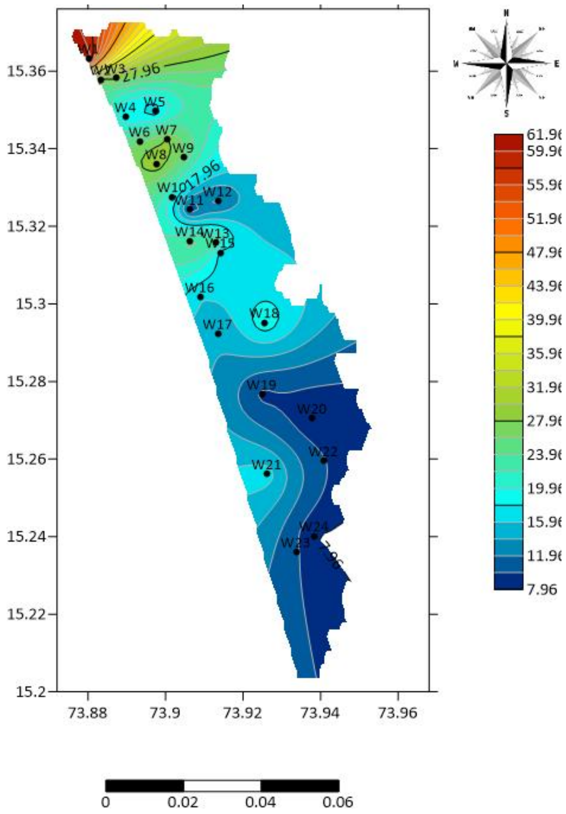


Figure 4.15: Premonsoon magnesium contour map

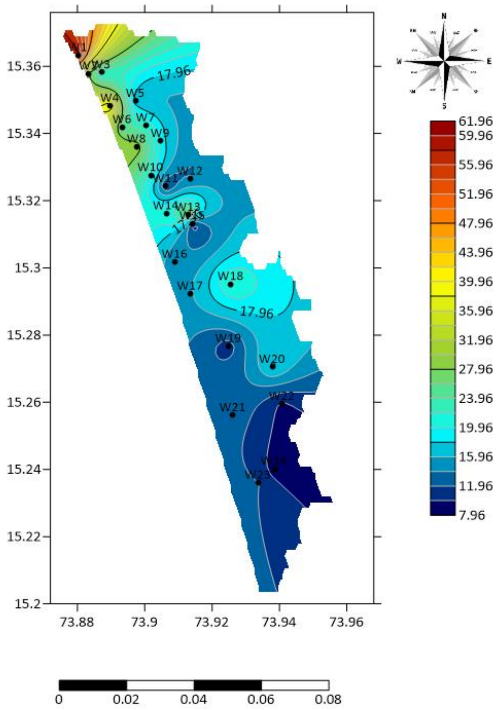


Figure 4.16: Postmonsoon magnesium contour map

4.2.3 Total Hardness

The total amount of polyvalent metallic ions which are dissolved in water, mainly calcium and magnesium cations determines its hardness. Hardness is commonly measured by expressing it as milligrams of calcium carbonate equivalent per liter. According to USGS classification of total hardness, as $CaCO_3$, 0-60 mg/L is considered soft, 61-120 mg/L is considered moderately hard, 121-180 mg/L is considered hard and more than 180 mg/L is considered as very hard. The acceptable limit for total hardness is 300mg/L and permissible upto 600mg/L in absence of alternate source (BIS, 2012).

4.2.3.a Observations:

The total hardness values in the water samples ranges from 52-336 mg/L during pre-monsoon and 44-340mg/L during post-monsoon. The highest value of total hardness during pre-monsoon is 336mg/L shown by W1 and the lowest value is 52mg/L shown by W23. During post-monsoon, the highest value of total hardness is 340mg/L shown by W1 and the lowest value is 44mg/L shown by W22 and W24. The Average value of total hardness is 120.83mg/L during pre-monsoon and 116mg/L during post-monsoon.

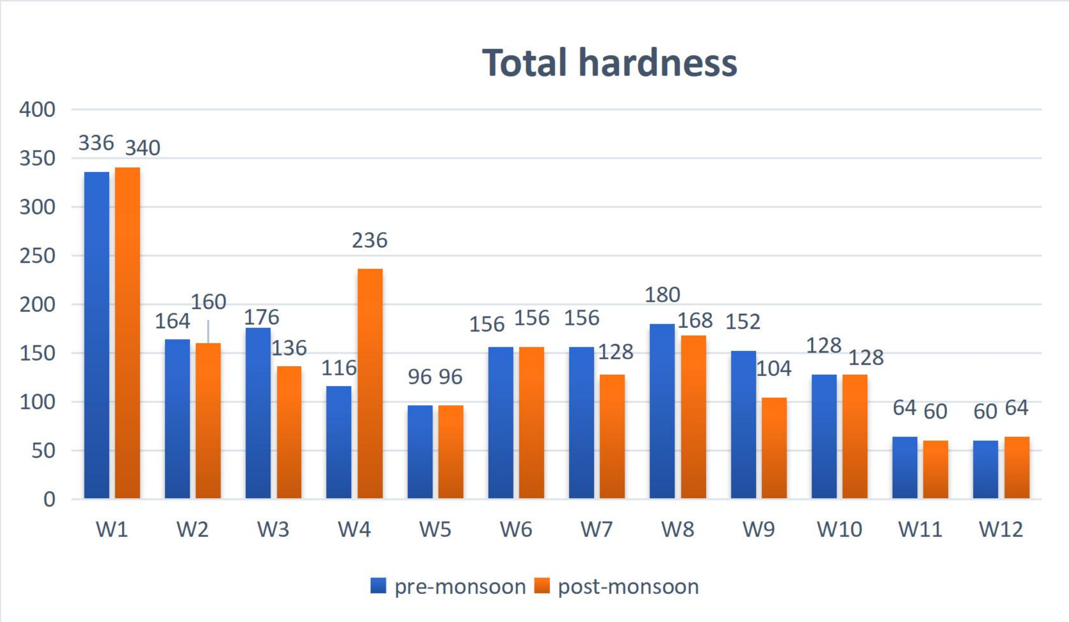
Analysis of the data indicates that 62.5% of the samples exhibit lower total hardness levels during post-monsoon compared to pre-monsoon. The decrease in total hardness levels during the post-monsoon period compared to pre-monsoon could be attributed to several factors. One possible explanation is the dilution effect caused by heavy rainfall during the monsoon season, which can increase the volume of groundwater and subsequently reduce the concentration of dissolved minerals, including calcium and magnesium. Additionally, increased groundwater recharge during the monsoon period might flush out minerals from the aquifer, leading to lower total hardness levels in groundwater. Furthermore, the leaching of minerals from soil and rock formations due to intense rainfall and surface runoff could contribute to the observed decrease in total hardness levels during the post-monsoon period. The remaining percentage of samples showing high total dissolved solids (TDS) levels post-monsoon despite the overall decrease in total hardness levels could be attributed to localized factors influencing groundwater quality. Anthropogenic activities such as agricultural runoff, industrial discharge, or improper waste disposal can introduce contaminants into groundwater, leading to elevated TDS levels. Additionally, geological features such as rock formations with high mineral content or proximity to saline water bodies could contribute to higher TDS concentrations in certain areas despite the general trend of decreasing total hardness levels post-monsoon.

Based on the USGS classification of total hardness, in the premonsoon period, three wells, namely W12, W22, and W24, were found to be soft (0–60 mg/l). Eleven wells, including W4, W5, W11, and W15 to W21, along with W23, were "moderately hard." Nine wells, identified as W2, W3, W6, W7, W8, W9, W10, W13, and W14, were as "hard." Lastly, well W1 is classified as "very hard."

According to BIS standards, 23 out of the 24 wells showed total hardness values within the acceptable limits (below 300mg/L). W1 had the highest value of total hardness during premonsoon and postmonsoon which was above the acceptable limit for drinking.

Table 4.7: Total hardness measurements of observed wells

Well. No.	Latitude	Longitude	Total hardness	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	336	340
W2	15.3577653	73.8834055	164	160
W3	15.3581904	73.8871344	176	136
W4	15.3482475	73.8897655	116	236
W5	15.3496944	73.8973556	96	96
W6	15.3418889	73.8934056	156	156
W7	15.3423972	73.9003778	156	128
W8	15.3361111	73.8976833	180	168
W9	15.3377833	73.9047333	152	104
W10	15.3275944	73.9018	128	128
W11	15.3243028	73.9063167	64	60
W12	15.3265605	73.9135654	60	64
W13	15.3157722	73.9129626	144	156
W14	15.3161944	73.9063889	164	124
W15	15.3132211	73.9142819	100	60
W16	15.3017421	73.9089825	108	76
W17	15.2923083	73.913575	76	84
W18	15.2952	73.9256083	120	128
W19	15.2767354	73.9249303	68	56
W20	15.2704912	73.9379095	68	104
W21	15.256141	73.9262251	92	68
W22	15.2595509	73.9408465	56	44
W23	15.2360379	73.9337071	68	64
W24	15.2401466	73.938463	52	44



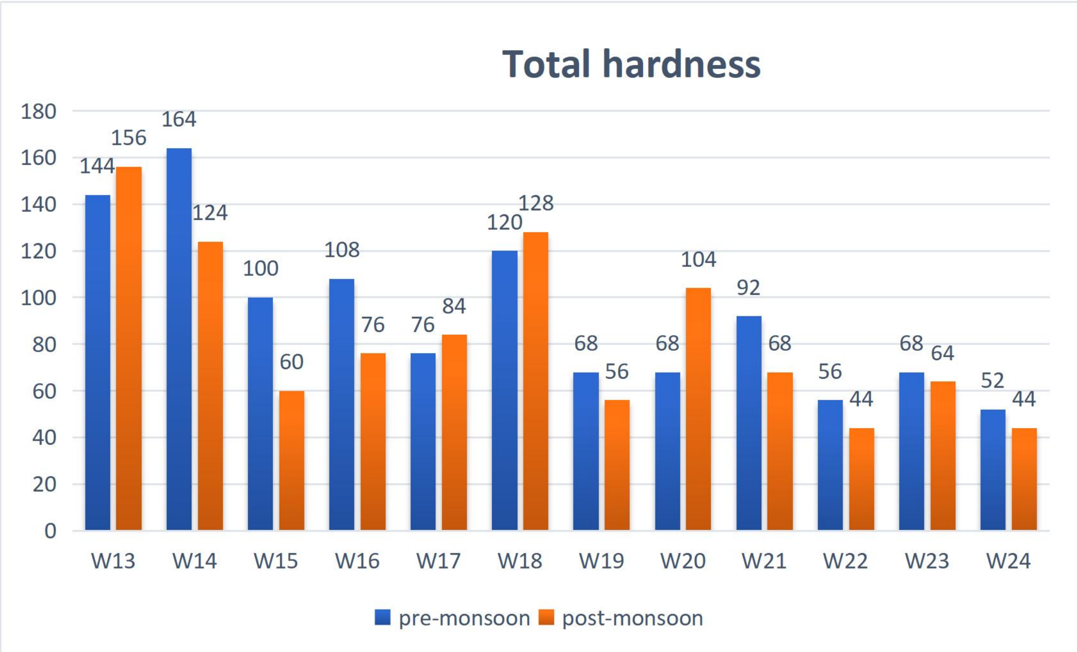


Figure 4.17: Total hardness measurement graph

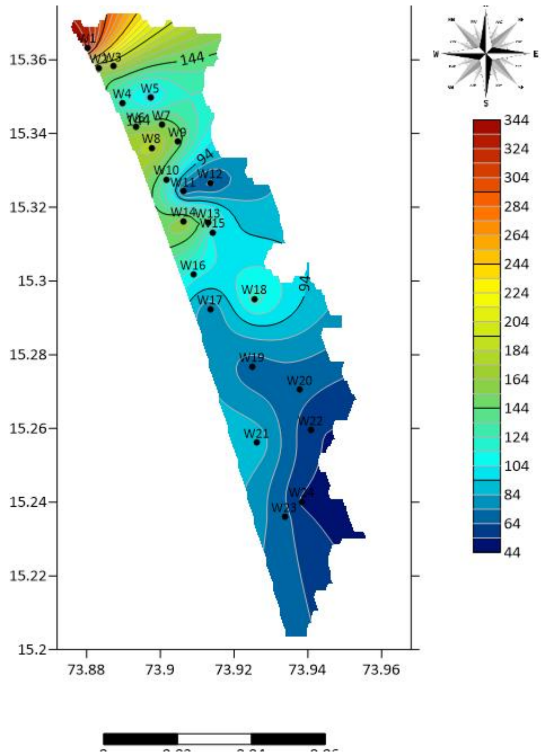


Figure 4.18: Premonsoon total hardness contour map

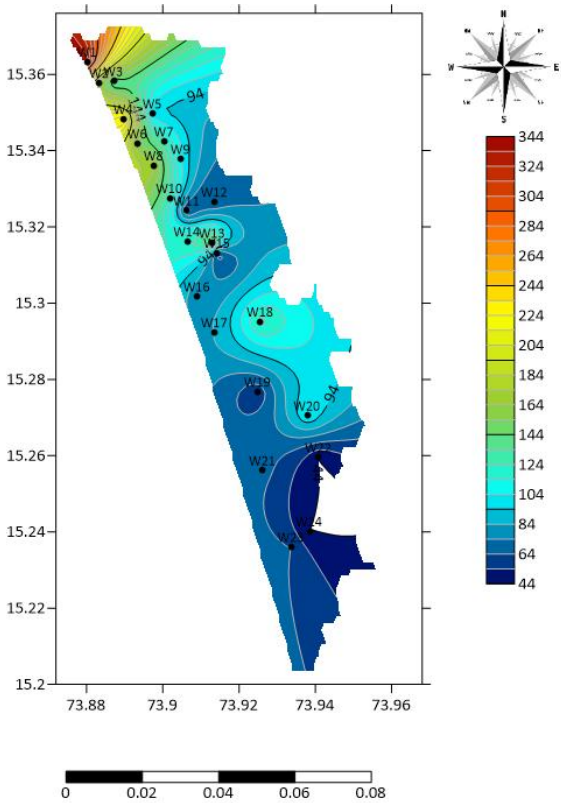


Figure 4.19: Postmonsoon total hardness contour map

4.2.4 Chloride:

Chloride (Cl-) is an essential ion found in groundwater, and its concentration is an important parameter when assessing the quality of groundwater for drinking purposes. While chloride is naturally occurring in groundwater, elevated levels can indicate contamination from various sources, including natural geological processes, industrial activities, agricultural practices, and human settlements.Chloride can originate from natural sources such as weathering of rocks and minerals containing chloride compounds (e.g., halite), dissolution of salt deposits, and seawater intrusion in coastal areas. Human activities can significantly contribute to chloride contamination in groundwater. These sources include road salt application, wastewater discharges from industries, sewage treatment plants, and septic systems, as well as agricultural practices involving fertilizers and animal waste. Elevated chloride levels may indicate the presence of other contaminants, such as sodium, heavy metals, or pathogens, which can pose health risks. High chloride levels in drinking water can result in a salty taste, which may be undesirable to consumers.

According to BIS, the acceptable limits for Chloride concentrations is specified as 250mg/L and permissible upto 1000mg/L.(BIS,2012)

4.2.4.a Observations:

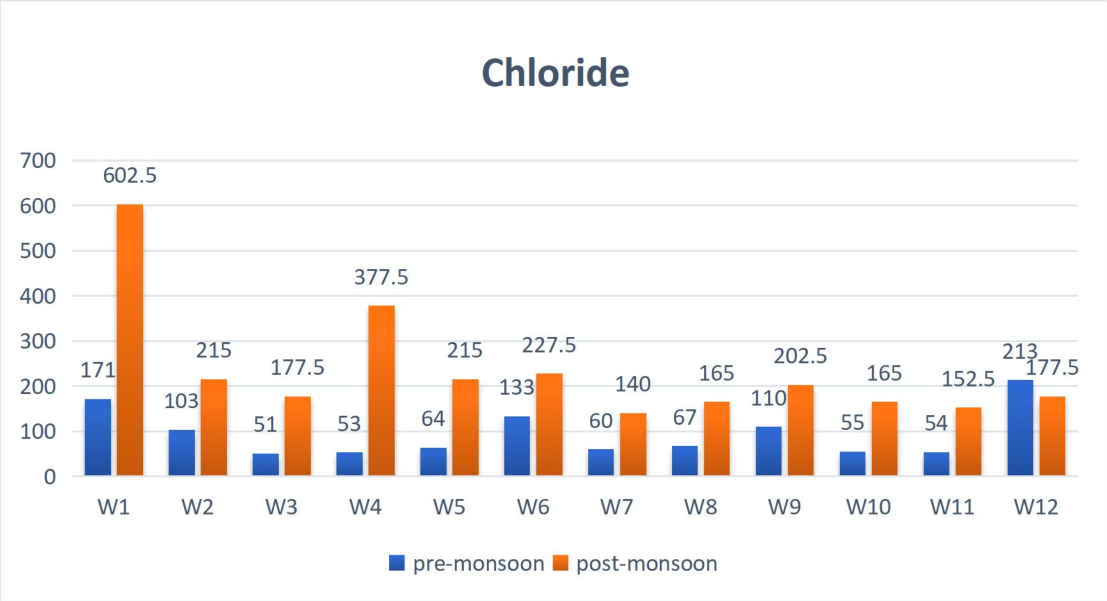
The chloride concentrations in the water samples range from 44 to 244 mg/L during the pre-monsoon period and 140 to 602.5 mg/L during the post-monsoon period. Well W13 exhibits the highest chloride level during pre-monsoon (244 mg/L), while W16 shows the lowest (44 mg/L). In contrast, during post-monsoon, well W1 records the highest chloride concentration (602.5 mg/L), with W7 and W23 showing the lowest values (140 mg/L). On average, chloride content measures 88 mg/L during the pre-monsoon and increases to 216.56 mg/L during the post-monsoon period.

Analysis of the data indicates that 95.8% of the samples exhibit higher chloride levels during post-monsoon compared to pre-monsoon. Heavy rainfall during the monsoon season can lead to surface runoff, carrying chloride-rich sediments and debris into nearby water bodies. Additionally, tidal fluctuations and seawater intrusion along the coast can introduce marine-derived chloride ions into groundwater sources, particularly in areas with shallow aquifers or permeable geological formations. Furthermore, anthropogenic activities such as urbanization, industrial discharge, and agricultural runoff may contribute to chloride contamination in groundwater, especially in densely populated coastal areas where human activities intersect with natural water sources.

All samples are within the acceptable limits for drinking water according to BIS standards (2012) during the pre-monsoon period. However, during post-monsoon, 23 out of 24 samples maintain chloride levels within the acceptable limit of 250 mg/L, except for well W1, which exceeds this threshold with a chloride value of 602.5 mg/L.

Table 4.8: Chloride measurements of observed wells

Well. No.	Latitude	Longitude	Chloride	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	171	602.5
W2	15.3577653	73.8834055	103	215
W3	15.3581904	73.8871344	51	177.5
W4	15.3482475	73.8897655	53	377.5
W5	15.3496944	73.8973556	64	215
W6	15.3418889	73.8934056	133	227.5
W7	15.3423972	73.9003778	60	140
W8	15.3361111	73.8976833	67	165
W9	15.3377833	73.9047333	110	202.5
W10	15.3275944	73.9018	55	165
W11	15.3243028	73.9063167	54	152.5
W12	15.3265605	73.9135654	213	177.5
W13	15.3157722	73.9129626	224	352.5
W14	15.3161944	73.9063889	80	152.5
W15	15.3132211	73.9142819	82	202.5
W16	15.3017421	73.9089825	44	190
W17	15.2923083	73.913575	47	165
W18	15.2952	73.9256083	63	190
W19	15.2767354	73.9249303	74	202.5
W20	15.2704912	73.9379095	69	190
W21	15.256141	73.9262251	90	215
W22	15.2595509	73.9408465	57	177.5
W23	15.2360379	73.9337071	62	140
W24	15.2401466	73.938463	86	202.5



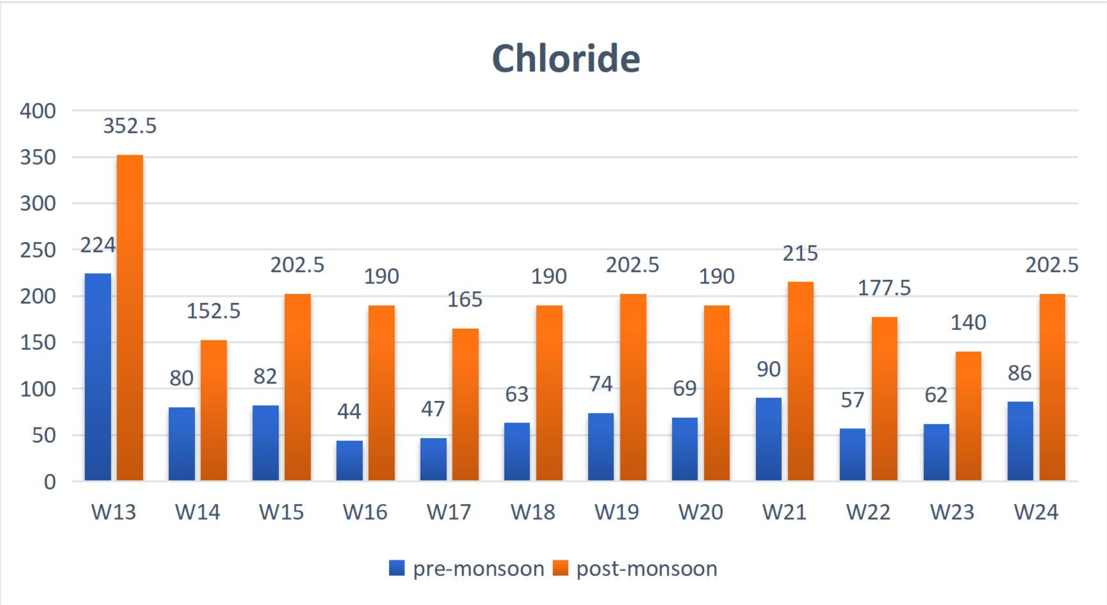


Figure 4.20: Chloride measurement graph

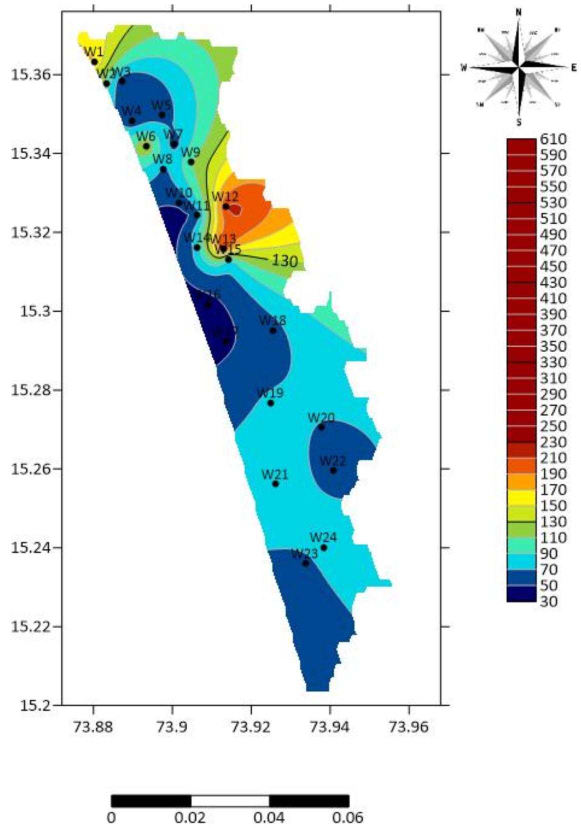


Figure 4.21: Premonsoon chloride contour map

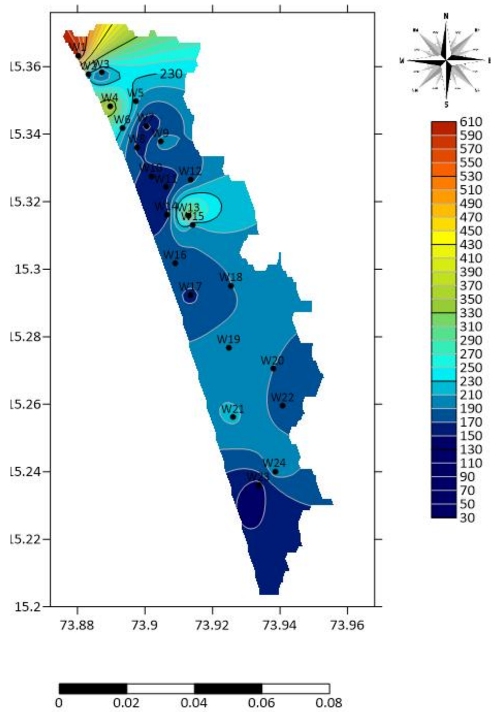


Figure 4.22: Postmonsoon chloride contour map

4.2.5 Sodium

Sodium is one of the most common elements found in natural waters, originating primarily from the weathering of rocks and minerals in the Earth's crust. Rocks containing sodium-bearing minerals, such as feldspars, can release sodium ions into groundwater through chemical weathering processes. The presence of sodium in groundwater can influence its quality and suitability for various purposes. Excessive sodium levels in drinking water can impart a salty taste and may pose health risks, particularly for individuals on sodium-restricted diets or those with certain health conditions such as hypertension. High sodium concentrations can also lead to aesthetic issues, such as the development of scale deposits in pipes and appliances. According to WHO (1993) the maximum allowable limit for Sodium is 200mg/L.

4.2.5 a Observations:

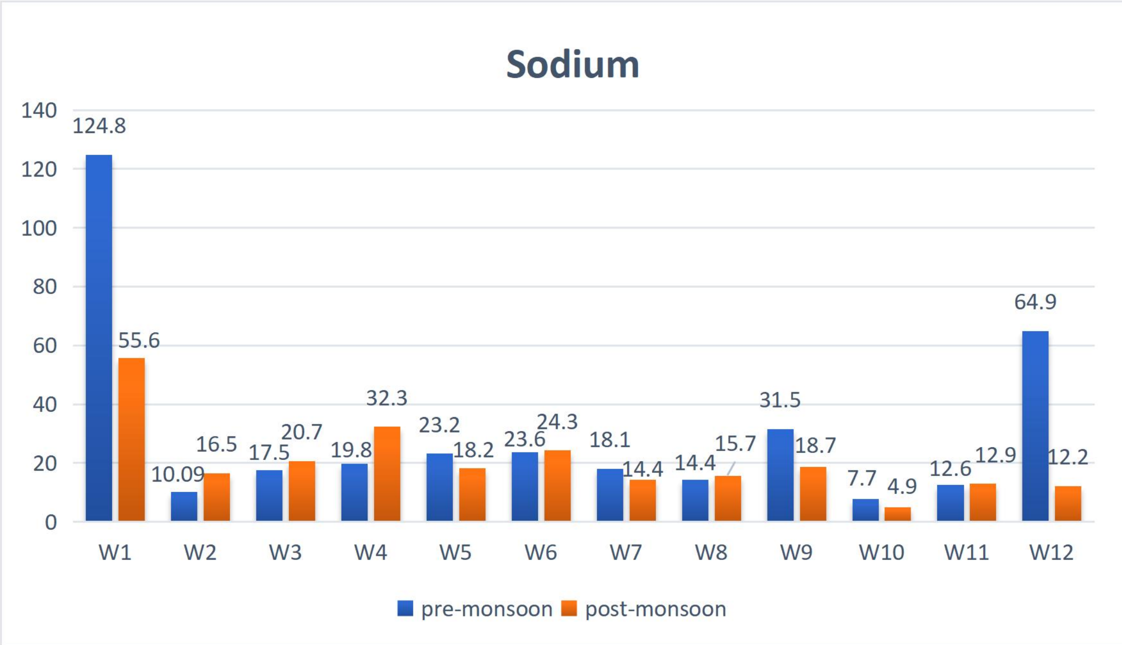
The Sodium concentrations in the water samples range from 3.2 to 124.8 mg/L during the pre-monsoon period and 4.9 to 55.6 mg/L during the post-monsoon period. Well W1 exhibits the highest Sodium level during pre-monsoon (124.8 mg/L), while W22 demonstrates the lowest (3.2mg/L). In contrast, during post-monsoon, well W1 records the highest Sodium concentration (55.6mg/L), with W10 showing the lowest values (4.9 mg/L). On average, Sodium content measures 29.22 mg/L during the pre-monsoon and decreases to 19.73 mg/L during the post-monsoon period.

Analysis of the data indicates that 45.8% of the samples exhibit higher sodium levels during post-monsoon compared to pre-monsoon. The increase in sodium levels during the post-monsoon period compared to pre-monsoon could be influenced by several factors related to the coastal environment of the study area. Firstly, heavy rainfall during the monsoon season may result in the leaching of salts from the soil and the flushing of surface runoff into groundwater, thereby increasing the sodium concentration. Additionally, tidal fluctuations and seawater intrusion, common phenomena in coastal regions, could introduce saline water into the groundwater, elevating sodium levels. Human activities such as agriculture, urbanization, and industrialization along the coast may also contribute to higher sodium levels through the discharge of saline effluents or the excessive use of fertilizers containing sodium compounds. Furthermore, changes in groundwater flow patterns and aquifer dynamics during the post-monsoon period, influenced by factors such as recharge rates and freshwater-saltwater interface dynamics, may affect the distribution and concentration of sodium in the groundwater.The remaining 54.2% of samples exhibiting lower sodium levels during the post-monsoon period compared to pre-monsoon could be attributed to various factors specific to the coastal environment of the study area. One potential factor is the dilution effect caused by increased freshwater recharge during the monsoon season, which may reduce the concentration of salts, including sodium, in groundwater. Additionally, enhanced groundwater flushing due to heavy rainfall can help to flush out dissolved salts from the aquifer system, leading to lower sodium levels post-monsoon.

All samples fall within the acceptable limits for drinking water according to BIS standards (2012) during the pre-monsoon and postmonsoon period.

Table 4.8: Sodium measurements of observed wells

Well. No.	Latitude	Longitude	Sodium	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	124.8	55.6
W2	15.3577653	73.8834055	10.09	16.5
W3	15.3581904	73.8871344	17.5	20.7
W4	15.3482475	73.8897655	19.8	32.3
W5	15.3496944	73.8973556	23.2	18.2
W6	15.3418889	73.8934056	23.6	24.3
W7	15.3423972	73.9003778	18.1	14.4
W8	15.3361111	73.8976833	14.4	15.7
W9	15.3377833	73.9047333	31.5	18.7
W10	15.3275944	73.9018	7.7	4.9
W11	15.3243028	73.9063167	12.6	12.9
W12	15.3265605	73.9135654	64.9	12.2
W13	15.3157722	73.9129626	163.9	36.8
W14	15.3161944	73.9063889	19.2	14.8
W15	15.3132211	73.9142819	22.3	17.8
W16	15.3017421	73.9089825	18.2	11.9
W17	15.2923083	73.913575	3.9	6.2
W18	15.2952	73.9256083	9.9	14.9
W19	15.2767354	73.9249303	20.8	28.1
W20	15.2704912	73.9379095	17.1	18.8
W21	15.256141	73.9262251	26.5	36
W22	15.2595509	73.9408465	3.2	7.2
W23	15.2360379	73.9337071	13.2	11.5
W24	15.2401466	73.938463	14.8	23.2



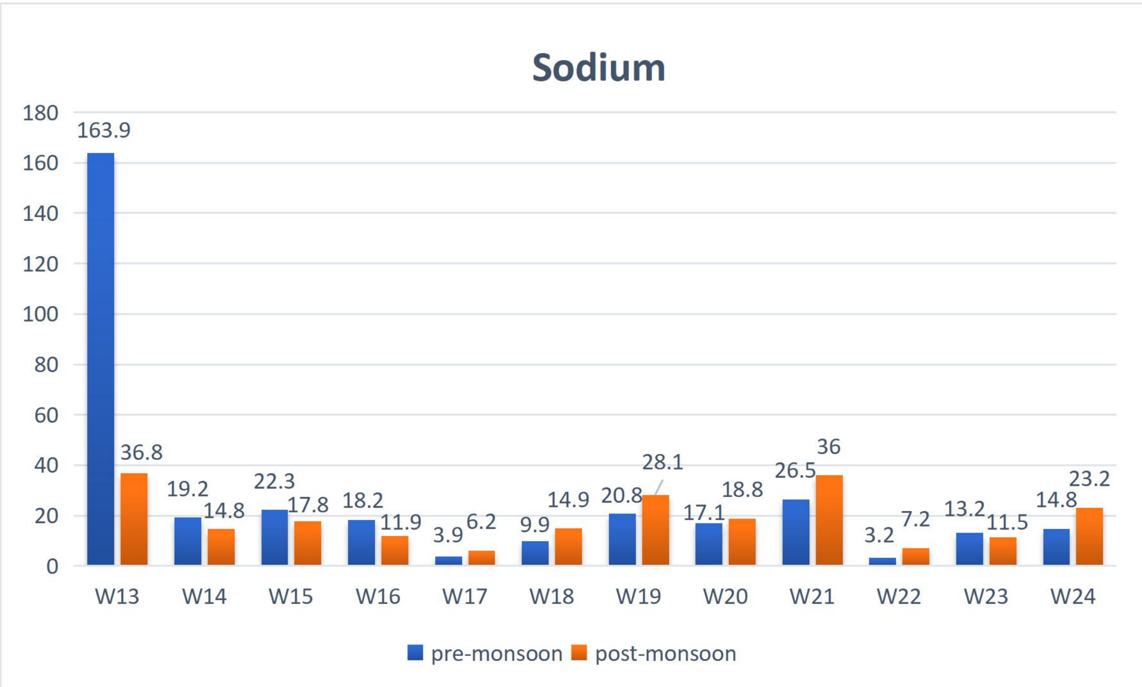


Figure 4.23: Sodium measurement graph

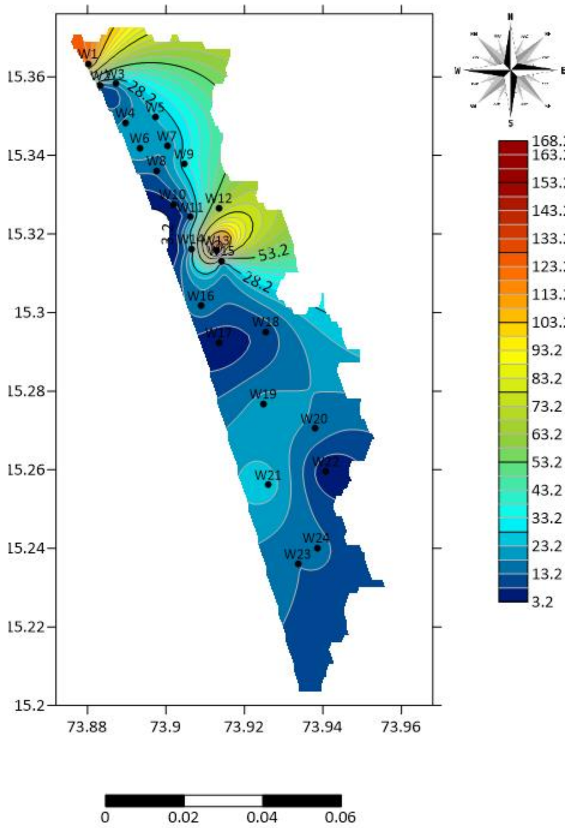


Figure 4.24: Premonsoon sodium contour map

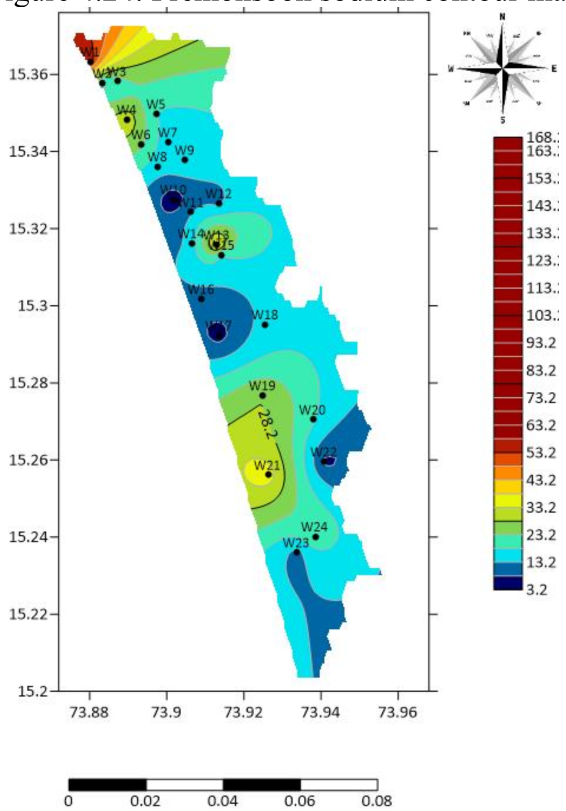


Figure 4.25: Postmonsoon sodium contour map

4.2.6 Potassium

Potassium (K) is an essential nutrient for plant and animal life, and it occurs naturally in groundwater due to the weathering of rocks and minerals. Potassium is an essential nutrient for human health, playing a vital role in various physiological processes such as nerve transmission, muscle function, and electrolyte balance. However, excessive intake of potassium can be harmful, particularly for individuals with certain medical conditions such as kidney disease. High concentrations of potassium in drinking water can sometimes impart a salty or brackish taste, which may affect the aesthetic quality of the water. Monitoring potassium levels in groundwater is important to ensure compliance with regulatory standards and to address any potential concerns related to taste or health effects.

According to WHO (1993) the maximum allowable limit for potassium is 12mg/L.

4.2.6 a Observations:

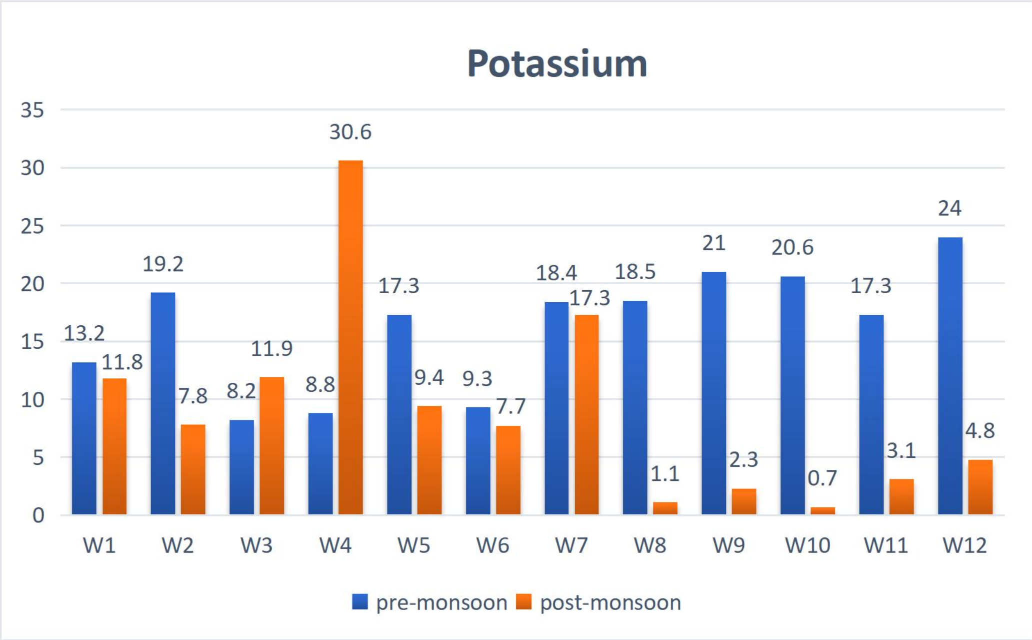
The potassium concentrations in the water samples range from 5.1 to 34.6 mg/L during the pre-monsoon period and 0.7 to 30.6 mg/L during the post-monsoon period. Well W13 exhibits the highest potassium level during pre-monsoon (34.6 mg/L), while W14 shows the lowest (5.1mg/L). In contrast, during post-monsoon, well W4 records the highest potassuim concentration (30.6mg/L), with W10 and W17 showing the lowest values (0.7 mg/L). On average, potassium content measures 19.17 mg/L during the pre-monsoon and decreases to 6.75 mg/L during the post-monsoon period.

Analysis of the data indicates that 83.4% of the samples exhibit lower potassium levels during post-monsoon compared to pre-monsoon. The decrease in potassium levels during the post-monsoon period compared to pre-monsoon could be influenced by several factors inherent to the coastal environment of Goa. One possible explanation is the leaching effect caused by heavy rainfall during the monsoon season. Intense precipitation can facilitate the movement of water through the soil, carrying away dissolved potassium ions and other nutrients from the root zone. Moreover, increased groundwater recharge during the monsoon may dilute the concentration of potassium in the soil and groundwater, further contributing to lower potassium levels post-monsoon. Additionally, the flushing effect of heavy rains could lead to the removal of potassium-rich minerals from the soil, resulting in decreased potassium availability for plants and subsequently lower potassium levels in groundwater samples.

During the pre-monsoon period, 5 out of 24 samples (W3, W4, W6, W14, W17) met the acceptable drinking water limit of 12 mg/L set by the WHO (1993). In the post-monsoon period, 21 out of 24 samples were within the acceptable limits for drinking. However, samples W4, W7, and W21 exceeded the maximum allowable limit according to the WHO (1993).

Table 4.9: Potassium measurements of observed wells

Well. No.	Latitude	Longitude	Potassium	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	13.2	11.8
W2	15.3577653	73.8834055	19.2	7.8
W3	15.3581904	73.8871344	8.2	11.9
W4	15.3482475	73.8897655	8.8	30.6
W5	15.3496944	73.8973556	17.3	9.4
W6	15.3418889	73.8934056	9.3	7.7
W7	15.3423972	73.9003778	18.4	17.3
W8	15.3361111	73.8976833	18.5	1.1
W9	15.3377833	73.9047333	21	2.3
W10	15.3275944	73.9018	20.6	0.7
W11	15.3243028	73.9063167	17.3	3.1
W12	15.3265605	73.9135654	24	4.8
W13	15.3157722	73.9129626	34.6	1.8
W14	15.3161944	73.9063889	5.1	5.4
W15	15.3132211	73.9142819	32.1	2.8
W16	15.3017421	73.9089825	17.8	1.3
W17	15.2923083	73.913575	8.1	0.7
W18	15.2952	73.9256083	21.4	3.0
W19	15.2767354	73.9249303	23	3.3
W20	15.2704912	73.9379095	25.8	3.1
W21	15.256141	73.9262251	23.3	16.1
W22	15.2595509	73.9408465	23.9	3.3
W23	15.2360379	73.9337071	25	5.9
W24	15.2401466	73.938463	24.2	6.7



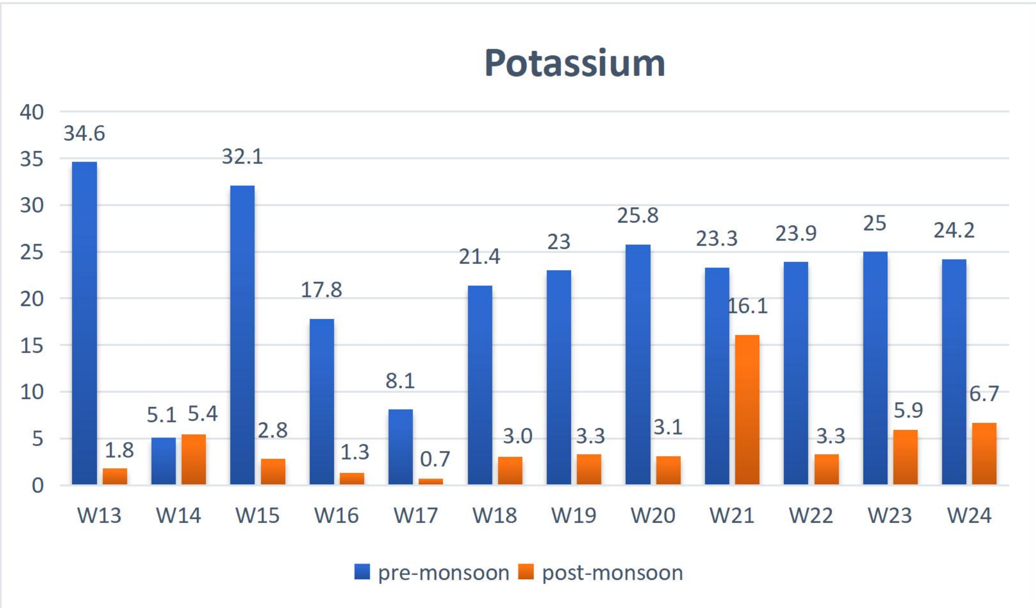


Figure 4.26: Potassium measurement graph

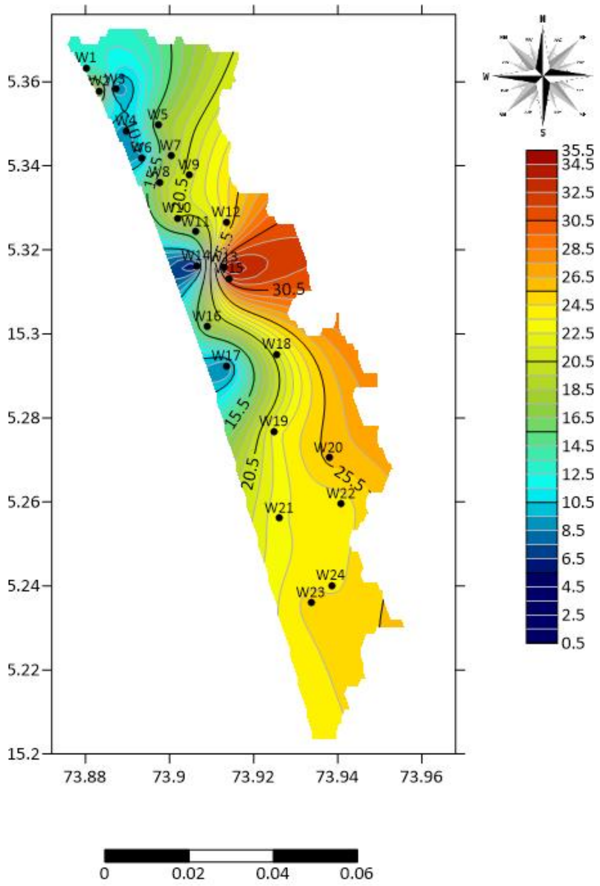


Figure 4.27: Premonsoon potassium contour map

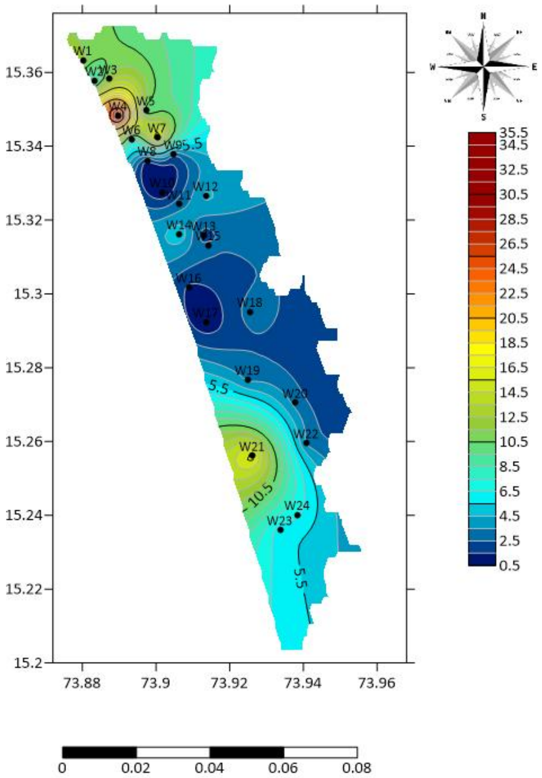


Figure 4.28: Postmonsoon potassium contour map

4.2.7 Nitrite

Nitrites are a group of chemical compounds composed of nitrogen and oxygen, commonly found in the environment and often associated with human activities such as agriculture, industry, and wastewater treatment. Nitrites in groundwater can originate from various sources, including fertilizers, animal waste, septic systems, and industrial discharges. When these sources come into contact with water, particularly in areas with porous soils or shallow aquifers, nitrites can leach into groundwater supplies. Excessive levels of nitrites in drinking water pose significant health risks, especially for vulnerable populations such as infants and pregnant women. Nitrites can interfere with the blood's ability to transport oxygen, leading to a condition known as "blue baby syndrome" in infants and reduces the blood's oxygen-carrying capacity. The guideline for nitrite of 3mg/L according to WHO (2011).

The nitrite concentrations in the water samples range from 0.0473 to 0.0496 mg/L during the pre-monsoon period and 0.0474 to 0.0609 mg/L during the post-monsoon period. Well W1 exhibits the highest nitrite level during pre-monsoon (0.0496 mg/L), while W16 shows the lowest (0.0473mg/L). In contrast, during post-monsoon, W9 records the highest nitrite concentration (0.0609 mg/L), with W7 and W11 showing the lowest values (0.0474 mg/L). On average, nitrite content measures 0.0478 mg/L during the pre-monsoon and increases to 0.0486 mg/L during the post-monsoon period.

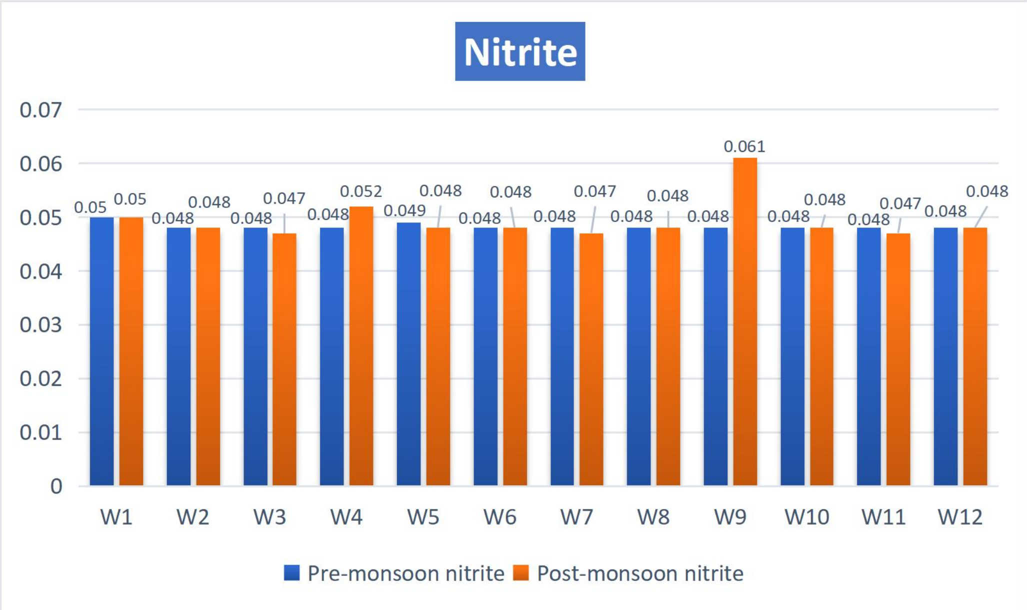
Analysis of the data indicates that 54.16% of the samples exhibit higher nitrite levels during post-monsoon compared to pre-monsoon.During the monsoon season, heavy rainfall can lead to runoff from agricultural lands, urban areas, and other sources, carrying nitrogen-rich pollutants such as fertilizers, sewage, and organic matter into nearby water bodies and groundwater reservoirs. This runoff, along with increased soil erosion, can introduce higher concentrations of nitrites into the water system. Additionally, the warm and humid conditions characteristic of the post-monsoon period can promote microbial activity and decomposition processes, accelerating the breakdown of organic matter and releasing nitrogen compounds like nitrites into the water. Moreover, the coastal location of the study area may exacerbate nitrite pollution due to the proximity to marine environments, where nitrogen cycling and nutrient exchange processes occur, contributing to elevated nitrite levels in groundwater during the post-monsoon period.

The remaining percentage of samples exhibiting higher nitrite levels during the post-monsoon period could be attributed to other localized factors impacting water quality in the coastal stretch of Goa. These factors might include industrial activities, sewage discharge, agricultural practices, and urbanization, which can introduce pollutants and nutrients into the water system. For example, industrial effluents and untreated sewage can contain high levels of nitrogen compounds, including nitrites, which may contaminate groundwater and surface water bodies. Similarly, agricultural runoff containing fertilizers and pesticides can contribute to nitrite pollution in water sources.

All the samples were within the acceptable drinking water limit of 3 mg/L set by the WHO (1993) during the premonsoon and post monsoon periods.

Table 4.10: Nitrite measurement of observed wells

Well. No.	Latitude	Longitude	Nitrite mg/L	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	0.04953	0.0498
W2	15.3577653	73.8834055	0.04833	0.0476
W3	15.3581904	73.8871344	0.0481	0.0475
W4	15.3482475	73.8897655	0.0476	0.0518
W5	15.3496944	73.8973556	0.04856	0.0476
W6	15.3418889	73.8934056	0.04778	0.0476
W7	15.3423972	73.9003778	0.04751	0.0474
W8	15.3361111	73.8976833	0.04751	0.0482
W9	15.3377833	73.9047333	0.04806	0.0609
W10	15.3275944	73.9018	0.04778	0.0478
W11	15.3243028	73.9063167	0.04751	0.0474
W12	15.3265605	73.9135654	0.0482	0.0477
W13	15.3157722	73.9129626	0.04737	0.0476
W14	15.3161944	73.9063889	-	0.0478
W15	15.3132211	73.9142819	0.04741	0.0475
W16	15.3017421	73.9089825	0.04728	0.0484
W17	15.2923083	73.913575	0.04732	0.0477
W18	15.2952	73.9256083	0.04732	0.048
W19	15.2767354	73.9249303	0.04958	0.0475
W20	15.2704912	73.9379095	0.04732	0.0491
W21	15.256141	73.9262251	0.04737	0.0477
W22	15.2595509	73.9408465	0.04792	0.0477
W23	15.2360379	73.9337071	0.04741	0.0479
W24	15.2401466	73.938463	0.04732	0.0477



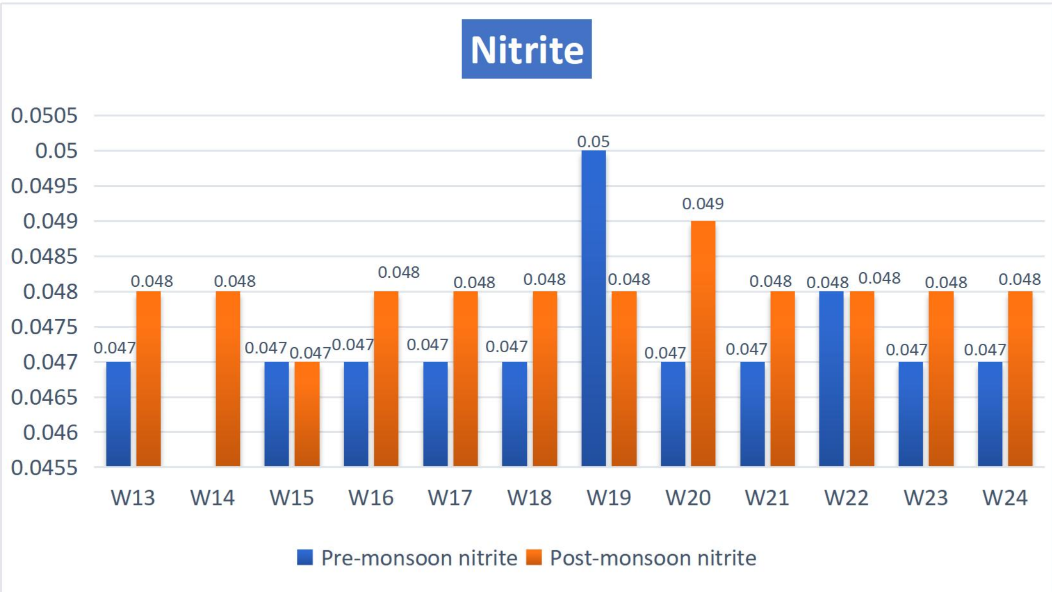


Figure 4.29: Nitrite measurement graph

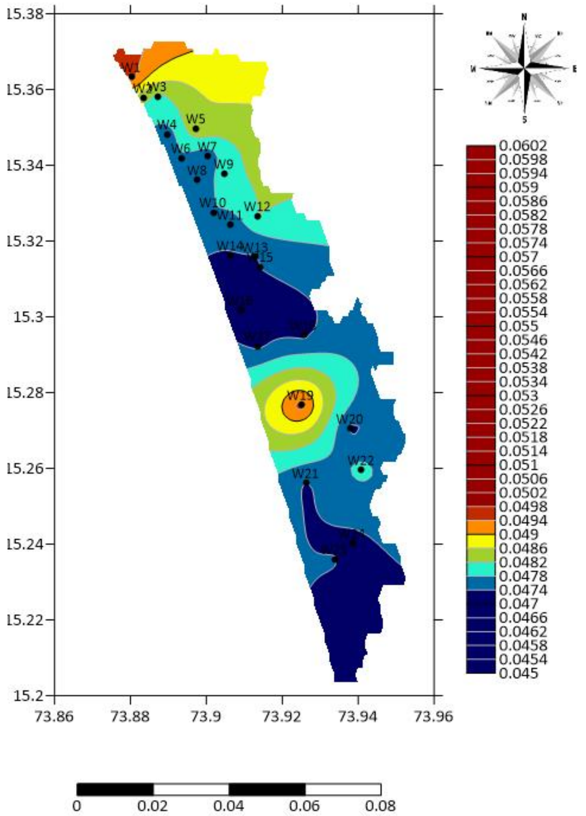


Figure 4.30: Premonsoon nitrite contour map

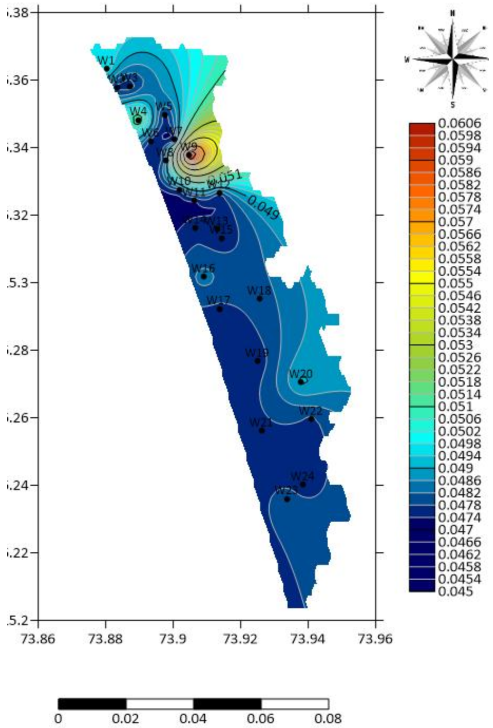


Figure 4.31: Postmonsoon nitrite contour map

4.2.8 Phosphate

Phosphates are a group of chemicals containing the element phosphorus, which are often found in groundwater sources. While phosphates themselves are not directly harmful to human health, they can significantly impact the quality of drinking water and ecosystems due to their role in promoting excessive algae and plant growth, a phenomenon known as eutrophication. This overgrowth of algae can deplete oxygen levels in the water, leading to fish kills and the deterioration of aquatic ecosystems. Elevated phosphate levels in drinking water sources can result in algal blooms, where rapid growth of algae occurs. These blooms can produce toxins harmful to humans and animals if ingested. The permissible limit for phosphate is 1mg/L according to WHO (2011).

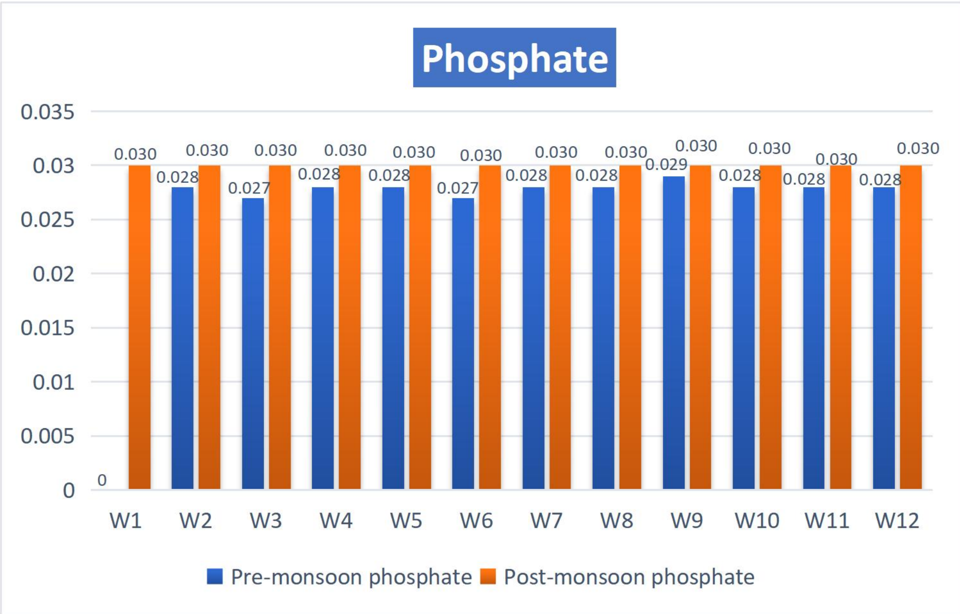
The phosphate concentrations in the water samples range from 0.0271 to 0.0291 mg/L during the pre-monsoon period and 0.0296 to 0.0299 mg/L during the post-monsoon period. Well W22 exhibits the highest phosphate level during pre-monsoon (0.02913 mg/L), while W6 shows the lowest (0.0271mg/L). In contrast, during post-monsoon, W1 records the highest phosphate concentration (0.0299mg/L), with W24 showing the lowest values (0.02956mg/L). On average, phosphate content measures 0.0277 mg/L during the pre-monsoon and increases to 0.0297 mg/L during the post-monsoon period.

Analysis of the data indicates that 83.33% of the samples exhibit higher phosphate levels during post-monsoon compared to pre-monsoon. The increase in phosphate levels during the post-monsoon period could be influenced by several factors. Firstly, heavy rainfall during the monsoon season can lead to soil erosion and runoff, carrying phosphorus-containing sediments into nearby water bodies. This influx of sediment can contribute to elevated phosphate levels in groundwater and surface water sources post-monsoon. Additionally, agricultural activities, including fertilizer application and livestock farming, may result in the leaching of phosphorus compounds into the groundwater during the monsoon season. As a result, the post-monsoon period may reflect the cumulative impact of these agricultural inputs, leading to higher phosphate concentrations in groundwater samples. Furthermore, the flushing effect of intense rainfall can mobilize phosphorus from soil surfaces into water bodies, further contributing to increased phosphate levels during the post-monsoon period.

All the samples were within the acceptable drinking water limit of 1 mg/L set by the WHO (2011) during the premonsoon and post monsoon periods.

Table 4.11: Phosphate measurement of observed wells

Well. No.	Latitude	Longitude	Phosphate mg/L	
			pre-monsoon	post-monsoon
W1	15.3633243	73.8802594	-	0.0299
W2	15.3577653	73.8834055	0.0283	0.0296
W3	15.3581904	73.8871344	-	0.0296
W4	15.3482475	73.8897655	0.0275	0.0297
W5	15.3496944	73.8973556	0.0276	0.0297
W6	15.3418889	73.8934056	0.0271	0.0296
W7	15.3423972	73.9003778	0.0275	0.0297
W8	15.3361111	73.8976833	0.0277	0.0296
W9	15.3377833	73.9047333	0.0285	0.0296
W10	15.3275944	73.9018	0.0279	0.0296
W11	15.3243028	73.9063167	0.0276	0.0299
W12	15.3265605	73.9135654	0.0279	0.0297
W13	15.3157722	73.9129626	0.0273	0.0296
W14	15.3161944	73.9063889	-	0.0298
W15	15.3132211	73.9142819	0.0273	0.0296
W16	15.3017421	73.9089825	0.0000	0.0297
W17	15.2923083	73.913575	0.0275	0.0297
W18	15.2952	73.9256083	0.0275	0.0296
W19	15.2767354	73.9249303	0.0276	0.0297
W20	15.2704912	73.9379095	0.0281	0.0296
W21	15.256141	73.9262251	-	0.0297
W22	15.2595509	73.9408465	0.0291	0.0296
W23	15.2360379	73.9337071	0.0275	0.0296
W24	15.2401466	73.938463	0.0279	0.0296



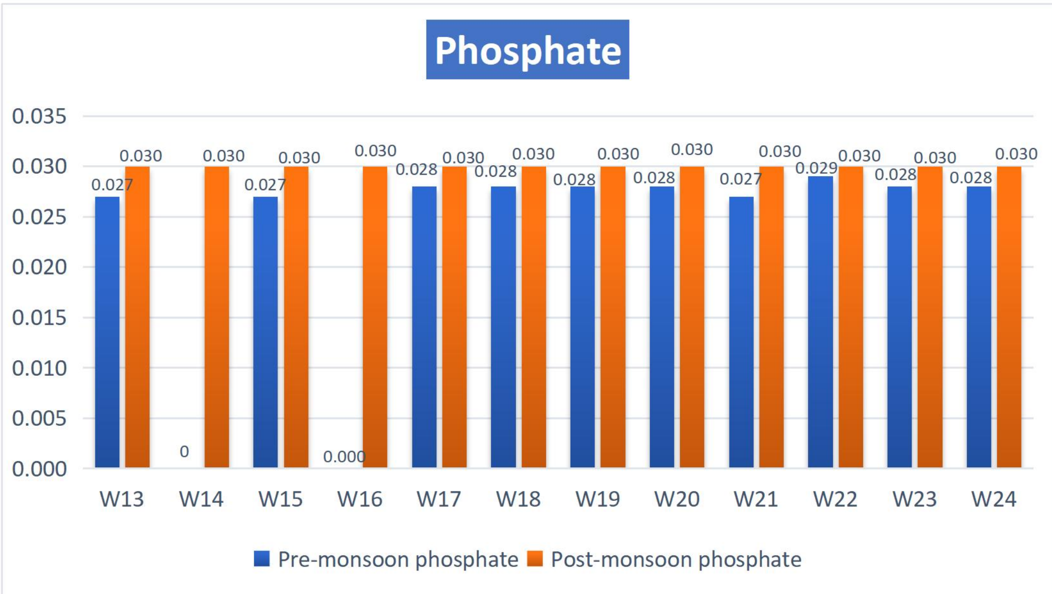


Figure 4.32: Phosphate measurement graph

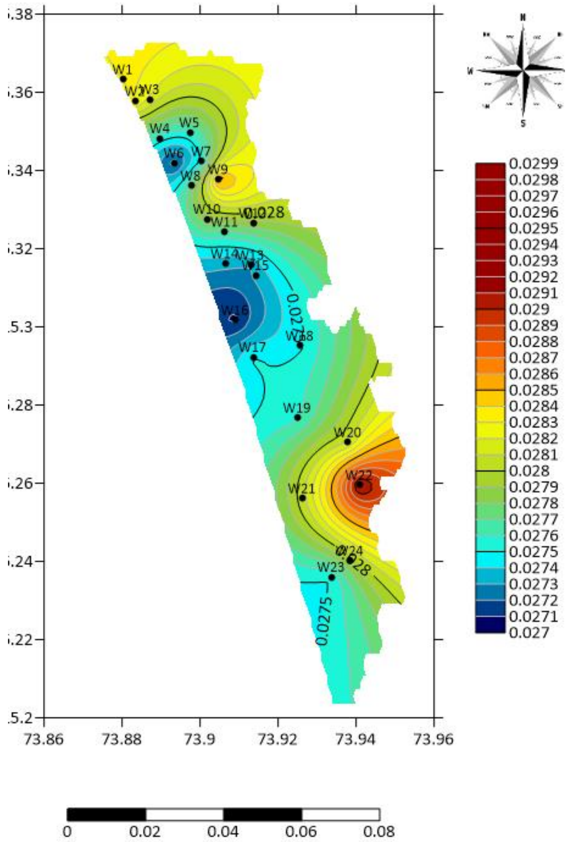


Figure 4.33: Premonsoon phosphate contour map

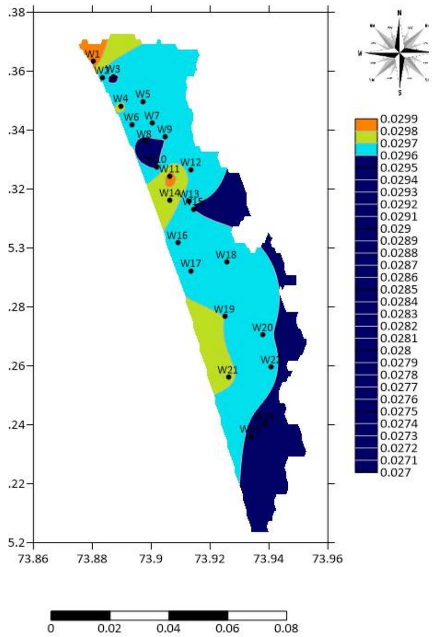


Figure 4.34: Postmonsoon phosphate contour map

4.3 Suitability for irrigation

Agriculture plays a crucial role as a sector in India, serving as the backbone of the economy and providing livelihoods to a significant portion of the population. The criterion for suitability of groundwater for irrigation is entirely different from drinking purposes (Haritash et al. 2008). The suitability of water for drinking may not necessarily align with its suitability for irrigation purposes. As such, various indices have been proposed to assess suitability based on the composition of cations and anions present in the water. These indices aim to evaluate key factors which can impact soil health and crop productivity if used for irrigation.

Electrical conductivity (EC) serves as an indirect indicator of total dissolved solids (TDS) present in groundwater. Based on electrical conductivity (EC) measurements, 22 out of 24 samples were deemed suitable for irrigation during the pre-monsoon period, with an average EC value of 323.29 µS/cm. Similarly, during the post-monsoon period, 23 out of 24 samples were considered suitable for irrigation, with an average EC value of 383 µS/cm. These findings suggest that the majority of groundwater samples in both seasons fell within the acceptable range for irrigation, as indicated by an EC value of less than 750 µS/cm.

Elevated sodium levels in irrigation water can negatively impact soil permeability. When water containing high concentrations of sodium is used for irrigation, sodium ions have the potential to displace other cations (like calcium, magnesium, and potassium) on the exchange sites of clay minerals through cation exchange reactions. The Sodium Adsorption Ratio (SAR) values exhibited a range from 0.023 to 0.993 meq/L during the pre-monsoon period, with an average value of 0.209meq/L. Similarly, during the post- monsoon period, SAR values ranged from 0.028 to 0.362meq/L, with an average of 0.149meq/L. These findings suggest that irrigation with groundwater is unlikely to significantly impact soil structure and permeability. During the pre-monsoon period, the percentage of sodium had an average concentration of 2.3%, with values ranging from 0.82% to 8.5%. Similarly, during the post-monsoon period, the average concentration of sodium was 1.2%, with values ranging from 0.2% to 3.02%. Water is considered suitable for irrigation if the magnesium hazard index is less than 50%. All 24 samples were deemed suitable for irrigation during both the premonsoon and postmonsoon periods based on magnesium hazard index. In the premonsoon period, the average magnesium hazard index was 24.80, ranging from 12.33 to 37.84. During the postmonsoon period, the average magnesium hazard index was 29.71, with values ranging from 21.56 to 44.25.

Kelly's ratio serves as a method for evaluating sodium-related risks. According to this ratio, the majority of the samples (91.6%) were determined to be free from salinity-relatedsalinit-related hazards, except for two samples, namely W12 and W13, during the premonsoon period. However, during the postmonsoon period, all samples were found to be free from salinity-related hazards.

In the postmonsoon period, analysis revealed negative Residual Sodium Carbonate (RSC) values across all samples, suggesting a minimal risk of bicarbonate ions interacting with calcium and magnesium to form carbonate minerals in the soil. While the present conditions appear favorable, any potential future occurrence of these reactions might result in a rise in sodium content. Such an increase in sodium levels could pose a threat to the overall long-term quality of irrigation water.

Table 4.12: Irrigation water quality standards

EC	SAR	Irrigation water quality	%Na	Irrigation water quality	Residual sodium Carbonate	Water class
<250	<10	Excellent	<30	Suitable	<1.25	Good
250-750	10-18	Good	30-60	Marginally suitable	1.25-2.50	Doubtful
750-2250	18-26	Acceptable	>60	Unsuitable	>2.50	Unsuitable
>2250	>26	Unacceptable				

Table 4.13: Premonsoon values for various parameters to assess suitability for irrigation

Well. No.	Latitude	Longitude	SAR	Na%	MHI (in %)	Kellys ratio
W1	15.3633243	73.8802594	0.50	5.60	37.84	0.85
W2	15.3577653	73.8834055	0.06	1.11	26.57	0.12
W3	15.3581904	73.8871344	0.09	1.03	29.63	0.20
W4	15.3482475	73.8897655	0.13	1.23	26.40	0.33
W5	15.3496944	73.8973556	0.17	1.88	27.31	0.53
W6	15.3418889	73.8934056	0.13	1.26	30.50	0.31
W7	15.3423972	73.9003778	0.11	1.52	32.55	0.27
W8	15.3361111	73.8976833	0.07	1.16	27.42	0.16
W9	15.3377833	73.9047333	0.18	2.08	27.57	0.44
W10	15.3275944	73.9018	0.04	1.05	22.83	0.12
W11	15.3243028	73.9063167	0.10	1.74	21.60	0.40
W12	15.3265605	73.9135654	0.65	4.97	23.76	2.67
W13	15.3157722	73.9129626	0.99	8.58	23.94	2.42
W14	15.3161944	73.9063889	0.09	0.91	26.77	0.22
W15	15.3132211	73.9142819	0.16	2.63	21.29	0.47
W16	15.3017421	73.9089825	0.11	1.65	21.36	0.32
W17	15.2923083	73.913575	0.04	0.82	35.57	0.12
W18	15.2952	73.9256083	0.06	1.23	24.04	0.17
W19	15.2767354	73.9249303	0.16	2.41	15.53	0.54
W20	15.2704912	73.9379095	0.11	2.31	12.33	0.41
W21	15.256141	73.9262251	0.22	2.66	27.01	0.67
W22	15.2595509	73.9408465	0.02	2.48	20.88	0.13
W23	15.2360379	73.9337071	0.11	2.22	16.91	0.37
W24	15.2401466	73.938463	0.12	2.71	15.51	0.54

Table 4.14: Postmonsoon values for various parameters to assess suitability for irrigation

Well. No.	Latitude	Longitude	SAR	Na%	MHI (in %)	Kelly's ratio	RSC
W1	15.3633243	73.8802594	0.21	2.59	27.77	0.08	-145.13
W2	15.3577653	73.8834055	0.09	0.97	30.50	0.11	-67.50
W3	15.3581904	73.8871344	0.12	1.32	23.73	0.17	-62.07
W4	15.3482475	73.8897655	0.15	2.11	28.15	0.28	-98.45
W5	15.3496944	73.8973556	0.13	1.23	25.78	0.21	-41.07
W6	15.3418889	73.8934056	0.13	1.35	23.88	0.10	-70.96
W7	15.3423972	73.9003778	0.09	1.25	29.19	0.29	-55.30
W8	15.3361111	73.8976833	0.09	0.70	32.24	0.01	-68.63
W9	15.3377833	73.9047333	0.13	1.02	30.07	0.05	-40.59
W10	15.3275944	73.9018	0.03	0.20	32.26	0.01	-54.07
W11	15.3243028	73.9063167	0.14	1.00	30.85	0.13	-21.02
W12	15.3265605	73.9135654	0.14	0.98	42.94	0.24	-17.96
W13	15.3157722	73.9129626	0.22	1.60	26.85	0.03	-64.13
W14	15.3161944	73.9063889	0.09	0.77	29.11	0.09	-44.16
W15	15.3132211	73.9142819	0.18	1.18	25.60	0.11	-23.04
W16	15.3017421	73.9089825	0.10	0.50	34.32	0.04	-28.14
W17	15.2923083	73.913575	0.06	0.30	38.26	0.02	-31.70
W18	15.2952	73.9256083	0.09	0.77	31.03	0.05	-55.32
W19	15.2767354	73.9249303	0.29	1.63	21.69	0.15	-18.83
W20	15.2704912	73.9379095	0.13	1.01	27.74	0.07	-42.20
W21	15.256141	73.9262251	0.36	3.02	21.56	0.61	-22.96
W22	15.2595509	73.9408465	0.10	0.98	44.25	0.23	-12.70
W23	15.2360379	73.9337071	0.11	1.24	31.75	0.22	-22.39
W24	15.2401466	73.938463	0.30	2.19	23.59	0.43	-13.10

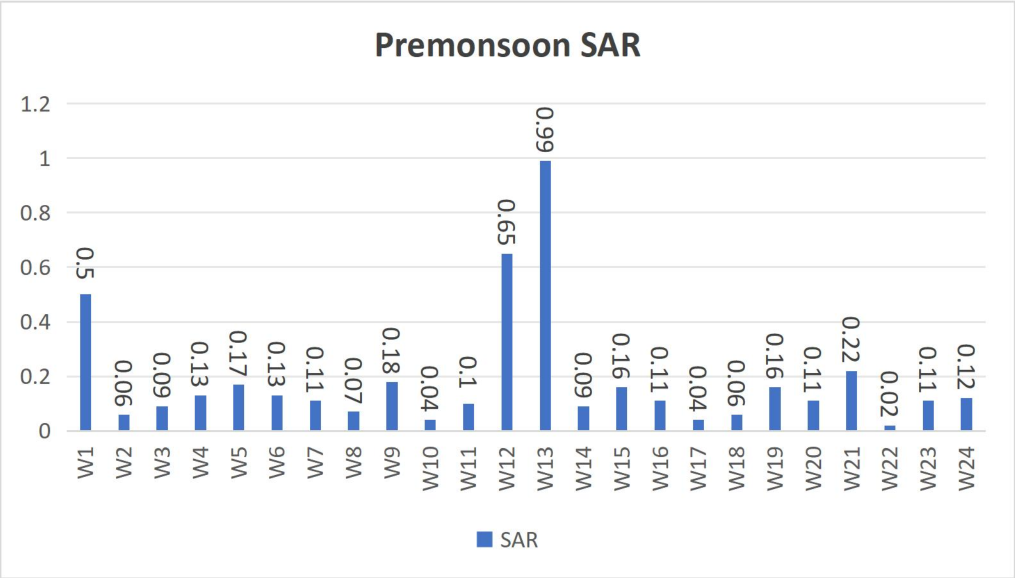


Figure4.35: Premonsoon sodium adsorption ratio graph

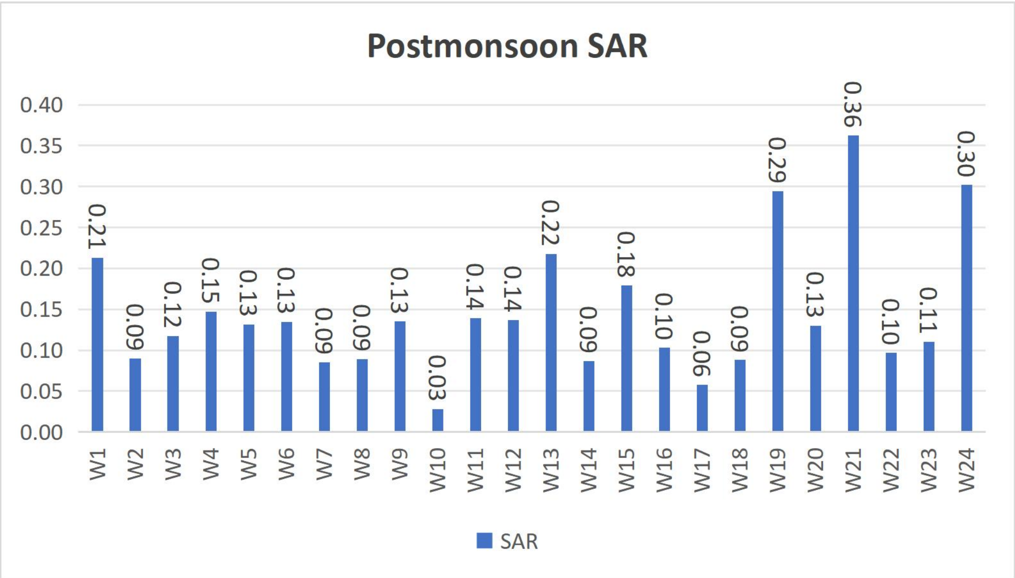


Figure 4.36: Postmonsoon sodium adsorption ratio graph

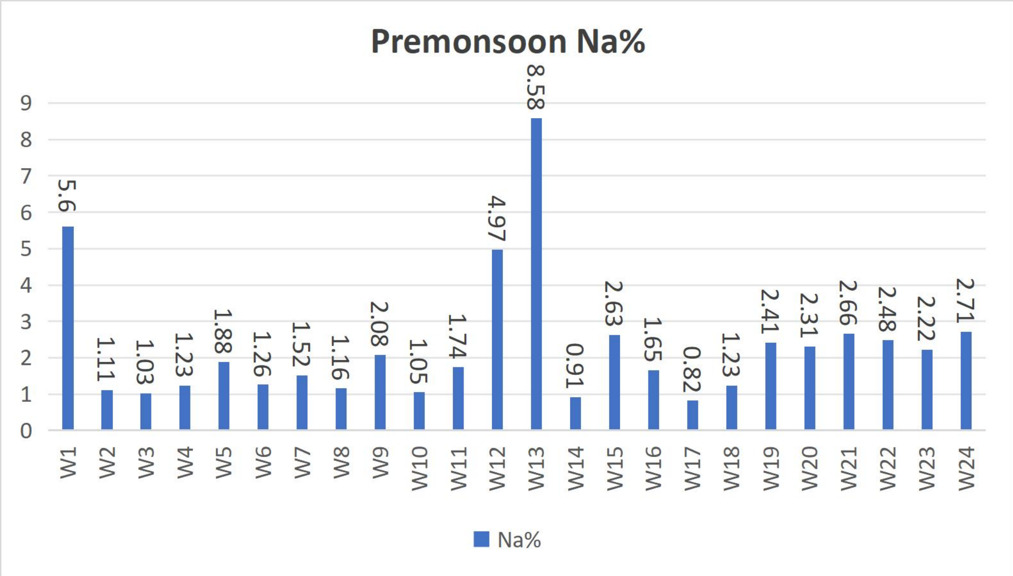


Figure 4.37: Premonsoon Na% graph

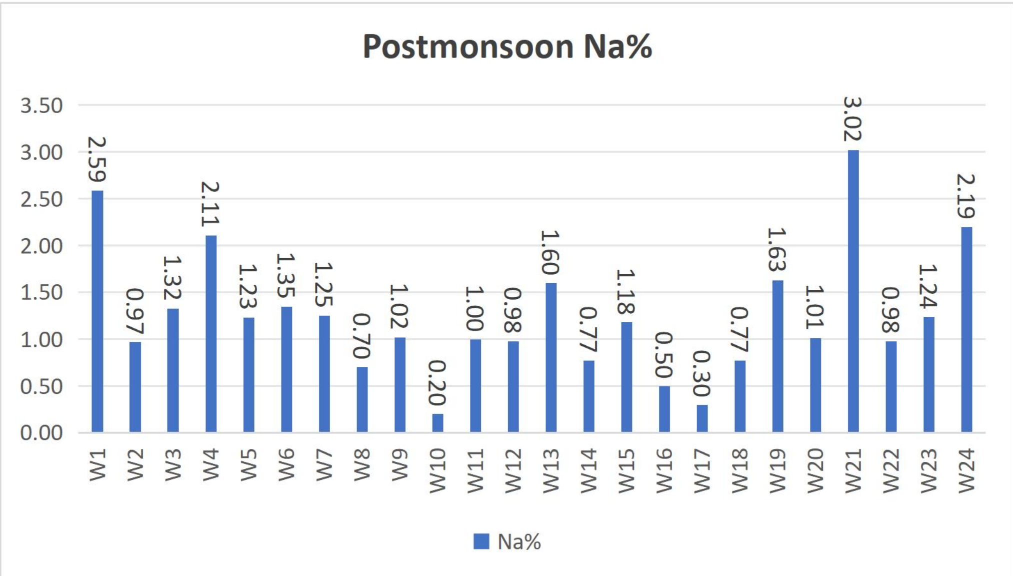


Figure 4.38: Postmonsoon Na% graph

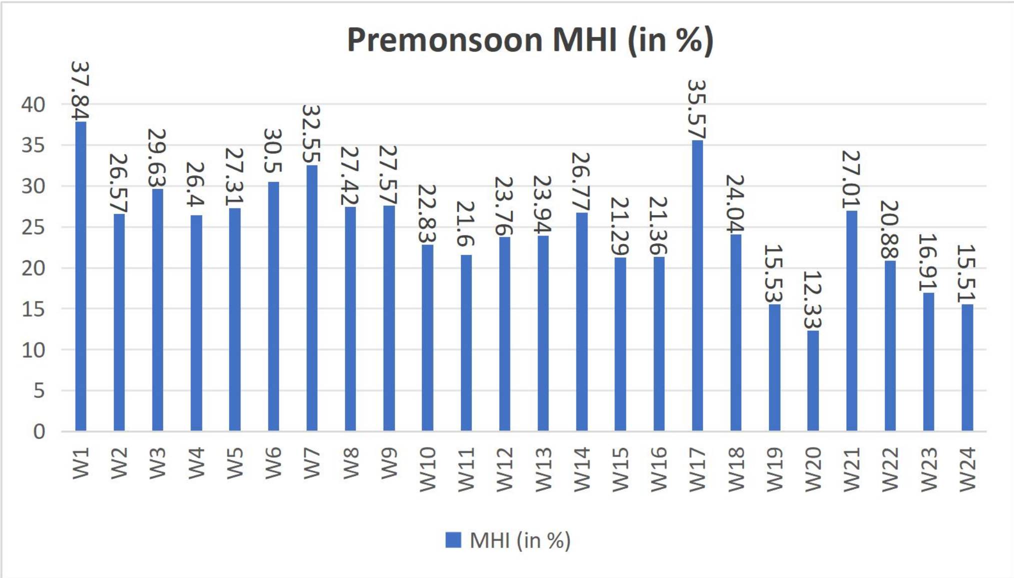


Figure 4.39: Premonsoon magnesium hazard index graph

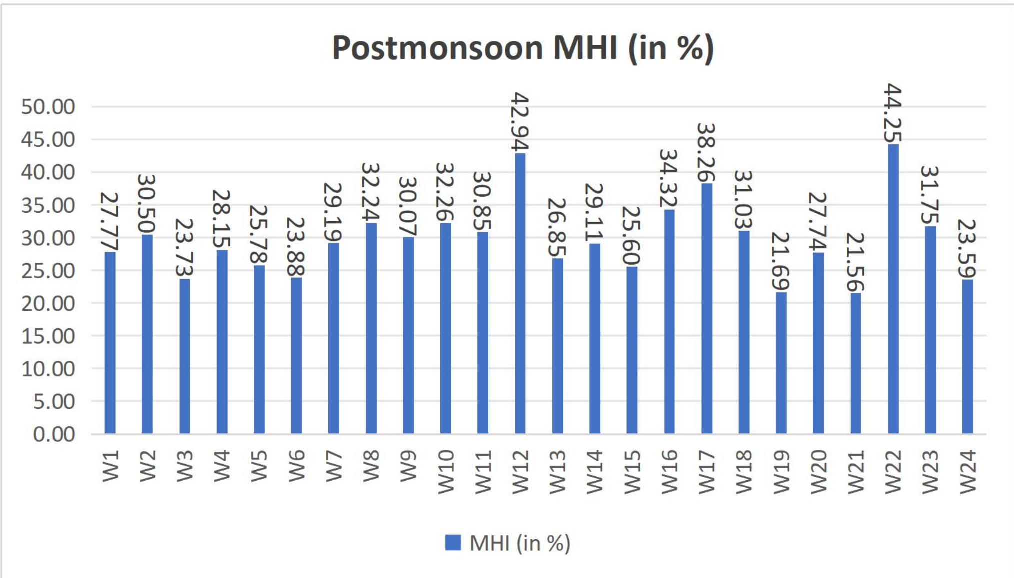


Figure 4.40: Postmonsoon magnesium hazard index graph

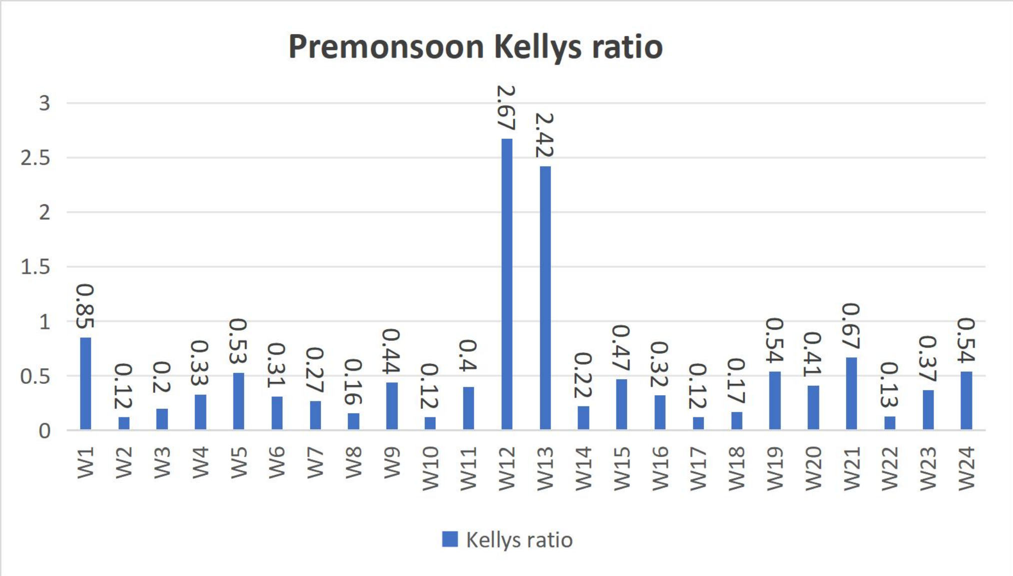


Figure 4.41: Premonsoon Kelly's ratio graph

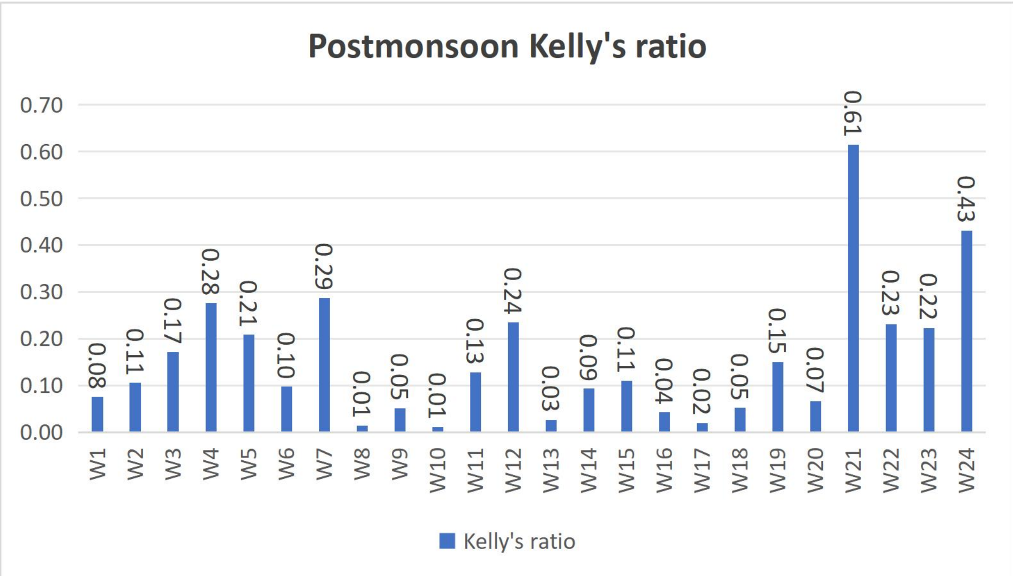


Figure 4.42: Postmonsoon Kelly's ratio graph

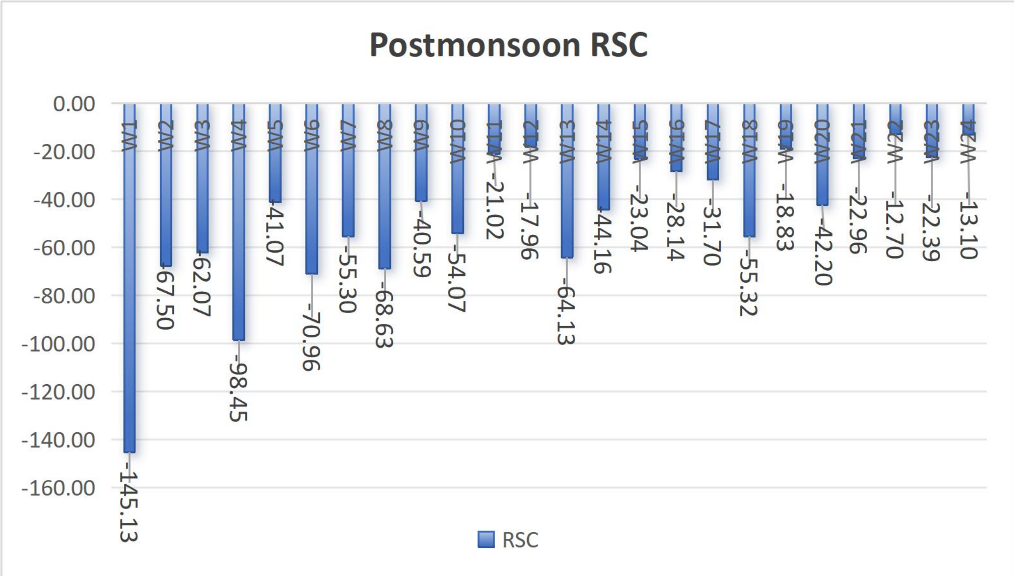


Figure 4.43: Postmonsoon residual sodium carbonate graph

4.4 Salinity Hazard

Salinity hazard refers to the risk or potential impact of high salinity levels in soil or water on agricultural productivity or environmental health. It's often assessed by measuring the concentration of salts, such as sodium chloride, in soil or water samples. The Wilcox diagram is a graphical tool used to evaluate the suitability of water for irrigation based on its sodium adsorption ratio (SAR) and its electrical conductivity (EC). During the premonsoon season, several water samples exhibited varying degrees of salinity and sodium (alkali) hazards. 29.2% of the wells (W4, W5, W7, W10, W15, W17, and W18) were categorized as having low salinity and sodium (alkali) hazard, while 50% of the wells (W2, W3, W6, W8, W9, W12, W14, W16, W19, W20, W21, W23, and W24) showed low sodium (alkali) hazard and medium salinity hazard. Only 8.3% of the wells (W1 and W13) were identified as having high salinity and low sodium (alkali) hazard during this period. In contrast, the postmonsoon period saw a shift in hazard classifications for the water samples. Notably, 25% of the wells (W11, W12, W17, W19, W22, and W24) were classified as having low salinity and sodium (alkali) hazard. Similarly, 75% of the wells (W2, W3, W4, W5, W6, W7, W8, W9, W10, W13, W14, W15, W16, W18, W20, W21, W23, and W24) were found to have low sodium (alkali) hazard and medium salinity hazard while W1 was classified as having high salinity and low sodium (alkali) hazard.

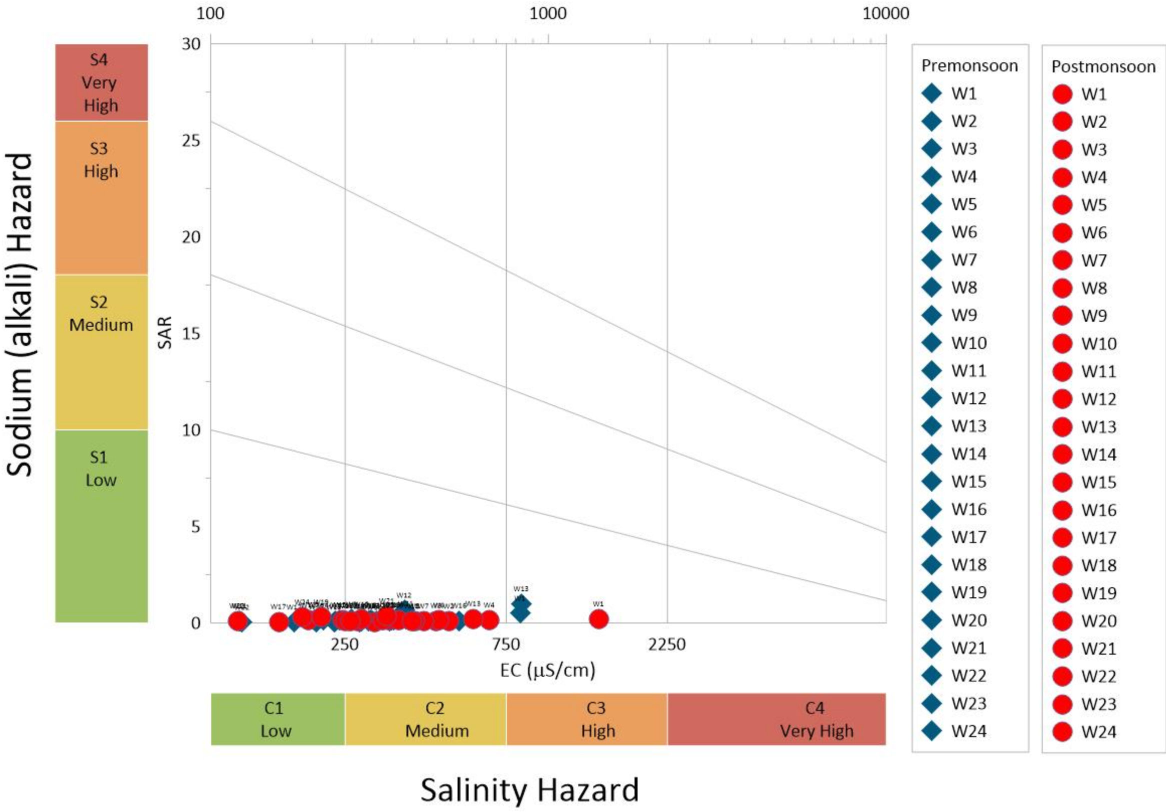


Figure 4.44: Salinity hazard diagram (SAR vs EC)

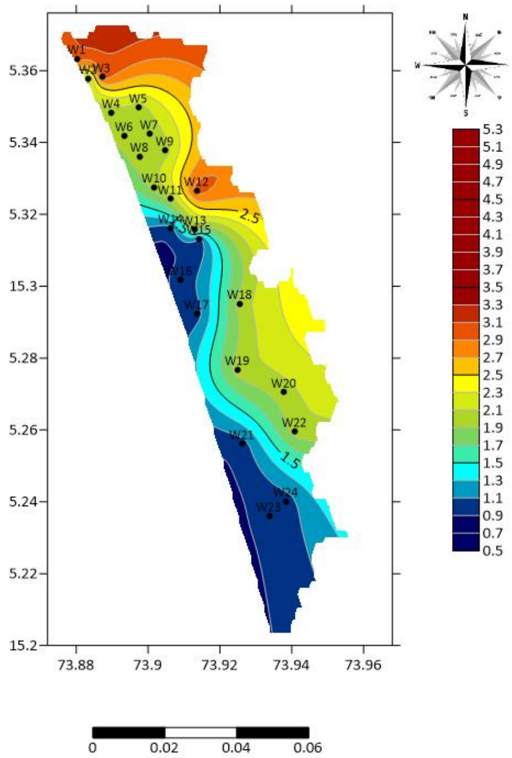


Figure 4.45: Premonsoon salinity graph

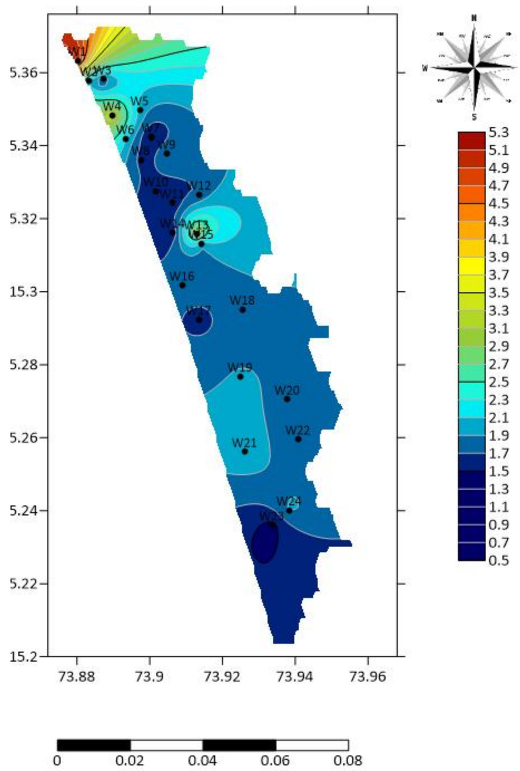


Figure4.46: Postmonsoon salinity graph

4.5 Gibbs diagram

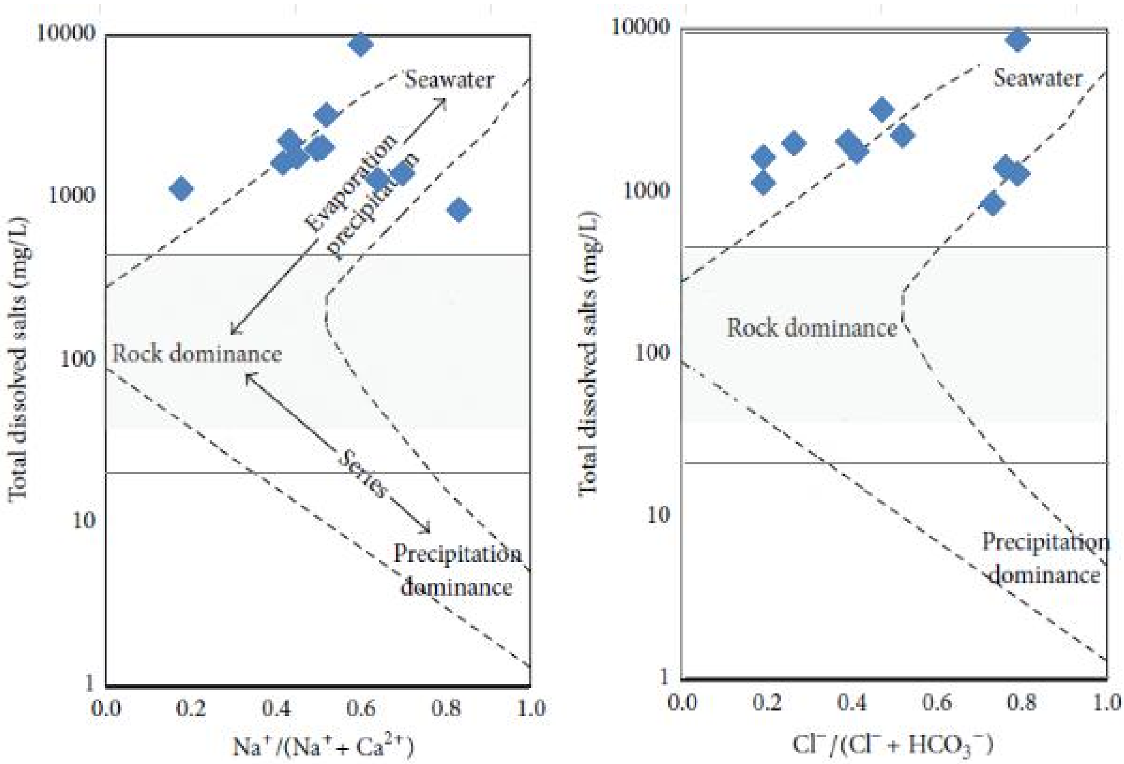


Figure 4.47: Gibbs diagram for controlling factor of groundwater quality

TDS vs Na/(Na+Ca) Plot:

The predominance of samples in the "evaporation/precipitation" area of the TDS vs Na/(Na+Ca) plot suggests that the primary geochemical processes shaping water chemistry are related to evaporation or precipitation phenomena. This observation is indicative of environmental conditions conducive to water evaporation, such as shallow groundwater systems with limited recharge. The higher concentrations of total dissolved solids (TDS) in these samples imply the concentration of dissolved ions due to evaporation processes. Additionally, the higher ratio of Na/(Na+Ca) indicates a relatively greater contribution of sodium ions compared to calcium ions, further supporting the influence of evaporation. Overall, the distribution of samples in this plot area highlights the significance of evaporative processes in shaping the geochemical composition of the water samples.

TDS vs Cl/(Cl+HCO3) Plot:

The positioning of samples near seawater in the TDS vs Cl/(Cl+HCO3) plot suggests that the water chemistry of these samples resembles that of seawater. This resemblance to seawater composition may indicate the influence of marine sources on the water chemistry, such as seawater intrusion or proximity to coastal areas. The ratio of Cl/(Cl+HCO3) helps differentiate between the contributions of chloride ions relative to bicarbonate ions, with a higher ratio indicating a greater proportion of chloride ions. The presence of samples resembling seawater chemistry in the plot suggests potential inputs of marine-derived salts, which could be attributed to geological factors or anthropogenic activities. Understanding the influence of marine sources on water chemistry is crucial for assessing water quality and managing water resources, especially in coastal regions where seawater intrusion and contamination may pose significant challenges.

4.6 Cation piper plots

The Piper plots of cations illustrate that during the premonsoon period, most samples exhibit lower magnesium values and higher concentrations of $Na^{+} + K^{+}$. However, in the postmonsoon period, there is a slight increase in magnesium content alongside a decrease in $Na^{+} + K^{+}$ values. Additionally, there is a subtle variation observed in the calcium values depicted in the Piper plots.

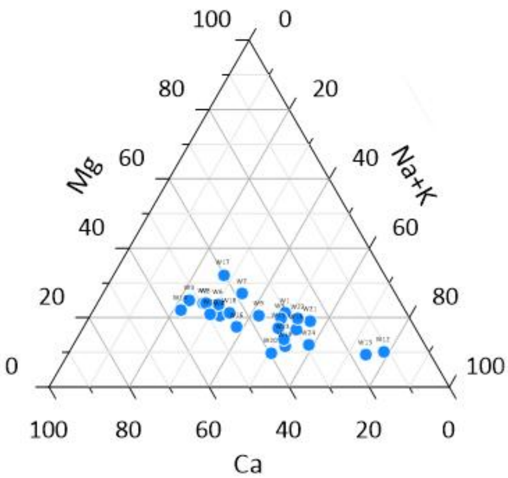


Figure 4.48: Premonsoon piper plot of cation

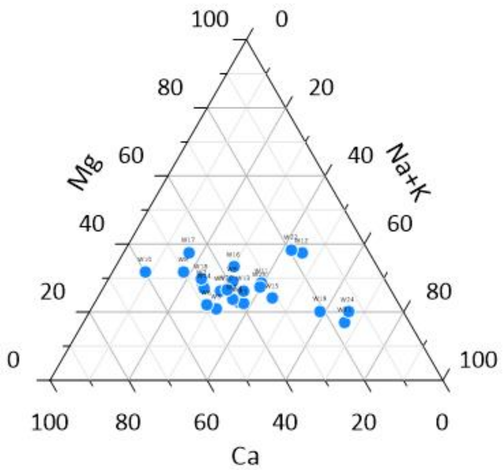


Figure 4.49: Postmonsoon piper plot of cations

4.7 Flow net analysis

Flow net maps were generated for both the premonsoon and postmonsoon periods, revealing that the groundwater follows the natural topography of the region. The predominant flow direction is from high elevations towards the lower lying coastal plains, with the groundwater primarily flowing towards the sea. Areas characterized by elevated water tables serve as regions of groundwater recharge. Groundwater crests are seen in the villages of Utorda, Betalbatim and Benaulim. Groundwater troughs are seen in the villages of Velsao, Cansaulim, Gonsua, Majorda, Mungul, Benaulim, and Varca. In contrast to the premonsoon and postmonsoon flow nets, the groundwater gradient remains consistent, resulting in minimal variation in flow direction. In the low lying coastal area, the gradient of the groundwater table remains consistent, resulting in minimal variation in flow direction. Both flow net maps depict gentle hydraulic gradients, indicating slow groundwater flow. Additionally, the contours in the low lying coastal area are widely spaced, suggesting moderate to low hydraulic conductivity. Groundwater flow is observed to be directed towards streams in the western part of the study area.

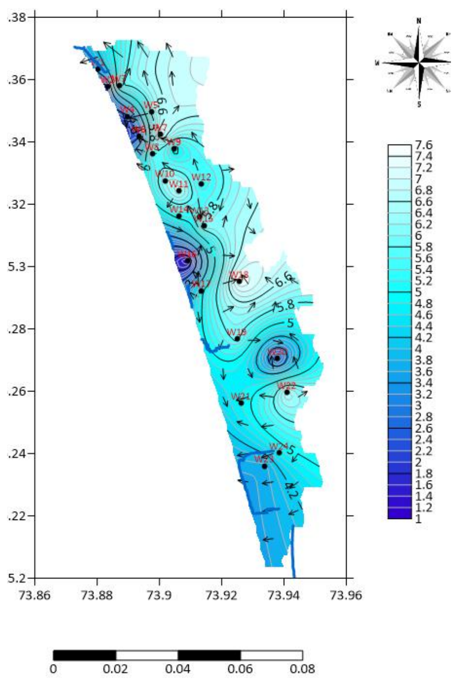


Figure 4.50: Premonsoon flow net map

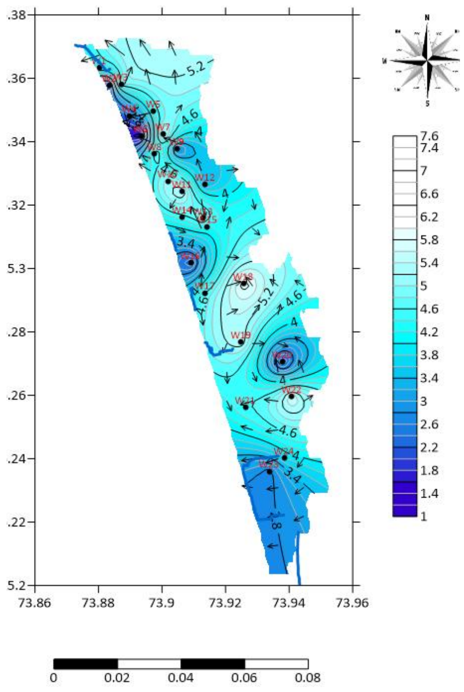


Figure 4.51: Postmonsoon flow net map

4.4 Conclusion

- This comprehensive study provides an analysis of groundwater quality and hydro-geological dynamics in the study area during both pre-monsoon and post-monsoon periods. The investigation encompassed various physico-chemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), total hardness, and concentrations of ions including calcium, magnesium, chloride, sodium, potassium, nitrite, and phosphate.
- During pre-monsoon, pH levels for water samples ranged from 5.36 to 7.41. On average, the pH value during pre-monsoon was 6.77.
- EC values range from 112-833µS/cm during premonsoon and 120-1410µS/cm during postmonsoon. The average EC value during pre-monsoon was 323.29µS/cm, slightly lower than the.
- TDS values range from 79.3-541.45 ppm during premonsoon and 78-916.5 ppm. On average, TDS levels were 210.13 ppm during pre-monsoon and 248.95 ppm during post-monsoon.
- 383µS/cm recorded during post-monsoon.
- DO for water samples ranged from 1.72 - 13.35 during premonsoon. The average DO value during pre-moonsoon is 5.22.
- The Calcium values in the water samples ranges from 14.4-86.41 mg/L during pre-monsoon and 4.8-97.62mg/L during post-monsoon. The Average value of Calcium is 38.47mg/L during pre-monsoon and 31.47mg/L during post-monsoon.
- The magnesium levels in the water samples exhibit a range of 7.96-60.64 mg/L during the pre-monsoon period and 9.14-58.9 mg/L during the post-monsoon period. On average, the magnesium content is measured at 20 mg/L during the pre-monsoon and slightly higher at 20.54 mg/L during the post-monsoon period.
- The total hardness values in the water samples ranges from 52-336 mg/L during pre-monsoon

and 44-340mg/L during post-monsoon. The Average value of total hardness is 120.83mg/L d The chloride concentrations in the water samples range from 44 to 244 mg/L during the pre-monsoon period and 140 to 602.5 mg/L during the post-monsoon period. On average, chloride content measures 88 mg/L during the pre-monsoon and increases to 216.56 mg/L during the post-monsoon period.

- The Sodium concentrations in the water samples range from 3.2 to 124.8 mg/L during the pre-monsoon period and 4.9 to 55.6 mg/L during the post-monsoon period. On average, Sodium content measures 29.22 mg/L during the pre-monsoon and decreases to 19.73 mg/L during the post-monsoon period.
- The potassium concentrations in the water samples range from 5.1 to 34.6 mg/L during the pre-monsoon period and 0.7 to 30.6 mg/L during the post-monsoon period. On average, potassium content measures 19.17 mg/L during the pre-monsoon and decreases to 6.75 mg/L during the post-monsoon period.
- The nitrite concentrations in the water samples range from 0.0473 to 0.0496 mg/L during the pre-monsoon period and 0.0474 to 0.0609 mg/L during the post-monsoon period. On average, nitrite content measures 0.0478 mg/L during the pre-monsoon and increases to 0.0486 mg/L during the post-monsoon period.
- The phosphate concentrations in the water samples range from 0.0271 to 0.0291 mg/L during the pre-monsoon period and 0.0296 to 0.0299 mg/L during the post-monsoon period. Well W22 exhibits the highest phosphate level during pre-monsoon (0.02913 mg/L), while W6 shows the lowest (0.0271mg/L). In contrast, during post-monsoon, W1 records the highest phosphate concentration (0.0299mg/L), with W24 showing the lowest values (0.02956mg/L). On average, phosphate content measures 0.0277 mg/L during the pre-monsoon and increases to 0.0297 mg/L during the post-monsoon period.
- Overall, the majority of the groundwater samples met the permissible limits set by regulatory bodies for drinking water quality, indicating that the water is generally suitable for human

consumption. However, there were exceptions noted in certain wells where concentrations of specific ions exceeded the acceptable limits, particularly for TDS, chloride, and sodium.

- In terms of irrigation suitability, the study found that the groundwater samples generally were within acceptable ranges for electrical conductivity and sodium content, indicating minimal risk to soil permeability and crop productivity. The assessment of magnesium hazard index and Kelly's ratio further supported the conclusion that the groundwater is suitable for irrigation purposes.
- With respect to the assessment of salinity hazards in the study area during the premonsoon season, 29.2% of the wells were categorized as having low salinity and sodium (alkali) hazard, while 50% of the wells showed low sodium (alkali) hazard and medium salinity hazard. Only 8.3% of the wells were identified as having high salinity and low sodium (alkali) hazard during this period. In contrast, the postmonsoon period witnessed a shift in hazard classifications, 25% of the wells were classified as having low salinity and sodium (alkali) hazard. Similarly, 75% of the wells (W2, W3, W4, W5, W6, W7, W8, W9, W10, W13, W14, W15, W16, W18, W20, W21, W23, and W24) were found to have low sodium (alkali) hazard and medium salinity hazard while W1 was classified as having high salinity and low sodium (alkali) hazard.
- in the percentage of wells categorized as having high salinity and low sodium (alkali) hazards.
- The analysis using Gibbs diagrams provided valuable insights into the geochemical processes shaping water chemistry in the study area. The TDS vs Na/(Na+Ca) plot highlighted the influence of evaporation or precipitation phenomena, indicating environmental conditions conducive to water evaporation, particularly in shallow groundwater systems. Similarly, the TDS vs Cl/(Cl+HCO3) plot suggested a resemblance to seawater composition in some samples, hinting at potential inputs of salts, possibly due to seawater intrusion or proximity to coastal areas.
- The cation piper plots depicted variations in cation concentrations between the premonsoon

and postmonsoon periods, with subtle changes observed in magnesium, sodium, potassium, and calcium values. These variations could be attributed to groundwater recharge, hydrological processes.

- The analysis of flow net maps indicates that the groundwater predominantly flows towards the sea, with areas of elevated water tables serving as recharge zones in the villages of Utorda, Betalbatim and Benaulim. Groundwater troughs are seen in the villages of Velsao, Cansaulim, Gonsua, Majorda, Mungul, Benaulim, and Varca. The consistent hydraulic gradients and widely spaced contours in the low lying coastal area suggest slow groundwater flow velocities and low to moderate hydraulic conductivity.
- Overall, these findings contribute to our understanding of groundwater quality and hydro-geological processes in the study area, providing valuable information for water resource management and sustainable development initiatives. Further research and monitoring efforts are recommended to ensure the continued protection and utilization of groundwater resources in the region.

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