GROUNDWATER QUALITY IN THE COASTAL AREAS OF MAHABALIPURAM, CHENNAI, INDIA: A HYDROGEO CHEMICAL ANALYSIS

Abstract

The present study examines coastal groundwater quality in Kanchipuram District, East Coast, and Tamil Nadu. A total of 72 groundwater samples were obtained both before to and during the monsoon season. These samples were analyzed for several parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), bicarbonate (HCO_3), chloride (Cl), sulfate (SO_4), nitrate (NO_3), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), and total hardness. GIS created spatial distribution maps for all physicochemical parameters. The obtained findings were compared to the water quality guidelines established by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS). Piper plot and correlation methods are commonly used to assess water quality and pollutants. Coastal areas with shallow groundwater tube wells have worse groundwater quality issues. Groundwater is fresh to brackish, according to results. Cations and anions are dominated by Na and Cl. Few samples have Cl, Ca, and Mg ions within the acceptable limit. Gibbs figure shows that most samples are rock–water interactions. The Piper diagram displays Na–Cl and mixed Ca-Mg-Cl groundwater samples. The majority of water quality samples are excellent to good and appropriate for drinking. The USSL graph demonstrates that most groundwater samples have high and medium salinity and low alkali risks. The use of factor analysis was employed in the classification of groundwater samples and the identification of pollutants and leaching of secondary salts dominates groundwater hydro geochemistry in the research area. The investigation found all groundwater samples appropriate for irrigation.

Keywords: Groundwater, Coastal, Spatial diagram, Piper diagram, SPSS.

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I. INTRODUCTION

Groundwater plays a pivotal function in the fundamental sustenance of organisms. Several variables, such as industrial activities and sewage disposal, have a significant impact on the quality of groundwater, leading to its degradation and reduced suitability for consumption. Groundwater is widely utilized as the primary drinking water source in both rural and urban areas, with a significant majority of the population relying on it. The study conducted by Ramachandran and Sivakumar et al. (2020), (Venkatramanan et al 2015) examined the evaluation of groundwater zone identification using the Water Quality Index and GIS technology in the Adyar river basin. The findings revealed that the groundwater quality in this area falls into the very bad to inappropriate category. The deployment of artificial groundwater recharge in the Adyar river basin is proposed as a means to enhance the quality of groundwater and render it appropriate for potable use. A study conducted by Aishwarya (2021) examined the spatial distribution of physicochemical parameters of groundwater in the vicinity of the Kodungaiyur dump yard. The research emphasized the utilization of GIS for testing and spatial representation purposes. Annapoorani et al. (2013) conducted a study on groundwater analysis in the coastal area of Chennai city, Tamil Nadu. The researchers focused on the impact of saltwater intrusion on groundwater basins in the coastal region, specifically examining changes in geochemical properties such as total dissolved solids (TDS), pH, electrical conductivity (EC), as well as the presence of cations and anions in the groundwater surrounding the study area. In their study, Elango and Gnanasundar (1999) conducted an evaluation of the groundwater quality within a coastal aquifer located south of Chennai. They employed geo-electrical techniques as a means of analysis. The coastal environment exerts a substantial influence on the availability of resources, the development of productive behaviors, and the maintenance of diverse ecosystems. The study conducted by Elango et al. (1992) focused on the assessment of groundwater quality in the coastal areas of South Madras. The findings indicated that sodium ($Na+$) and chloride ($Cl-$) ions were the prevailing constituents in the groundwater. In their study, Lakshmanan et al. (2003) examined the ion chemistry of hydro-geochemical processes in groundwater within certain areas of the Kancheepuram district. They found that the chemical composition of groundwater is significantly impacted by interactions between rocks and water, as well as the dissolution and deposition of carbonate and silicate minerals, ion exchange, and interactions with surface water. Similarly, Sridhar et al. (2013) investigated the chemical composition of groundwater in the Kanchipuram District of Tamil Nadu, India, and concluded that it is strongly influenced by the aforementioned factors. Panigrah et al. (1996), Atwia et al. (1997), Ballukraya and Ravi (1999), and Ramappa and Suresh (2000) have conducted studies on this topic. Numerous investigations have been conducted to examine the issue of contamination resulting from the presence of high levels of heavy metals in both surface water and groundwater (Asubiojo et al., 1997; Klavins et al., 2000; Leung and Jiao, 2006; Kaushik et al., 2009; Mansouri et al., 2012). Several investigations have been conducted to investigate the presence of metal pollution. Impact of human activity and population growth on groundwater quality and its variability was investigated by hydrochemical tests (Ramesh and Purvaja, 1995; Kumaresan and Riyazuddin, 2008; Jayaprakash et al., 2012). In their study, Majumdar and Gupta (2005) examined the influence of many factors on the chemical composition of groundwater. These factors encompass the composition of precipitation, anthropogenic activities, as well as the geological composition and mineralogy of both the watershed and aquifer inside the aquifer medium. The District possesses a cumulative coastal extent of 87.2 kilometers and is placed 36 meters above sea

level. The southeastern coast of India holds significant importance due to its geographical features, including the convergence of numerous major rivers that flow into the Bay of Bengal. This region is also characterized by its abundant marine biodiversity, encompassing a diverse range of flora and animals (Rajkumar et al., 2011). The present study evaluates Kanchipuram groundwater quality namely in the coastal region spanning from Kovalam to Mahabalipuram in Tamil Nadu, India.

II. STUDY AREA

The study region encompasses the Chennai coast, spanning a linear distance of 10 kilometers from Kovalam to Mamallapuram in the Kanchipuram district. The study region is situated within the geographical coordinates of 12°35' to 12°50' East Latitude and 80°12' to 80°16' North Longitude. The location map depicted in Figure 1.The primary aquifer consists of the coastal sands, which reach to a depth of 30-40 feet. The thickness of sand is observed to exhibit an increasing trend in proximity to the coast, which can be attributed to the presence of the Buckingham canal that runs parallel to the coastline. The primary area of groundwater presence is located at the mouth of the Palar River, where the riverbed serves as a promising geological structure. Silica sands, a crucial mineral, are present along the coast of Mahabalipuram.
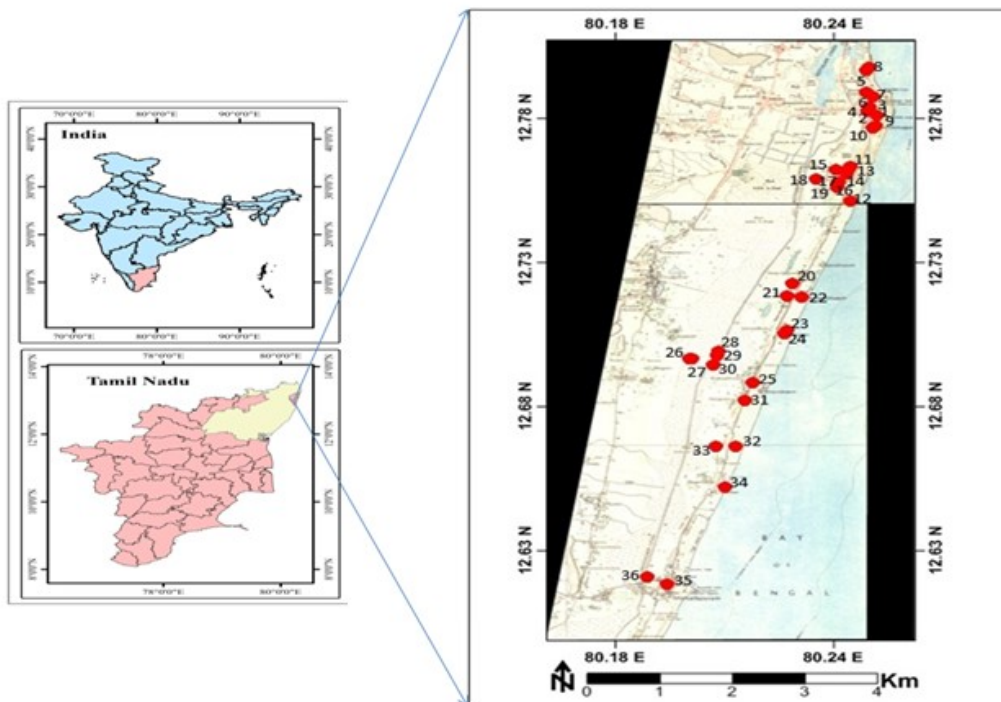

Figure 1: A map showing the location of the research area

III. METHODOLOGY

A total of seventy-two groundwater samples were gathered from the Kovalam – Mahabalipuram region, located in the Kanchipuram District has a total coastline length of 87.2 Km, and 36 meter above MSL east coast of Tamil Nadu. The collection of ground water

samples took place both before and after the monsoon season, from both bore wells and dug wells during the year of 2017. The samples were obtained using polyethylene (PVC) bottles with a volume of 1.5 liters. A portable bore well logger, the Multi probe system, model YSI 556 MPS, monitored pH, EC, and TDS in situ. The laboratory conducted an analysis of the samples in order to ascertain the concentration of significant ions. The technique employed in this study is ion chromatography.

IV. RESULTS AND DISCUSSION

Groundwater samples were collected systematically in both spatial and temporal dimensions, and subsequently subjected to analysis for the presence of main and minor dissolved ions, employing established and widely accepted protocols. Table 1 presents the findings of the physico-chemical study conducted on the groundwater samples collected from the coastal regions of Kovalam - Mahabalipuram during two distinct seasons.

**Table 1: Shows the estimated values of collected samples.**

Major ions	Pre monsoon		Post monsoon		WHO	BIS
EC µs/cm	148	1689	217	1136	500-1000	500-1000
pH	6.8	7.1	7	8.6	6.5-8.5	6.5-8.5
TDS mg/l	147	1336	112	1324	500-1000	500-2000
Ca mg/l	6	256	0	96	75	75-200
Mg mg/l	4.8	79	0	42	50	30-100
Na mg/l	2.4	432	2.5	244	200	X
K mg/l	2.3	178	0.1	166	20	X
HCO_3 mg/l	24.4	464	24.4	695	250	250-1000
SO_4 mg/l	11.7	519	0	326	X	X
Cl mg/l	10	1892	15	860	50	45
NO_3 mg/l	0	377	0	165	200	200-400

The pH of hydrogen ions in the research area exhibits a range of 6.8 to 8.6, with an average of 7.4 during the post-monsoon period. In the pre-monsoon pH ranges from 6.8 to 7.1, with an average of 7.17. The electrical conductivity (EC) ranges from 148 to 1689 µS/cm, with an average of 827 µS/cm, during the post-monsoon period. In the pre-monsoon period, the EC ranges from 217 to 1136 µS/cm, with an average of 827.32 µS/cm. The concentration of total dissolved solids (TDS) in the post-monsoon period varies between 72 and 884 mg/l, with an average value of 579.41 mg/l. In the pre-monsoon period, the TDS concentration ranges from 112 to 870 mg/l, with an average value of 581.82 mg/l. The water samples collected from the study area exhibit a classification ranging from fresh to brackish water type. Both pre and post-monsoon the major anion is HCO_3, followed by Cl, SO_4, NO_3, and PO_4. The prevailing cations during the post-monsoon period are primarily calcium (Ca), followed by sodium (Na), potassium (K), and magnesium (Mg). In contrast, in the pre-monsoon period, the prevailing cations are calcium, magnesium, sodium and potassium, in that order.

The spatial distribution analysis of EC in groundwater samples was conducted for both seasons, as depicted in Figure 2. Typically, elevated levels of EC are observed in proximity to coastal regions. To gain insights into the chemical properties of groundwater in the designated study area, the researchers employed a Triplot diagram (Piper, 1944) and AquaChem Software to visualize and classify the collected groundwater samples (Figure 3). The prevailing groundwater water types are arranged in the following order: NaCl > CaMgCl > mixed CaNaHCO$_3$ > CaHCO$_3$. However, the majority of the samples exhibit clustering within the Na Cl and Ca-Mg-Cl segments. The presence of water types characterized by high salinity, specifically CaMgCl and NaCl, indicates the occurrence of water mixing resulting from surface pollution sources, such as the introduction of irrigation return flow, residential wastewater, and effluents. This mixing process is subsequently followed by ion exchange processes. In conjunction with the Piper diagram, the Gibbs plot (1970) elucidated that plotting total dissolved solids (TDS) against the ratio of sodium to the sum of sodium and calcium (Na + Ca) yields insights into the underlying mechanisms governing the chemical composition of water bodies. Figure 2 illustrates that the majority of the groundwater samples were situated within the rock-water interaction zone, while only a limited number of samples were found within the evaporation zone. The Piper and Gibbs plots show that mixing saline water from surface pollution sources with pre-existing water, ion exchange processes, mineral dissolution, and perhaps evaporation regulate water chemistry.

V. SPATIAL ANALYSIS OF GROUNDWATER QUALITY OF PRE & POST-MONSOON RESPECTIVELY

The graphical representation of different ion concentrations serves as a straightforward method for illustrating the groundwater quality within the designated research region. The current study involved the utilization of GIS to analyze the spatial-temporal fluctuations of physicochemical parameters.
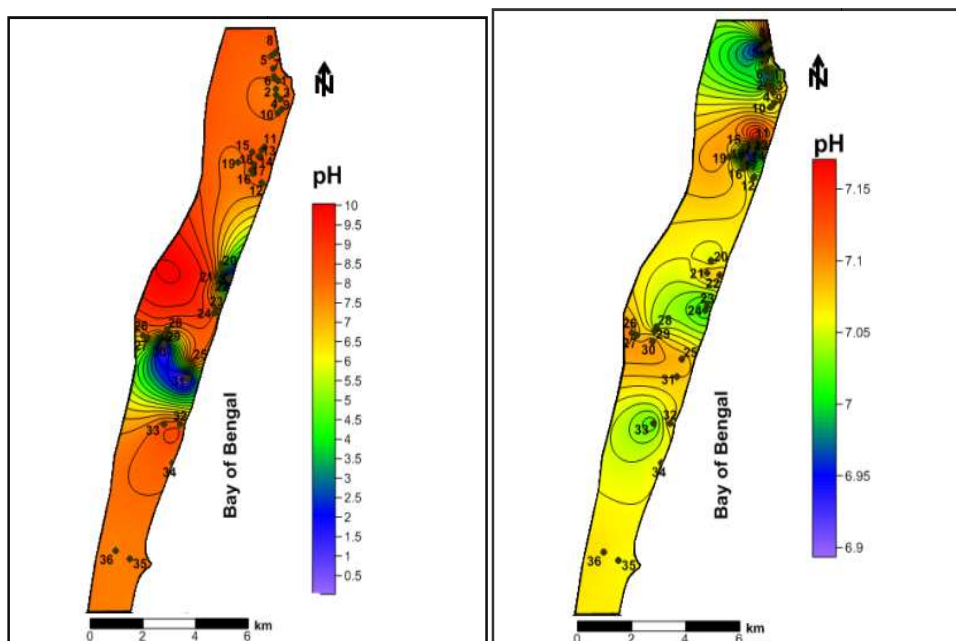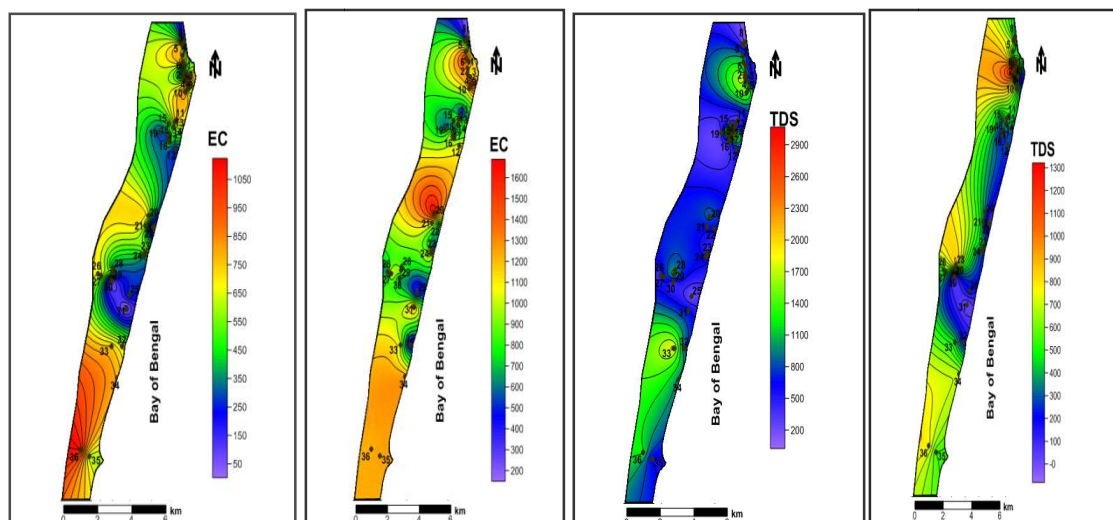
Figure 2: Spatial Diagrams of major elements (Pre and Post monsoon)

1. **Major Cations:** The prevalence of main cations is observed to be in the following order: Na > Mg > Ca > K throughout the periods of particulate matter (PRM) and primary organic matter (POM) emissions. The pre-monsoon sodium ion content is 2.4 to 432 mg/l, after monsoon, it's 2.5 to 244 mg/l. The evaluation of groundwater quality for irrigation is significantly influenced by the content of sodium, as it has been observed that sodium contributes to the increased soil hardness and reduced permeability (Tijani, 1994). Pre-monsoon calcium ions vary from 6 to 256 mg/l, after monsoon, it ranges from 0 to 96 mg/l. The concentration of Mg ions during the pre-monsoon season exhibits a range of 4.8 to 79 mg/l, however post-monsoon values vary from 0 to 42 mg/l. The pre-monsoon potassium (K) range is 2.3 to 178 mg/l, whereas the post-monsoon range is 0.1 to 166 mg/l.

2. **Major Anions:** The relative prevalence of anions is observed to be in the order of chloride> bicarbonate> nitrate> sulfate in both the times after and before the monsoon season. Pre-monsoon chloride ion concentrations range from 10 to 1892 mg/l, whereas monsoon concentrations are 15 to 860 mg/l. Saline water and ion exchange processes increase Cl- concentration (Freeze and Cherry, 1979). The concentration of HCO_3 ions during the pre-monsoon season exhibits a range of 24.4 to 464 mg/l, but in post-monsoon samples, it spans from 24.4 to 695 mg/l. A greater concentration of bicarbonate signifies the presence of country rock, also known as Charnockite. The concentration of SO_4 ions during the pre-monsoon season exhibits a range of 11.7 to 519 mg/l, but in the post-monsoon samples, it varies from 0 to 326 mg/l. The pre-monsoon ion NO_3 concentration varies from 0 to 377 mg/l, whereas the post-monsoon samples are 0 to 165 mg/l.
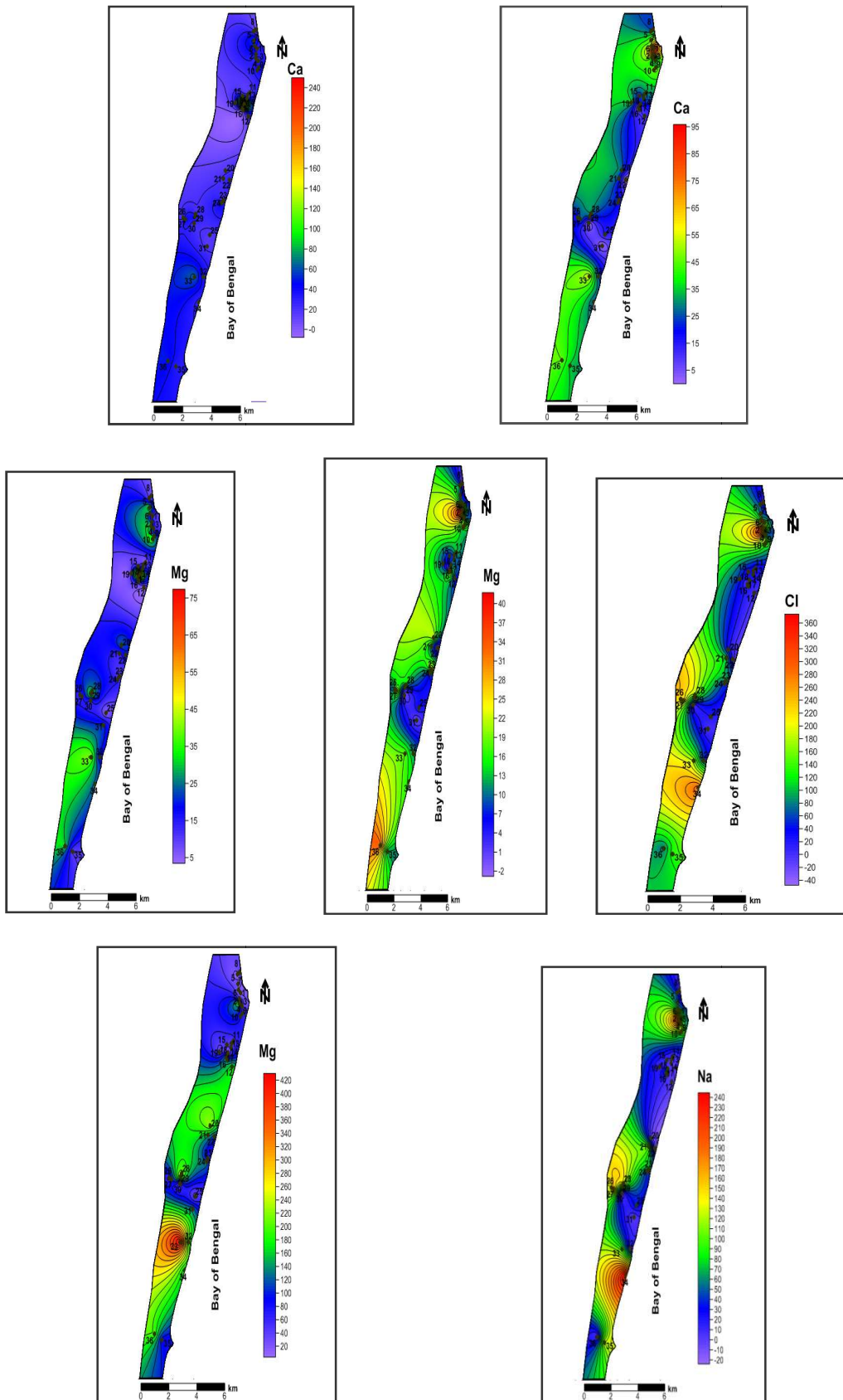
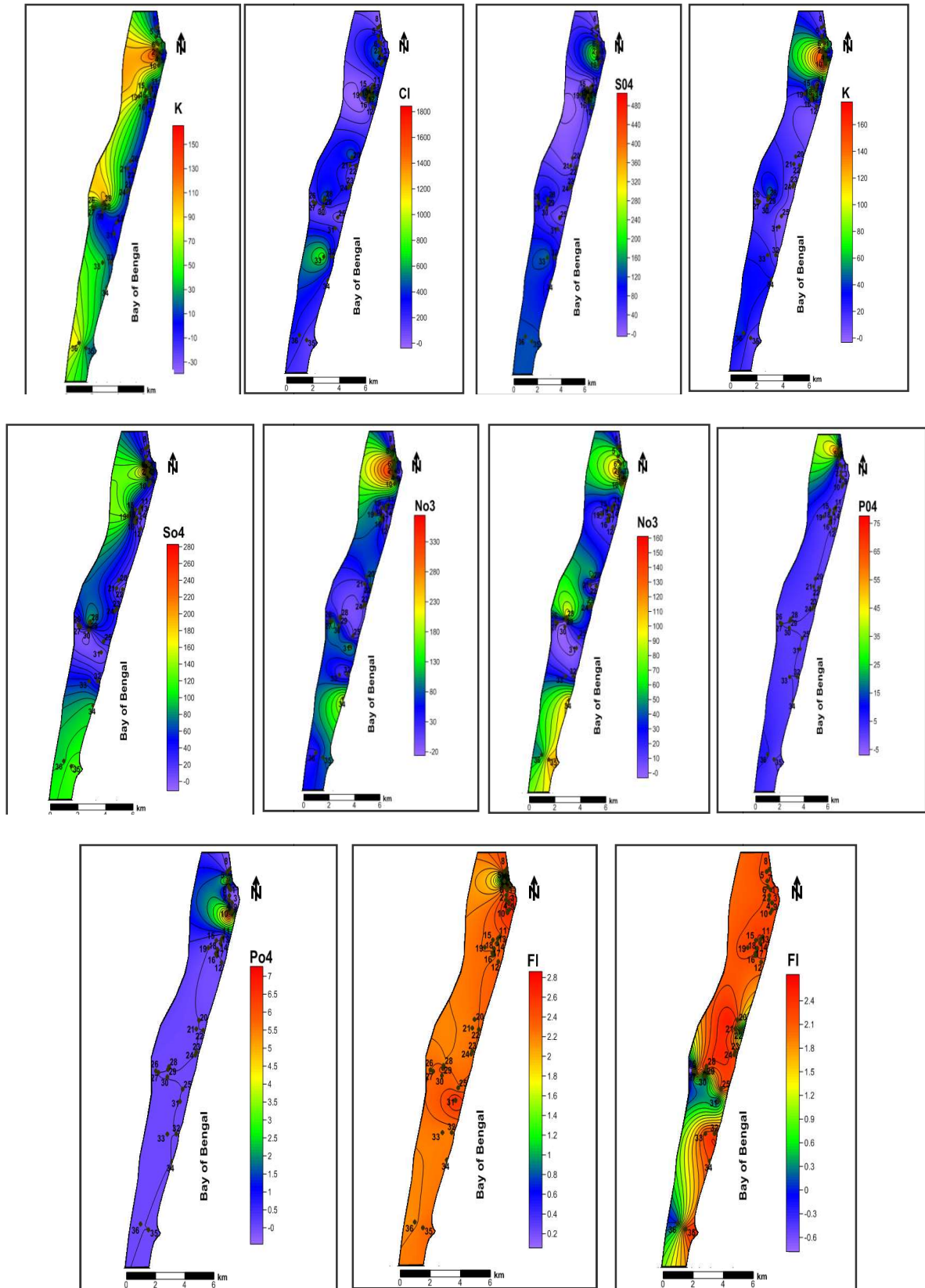**Figure 3:** Spatial Diagrams of Major Cations (both monsoons)

Figure 4: Spatial Diagrams of Major Anions (Pre and Post monsoon)

3. **Gibbs Plot:** The investigation of the chemical associations in groundwater, with respect to Gibb's Plot was used to study the aquifer's lithology (Gibb, 1970). The water that is mostly influenced by weathering processes exhibits elevated levels of calcium (Ca) and bicarbonate ions (HCO_{3-}), while the water that is primarily influenced by evaporation and crystallization processes is characterized by elevated levels of sodium ions (Na^+) and chloride ions (Cl^-). Figure 5 shows that rock-water interaction dominates groundwater chemical composition in the studied region with a few water samples falling within the evaporation range. This holds true for both seasons examined.
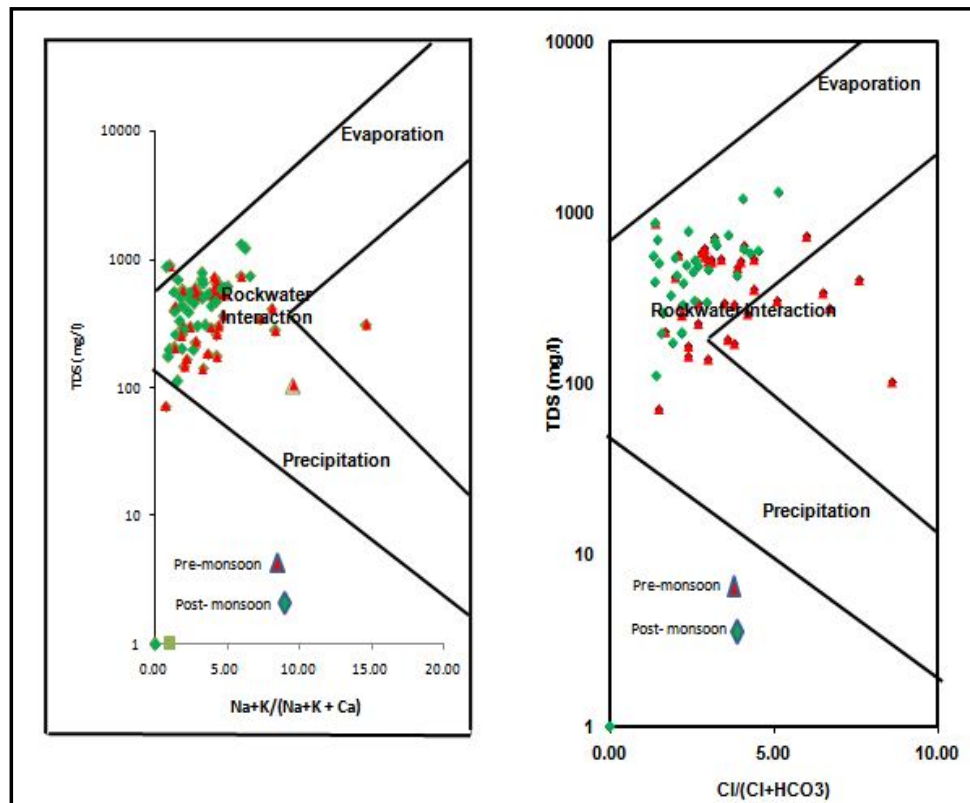

Figure 5: Shows Gibbs plot

4. **USSL Diagram:** The diagram serves as a mechanism for evaluating the suitability of groundwater for irrigation purposes. Figure 6 illustrates a graphic wherein the vertical axis represents the Sodium Absorption Ratio, while the horizontal axis represents conductance. An elevated concentration of dissolved salts in groundwater has the potential to impede soil permeability, which in turn can lead to a reduction in agricultural output. The United States Salinity Laboratory (USSL) diagram is used for the purpose of categorizing the appropriateness of groundwater for irrigation, which categorizes it into two distinct types: Sodium and salinity hazards. The assessment of salinity hazard is conducted by considering the electrical conductivity (EC) parameter, whereas the determination of sodium hazard is accomplished through the utilization of the SAR equation. The SAR is a method used to estimate the proportion of sodium in relation to calcium and magnesium. The USSL diagram defines sodium and salinity concerns as S1, S2, S3, S4 and C1, C2, C3, C4 respectively. A significant portion of samples in pre and

post-monsoon seasons fall into the C3S1 (medium salinity, low sodium) and C3S1 (high salinity, low sodium) categories.
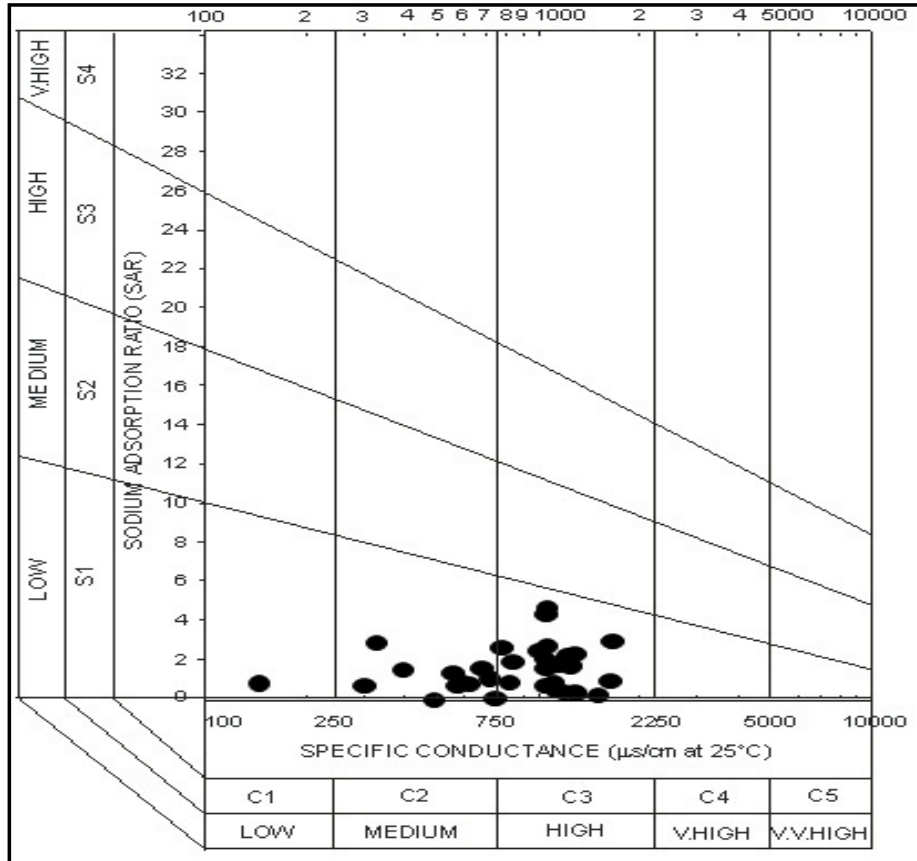

Figure 6: Shows the USSL Diagram

5. **Wilcox diagram:** The significance of sodium in the categorization of groundwater for agricultural purposes was underscored because to its reactivity with soil, leading to particle blockage and subsequent reduction in permeability (Todd, 1980; Domenico et al., 1990). Srinivasamoorthy (2004) highlights the significance of the Na cation, emphasizing its detrimental effects on soil structure and agricultural output when present in excessive quantities. The Wilcox diagram (Wilcox, 1955) utilizes milli equivalents per liter as the unit of measurement for expressing the concentrations of ions. Water classification is determined by the relative concentration of sodium (Na%) in relation to other cations present in the water. The values of groundwater samples collected before and during the monsoon season in the region were visually portrayed in the Wilcox diagram, as seen in Figure 7. In the designated study region, it was seen that 54% and 57% of the collected samples were classified as falling within the range of good to permitted before and after the rainy season, respectively. Additionally, 37% of the samples were categorized as very good during both seasons. During both seasons, only a small number of the samples were found to be either acceptable to doubtful or doubtful to unfit. The majority of the samples within the study area are classified as being within the good to very good category.
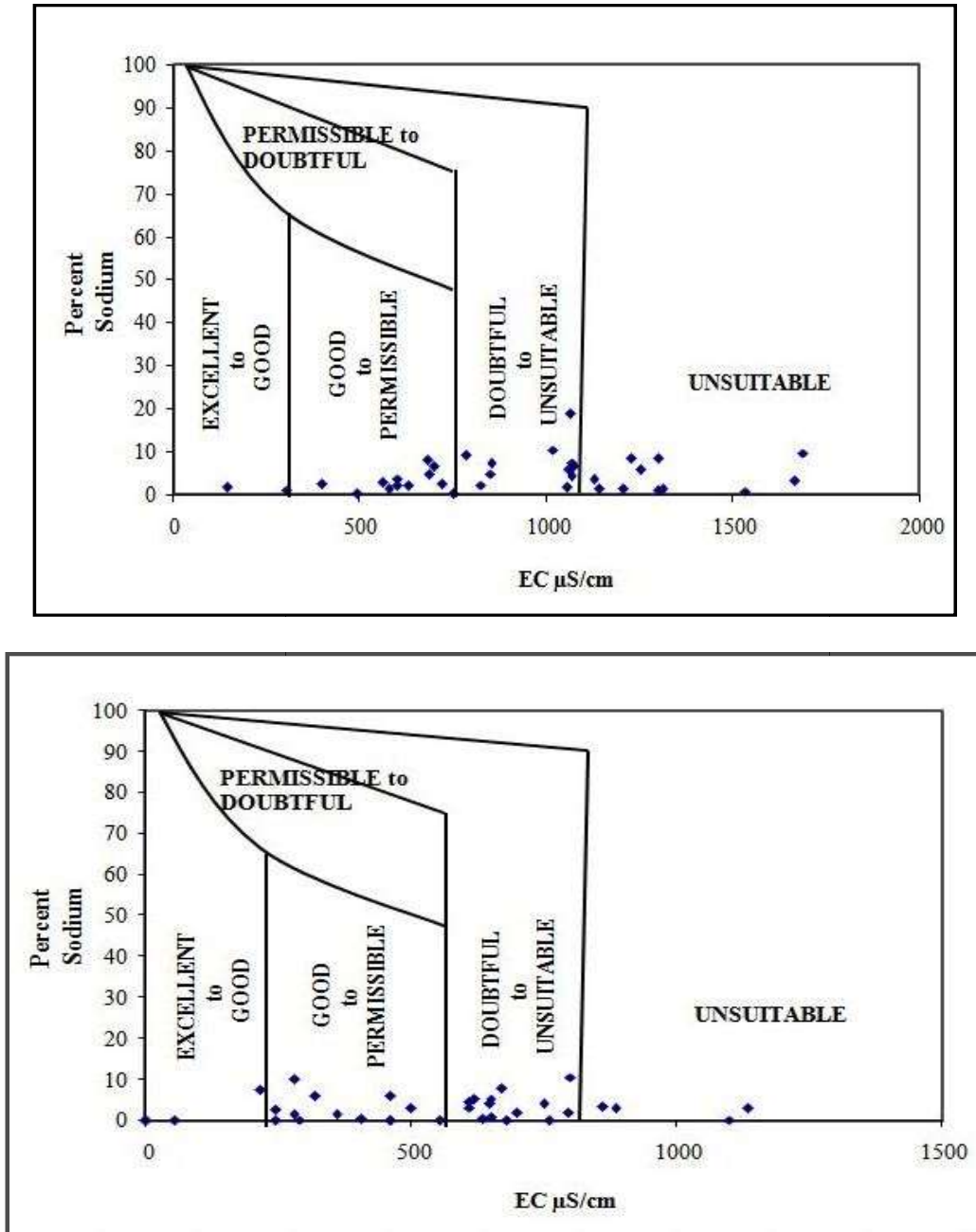
Figure 7: Shows the Wilcox preand Post-monsoon

6. **Box whisker plot:** The current research used Box plots to visually depict groundwater data, enabling the comparison of groundwater quality across different wells. The plots are created by using the median value as well as the interquartile range, which ranges from 25 to 75 cumulative frequencies., groundwater samples is shown in The primary cations are shown in Fig. 8 diagram to be sodium, calcium, and magnesium in that order for both summer and winter. During either season, the abundance of major anions follows the pattern of $Cl > HCO_3 > SO_4$ in that order.
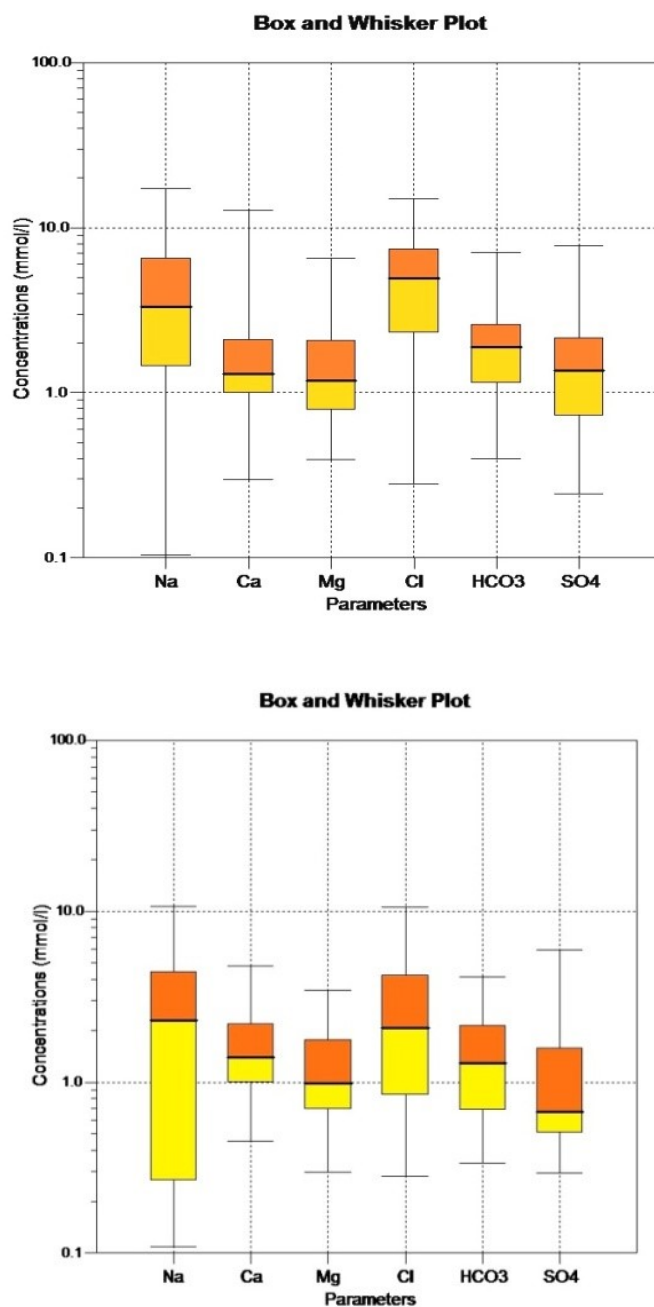
Figure 8: Shows the Pre and Post Monsoon Box plot diagram

VI. CHEMICAL RELATIONSHIP

The concentration of important ions in water samples may be used to assess its composition. Then, using a Trilinear Piper diagram, which was initially suggested by Piper in 1953, these concentrations are shown. The resulting diagram, depicted in Figure 9, provides a visual representation of the water's characteristics and composition. It was noted during the pre-monsoon season that 90.9% of strong acids (chloride) surpassed weak acids (bicarbonate and sulfate), while 78.8% of alkaline earth elements (calcium and magnesium) exceeded alkalies (sodium and potassium). Additionally, a majority of 63.6% exhibited a mixed

composition (calcium-sodium-bicarbonate). Similarly, during the post-monsoon period, all strong acids (chloride) were found to surpass weak acids (bicarbonate and sulfate), while 66.6% of alkaline earth elements (calcium and magnesium) exceeded alkalies (sodium and potassium). Furthermore, 63.6% of the samples displayed a mixed composition (calcium-sodium-bicarbonate). The rationale behind this phenomenon is that groundwater flowing through igneous rocks has limited capacity to dissolve mineral substances owing to the low solubility of the rock composition.
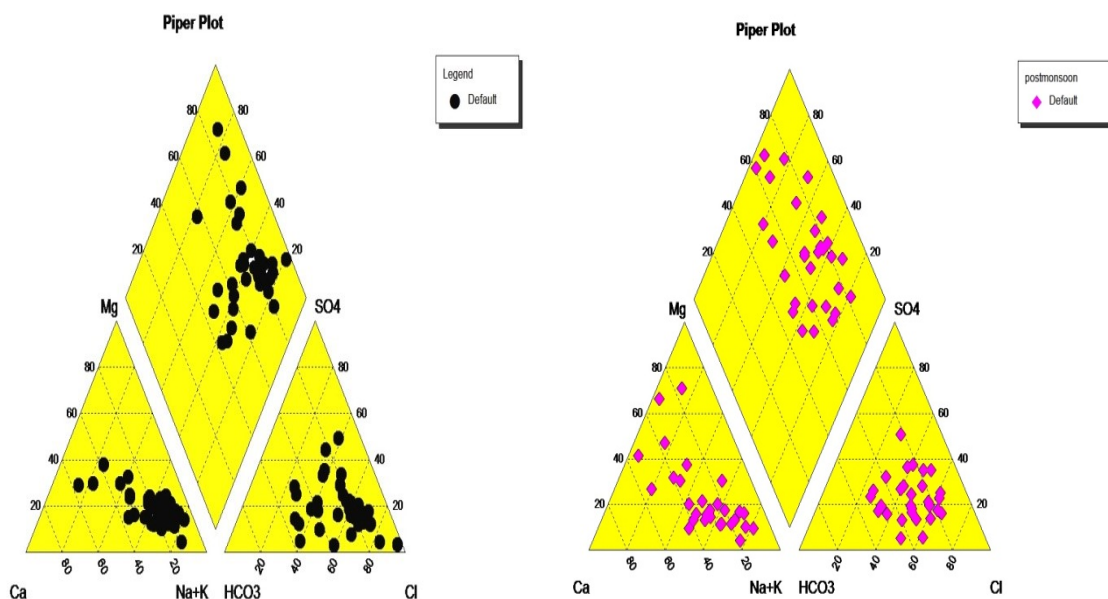

Figure 9: Shows the Pre and Post Monsoon samples Piper plot diagram

VII. CORRELATION ANALYSIS OF GROUNDWATER QUALITY

The use of the correlation coefficient is a prevalent approach in the current investigation for assessing the association between two variables. This metric serves to demonstrate the extent to which one variable may accurately anticipate the behavior of another variable. The findings indicate a substantial association between the electrical conductivity (EC) and calcium (Ca) levels in pre-monsoon groundwater samples, as observed in Table 2, with chloride (Cl) and sulfate (SO_4) levels. The analysis of Table 3, which comprises groundwater samples collected during post-monsoon, reveals a noteworthy link between the existence of Ca and Mg. Na is strongly associated with Cl, showing that evaporation and human activities impact salinization. The hydro-geochemical nature of alkalis elucidates the association between sodium (Na) and chloride (Cl) ions, with the prevalence of the latter as the dominant anion. Furthermore, a notable increase in sodium content is found in the coastal groundwater, potentially attributed to the infiltration of sewage or discharge of domestic effluents.

Table 2: Shows the correlation matrix for pre-monsoon groundwater sample

Parameters	EC	PH	TDS	Ca	Mg	HCO₃	Cl	Na	K	SO₄	NO₃	Fl
EC	1.0											
PH	-0.23	1.00										
TDS	0.57	-0.17	1.00									
Ca	-0.06	-0.40	-0.04	1.00								
Mg	0.21	-0.34	0.08	0.81	1.00							
HCO₃	0.31	-0.24	-0.08	0.34	0.49	1.00						
Cl	0.12	-0.38	0.09	0.90	0.92	0.38	1.00					
Na	0.25	0.06	-0.01	-0.08	0.27	0.30	0.21	1.00				
K	0.29	-0.38	0.28	0.36	0.50	0.59	0.45	-0.09	1.00			
SO₄	0.08	-0.42	0.09	0.84	0.80	0.43	0.85	0.03	0.62	1.00		
NO₃	0.57	-0.07	0.49	-0.05	0.19	0.25	0.04	-0.09	0.57	0.23	1.00	
Fl	-0.06	-0.07	-0.11	-0.09	-0.14	0.09	-0.02	0.03	0.18	0.07	-0.18	1.00

Table 3: Shows the correlation matrix for post monsoon groundwater sample

Parameters	EC	pH	TDS	Ca	Mg	Na	K	Cl	HCO3	Fl	SO4	NO3
EC	1.0											
PH	0.52	1.00										
TDS	0.27	0.41	1.00									
Ca	0.34	0.40	0.69	1.00								
Mg	0.28	0.31	0.71	0.55	1.00							
Na	0.17	0.24	0.67	0.38	0.51	1.00						
K	0.04	0.21	0.77	0.59	0.56	0.49	1.00					
Cl	0.19	0.24	0.78	0.53	0.66	0.94	0.65	1.00				
HCO₃	0.27	0.37	0.76	0.57	0.52	0.79	0.70	0.81	1.00			
Fl	0.22	0.73	0.27	0.34	0.16	0.17	0.05	0.09	0.30	1.00		
SO₄	-0.02	0.21	0.79	0.62	0.69	0.58	0.69	0.67	0.56	0.23	1.00	
NO₃	0.17	0.27	0.55	0.54	0.51	0.61	0.53	0.60	0.42	0.22	0.49	1.00

VIII. CONCLUSION

The present investigation observed the groundwater condition in the coastal area of Kanchipuram, Tamil Nadu, spanning from Kovalam to Mahabalipuram. The study found cation dominance in the research region: Sodium (Na) > Calcium (Ca) > Magnesium (Mg) > Potassium (K). Anions are arranged $HCO_3 > Cl > SO_4 > NO_3$. The concentration of EC was highest in the southern portion of the research region. Calcium distribution in the studied area

is mostly southern and western. The magnesium distribution map shows high amounts in the southern and northeastern research area. The regional distribution map of sulphate shows that the south has more of it than other places. Like sulphate ions, sodium ions have a high potassium (K) concentration in most sample locations. This distribution is acceptable. The high concentration may be due to fertilizer leaching. Bicarbonate is mostly found in the south, east, and northeast. Box plot illustrates key cations relative abundance: Na> Ca>Mg pre-monsoon, Ca>Na>Mg post-monsoon. A large percentage of groundwater samples are classified as C2S1, C2S2, C3S1, and C3S2 by USSL. This rating indicates groundwater irrigation in both seasons. Calcium bicarbonate (Ca-HCO$_3$) dominated groundwater. The Total Dissolved Solids (TDS) examination showed that 75% of the groundwater was fresh enough for consumption. Gibb's figure classifies most samples as rock-water interaction. This shows that rock chemical composition and underlying water infiltration occur frequently. Groundwater irrigation potential was assessed using sodium percentage, electrical conductivity, and sodium adsorption ratio. The groundwater here was drinkable and domestic. Some groundwater was unsuitable for irrigation. The correlation matrix analysis shows that EC, TDS, Ca, and Mg are positively correlated for both seasons. Additionally, most ions have a positive connection with EC. The Kovalam-Mahabalipuram groundwater quality is generally usable.

IX. ACKNOWLEDGEMENT

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