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Integrated Geophysical and Geochemical Studies of Aquifers in Vaippar Coastal Area, Thoothukudi District, Southern Tamil Nadu, India

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***Abstract*:In this present study to carried out from the coastal aquifer characteristics will be essential for freshwater and seawater research in the coastal area of Vaippar basin, southern Tamil Nadu, India. The Vaippar basin is largely seaward, although it also has a river and an estuary environment. A significant amount of fresh water is released into an ocean every time there is a significant amount of rainfall. In the current research, water outflow and saltwater intrusion during the pre-and post-monsoon seasons are analyzed. The lithology and aquifer depth of the researched region were examined in this study using the magneto telluric technique. Water samples were collected in the Vaippar river basin, Kullathur, Pallakulam, and Keelavaippar areas. Resistivity data interpretation from collected water samples yielded the coastal clay-rich alluvium coastal sand bar, shell limestone, and gneissic rock depths. Physicochemical parameters consisting of pH, Ec, TDS, cation (Na^+, $Ca^{2+,}$ Mg^{2+}, K^+), and anion (HCO_3^-, Cl^-, SO_4^{2-}) values have been used for assessment of quality using Aquachem software. For the purpose of attempting to comprehend water quality, the water types of HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, and Mg^{2+}-Cl^--- HCO_3^--, a combination of our data from the river, estuary, and beach were analyzed. The Vaippar River is a seasonal river enclosed by saltpans. The river will dry up entirely in the summer. At that time, saltpan brackish water and wastewater will be discharged into the river, polluting the well near the Vaippar River. The overexploitation of groundwater for industrial and saltpan usage is another major cause of saltwater intrusion. These findings show that groundwater extraction may increase groundwater quality issues while also providing useful options for long-term groundwater management in the coastal area.**

***Keywords*:Vaippar basin, Magneto telluric method, Aquachem, GIS, HFE-Diagram.**

I. INTRODUCTION

The world most inhabited regions are coastal regions. The coastline is home to around 70% of the world's inhabitants (Lubchenco& Haugan,2023). Freshwater demand in these areas has expanded dramatically as a result of the rapid development, expanding population, and climatic conditions (Han and Currell 2018,Bawoke and Anteneh 2020). According to (Idowu et al. 2022), the coastal aquifer characteristics study is essential for the livelihood of beach fishermen people in India, especially in southern India. The coastal aquifer and Geomorphology study were carried out using the electrical method (Udayaganesan,et al., 2002).Water quality research is essential in southern coastal areas for identifying and classifying drinking and household purposes (Selvakumar, et al.2014).According to a recent study, coastal aquifer salinization blends hydrochemical data with geoelectrical approaches to increase mapping efficacy (Selvakumar et al.2022). Aquifer salinization has resulted from increased groundwater abstraction caused by human activities along coastal zones. There are two main types of groundwater salinization: natural and anthropogenic (secondary salinization). Natural salinization is the measurement of dissolved solutes (also known as pollution). Natural salinization introduces solutes into the system by ion exchange, geogenic salt dissolution, and seawater invasion (Kouzana and Ben Mammou, 2009).The most useful application of the methods discussed in the literature is mostly based on the research of the geometric features of several physiographical goals, which includes the structure of the fresh-saline groundwater interface thickness of an aquifer, alluvial filling, gravel lenses over the bedrock, and the thickness, depth of the sand &gravel lenses in the till. Due to heavy agricultural activity, well-developed road networks, and over-exploitation of groundwater, the coastal area generally receives several issues related to maintaining groundwater quality (Post,2005). The current study is focusedand concerned with groundwater quality finding the level of seawater intrusion in the recent seawater intrusion studies carried out in the journal (Taşanet al.,2023). The mixing of seawater and freshwater aquifer zones is a coastal region. Groundwater overexploitation, climate change, sea level rise, and land use change are the major contributors to seawater intrusion in coastal aquifers (Yang et al., 2013). Groundwater level drops in coastal aquifers due to salty water moving into the freshwater zone, affecting major ions and nutrients (Martinez and Bocanegra 2002). Based on the previous studies and the present scenario a detailed study was carried out in the coastal aquifer of South Tamil Nadu, India,(Chidambaram, 2014)to understand the hydro-geochemical processes in groundwater and their effects on seawater intrusion in coastal aquifers by using geochemical and geophysical technologies. Several research on the hydrogeochemical processes of groundwater in coastal aquifers and their governing variables have been undertaken (Ziadi et al., 2019; Abboud, 2018; Selvakumar et al., 2017). The hydrodynamics and hydrogeochemical processes in coastal aquifers may be understood through multivariate statistical analyses of hydrogeochemical, environmental tracer analyses, and inverse geochemical model techniques, as per these studies. As per the present study, the analyzed and obtained data have induced a decline in water quality due to extensive groundwater abstraction for, mostly, agricultural purposes, salt pans, and a lack of knowledge about the water sources (Hassen et al. 2016). The necessity to map the land cover of the Bouficha aquifer using satellite pictures and GIS tools arose from the fact that several studies have demonstrated a positive correlation between different land use patterns and the degradation of water quality that is primarily attributable to human activities (Hua., 2017).An attempt was made to suggest and acknowledge a baseline for upcoming studies of water quality and its trends. Furthermore, there is an excess of understanding of seawater intrusion processes into the coastal aquifer system, as well as the impacts of both natural and human variables on hydrogeochemical processes in the region. In this area, hydrogeochemical research needed to take into account the relationship between aquifers and the impact of both human activity and natural processes on groundwater quality (Nam et al. 2019; An et al. 2018; Wang et al. 2018). The purpose of this research is to look into (1) to find out the aquifer zone using the geophysical technique in the magneto telluric method and (2) to identify the quality of water hydrogeochemical features of groundwater in the study area.

II. Study Area

The study area Vaippar estuary is located in the Gulf of Mannar coast of Thoothukudi. The study area geographically falls between latitudes 8°58'0" and 9°4'0" N and longitudes 78°10'0" and 78°18'0"E (Fig. 1). The Vaippar estuary region is surrounded by four coastal villages: Vaippar, Kallurani, Kulathur, and Keela Vaippar. Salt pans are present in the study areas mostly due to seawater intrusion levels. The rainy season falls in the months of November, and December. The northeast monsoon mainly causes the rainfall in the study region. The north-east trade winds direction of air from high to low in this type of monsoon wind flow from land to sea in the form of storm in the watershed of the Bay of Bengal. Most of the rain precipitation received by cyclonic storms formed due to the formation of depressions in the Bay of Bengal. The average rainfall in the study area is about 870 mm. The lithology report collected in coastal zone villages from Vaippar to Kallurani includes up to 10 km of distance covered by brown fine sand paleo beach ridge and was categorized using the GIS platform (Fig 2 and 3). In the inner part of the Vaippar River basin, black clay active tidal flats appeared in the top layer of the earth surface. The following sections discuss the overall geology and characteristics of distinct lithological units of the state and study region. The area is geologically composed of recent coastal sand, calcareous sandstone with and without shells, clay, kankar, and clayey sand along the coastal belt, and hornblende biotite gneiss in the rest of the study area. Alluvium of recent to sub-recent age is a trend all along the river courses and coastal alluvium exists in the study area coastal belt (Chandrasekar,2014). Due to the coastal and alluvial landforms, the region has a number of land uses. The majority of the land in the area is used for agriculture; the other features include sandy beaches, lake bodies, cultivation, wetlands, back wetland areas, and settlements with vegetation.

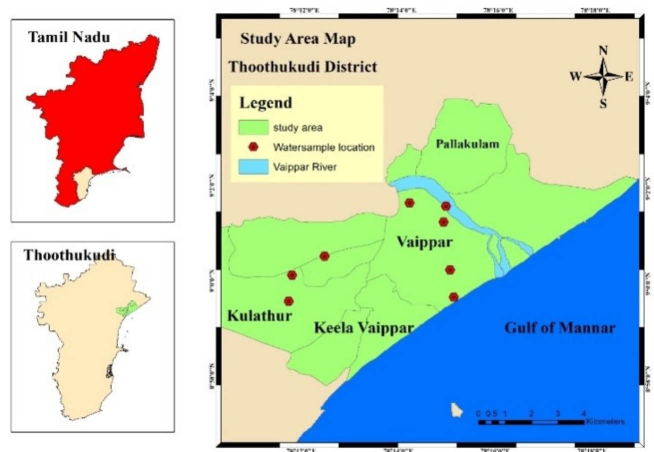

Fig.1: The study area map

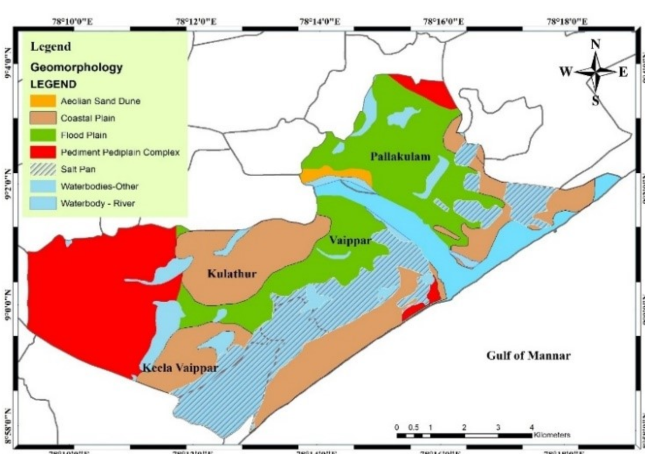

Fig.2: Geomorphology of Vaippar Basin

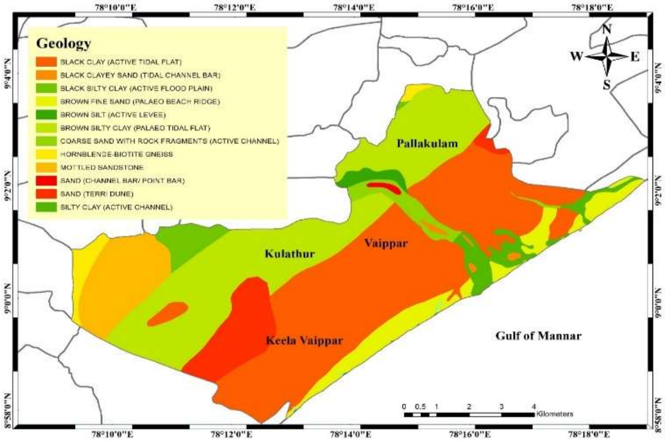

Fig.3: The soil and rock classification in the study area

III. MATERIALS& METHODS

Geophysics method identifies the subsurface geology and rocks. The magneto telluric method was used to identify the structure of the folded and disturbed zone in the study area. In the field of hydrological research, a total of 9 water samples were collected randomly in the pre and post-monsoon seasons for hydrochemical processes (Fig. 4). The basic cations and anions Na^+, $Ca^{2+,}$ Mg^{2+}, K^+ and HCO_3^-, Cl^-, SO_4^{2-} are analyzed and plotted in Aquachem software and GIS-based analysis was used to generate 2-dimension Inverse Distance Weighted interpolation (IDW) was used to generate an interpolation map for physico-chemical parameters in the pre and post-monsoon periods of the study area.The hydrochemical facies diagram is used to examine the salinization produced by seawater intrusion in the Vaippar Basin coastal area (Khan, 2021).

Fig.4 Water sample collection taken in open and bore well

IV. RESULTS & DISCUSSION

Magneto telluric method

A passive geophysical approach is developing for favour the magneto-telluric method. It can be used to image the distribution of electrical resistivity inside the Earth in a range of application sectors, from the lithosphere to the shallow subsurface. They identified and assessed the earth subsurface up to 300 metres deep using the magneto telluric approach (Vinoth Kingston 2022). The following sectors commonly use the electromagnetic telluric method, a subsurface conductivity imaging technique: solid mineral prospecting, oil and gas prospecting, and regional exploration. The electromagnetic telluric device comprises of two electrical copper rods linked to the device and two cable wires. The major purpose of our study area is to define the subsurface aquifer zone of the coastal region of Vaippar basin (Fig. 11).

Profile 1

The shallow marine deposit surface freshwater and seawater environment showed a resistivity of 0.032-0.031 ohm.m, forming hard and compact consolidation sandstone in the depth. At a freshwater distance of 60 m, a resistivity range of 0.030-0.028 ohm.m was shown, and coastal and continental upliftment was observed at a depth of 180 m (Fig. 5).

Profile 2

The resistivity of shell sediments and marine depositional sandstone was found to be 0.0332-0.0338 ohm.m. A freshwater outflow measured in Fig. 6 is delineated by a resistivity range of 60m to 65m (0.0302-0.0312 ohm.m). The resistivity range for the combined sandstone and coastal marine deposits was found to be 0.0242-0.0272 ohm.m (Fig. 6).

Profile 3

The sands, dunes, and clay deposits along the shore are observed in Profile 3. A marine coastal landform of the shallow freshwater aquifer is marked at the top of the strata at a depth of 0.038-0.036 ohm.m. At a depth of 60m, the intermediate 0.030-0.21 ohm.m was identified as a freshwater outflow zone. At 210m depth, the oceanic and continental coastline evolution of the upliftment ocean is delineated by very low resistivity ranging from 0.006-0.018 ohm.m (Fig. 7).

Water geochemistry

Different widely used geochemical maps can be obtained along with Aquachem techniques for analysis in order to graphically represent the chemical properties of data related to water quality. The Piper plan, Ludwig Langier plot, Durov plot, and Wilcox plot were all constructed using the Aquachem programme (Abishek2022). These water sample data were collected in the study region and displayed in the Vaippar basin of the coastal area.

A Piper diagram provides a graphical representation of the chemistry in water samples. Cations and anions are shown by separate ternary plots. The apexes of the cation and anion plots are represented by the cations calcium, magnesium, sodium, and potassium, and by the anions sulphate, chloride, and carbonate, as well as hydrogen carbonates anions (Fig. 8). The following are plotted in a triangular pattern: Na^+, $Ca^{2+,}$ Mg^{2+}, K^+ and HCO_3^-, Cl^-, SO_4^{2-}. Wilcox plots were used to plot salinity vs. sodium (SAR); high saline to low saline zone due to significant rainfall water quality will be the change in the study area (Fig. 9).

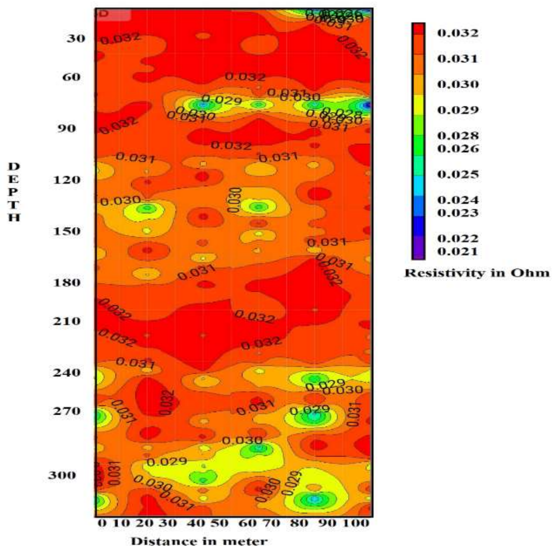

Fig.5: Magneto telluric profile a

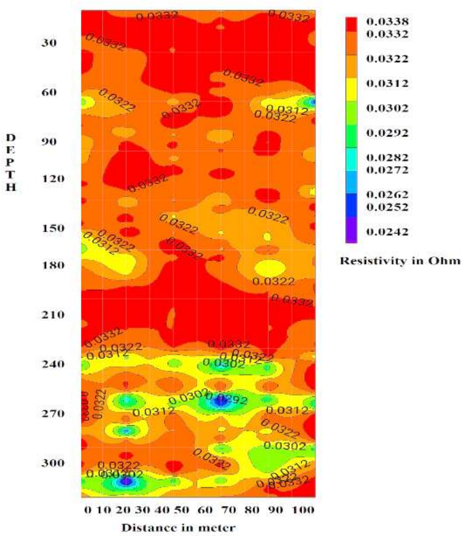

Fig.6: Magneto telluric method profile b

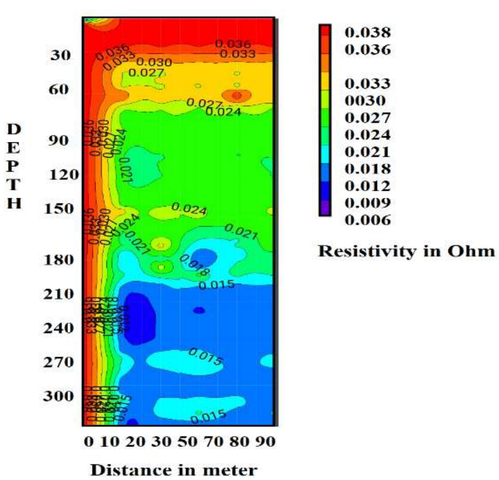

Fig.7: Magneto telluric profile c

The relative concentrations of anions and cations in mill equivalents per litter are displayed using Schoeller diagrams (Fig. 10). Many samples from different wells can be shown on a single diagram to discern comparable patterns in the ratios of particular anions and cations. Water concentrations are influenced by the chemical composition of the aquifer rock material and groundwater geochemistry. These patterns can be utilized to distinguish between common and different sources of water obtained from a variety of wells. In the pre-monsoon Schoeller plot, the values of chlorine, magnesium, and calcium are all greater than 1.0 meq/I, and five of the water samples are greater than 10.0 meq/I. When compared to the post-monsoon value, most of the water sample values are less than 10.0 meq/I, indicating that the large amount of rainwater flowing through the groundwater area causes the salinity value to be lower.

IDW analyses

IDW map interpolation using GIS; the fresh, saline water in the sample location is graphically portrayed (Govindaraj &Renganathan, 2021). The magneto telluric approach was used to scan the subsurface geology of shallow and deeper aquifers in lengths of 10m and 60m. It is an interaction research designed to identify river and coastal ecosystems that use water for home and agricultural reasons. According to Stanly (2022), the groundwater parameters' spatial distribution map created using a geographic information system (GIS) in both sessions is within a suitable range. The pH of groundwater ranges from 7.43-8.09 in the pre-monsoon period to 6.27-7.73 in the post-monsoon period (Fig. 12). The chlorine value in the pre-monsoon trials was 140-619 mg/l and 41-584 mg/l in the post-monsoon studies (Fig. 13). The pre-monsoon calcium and sodium value is 65-325 and13.3-109.9 mg/l, whereas the post-monsoon calcium and sodium value is 24-275 and 12-72 mg/l (Fig. 14 and15). In the selected study region, the total dissolved solids (TDS) content ranges from 560-2320 mg/l in the pre-monsoon to 176-2090 mg/l in the post-monsoon (Fig. 16). According to these findings, the post-monsoon has a lower sodium value than the pre-monsoon.

Hydro chemical Facies Evolution Diagram (HFE-D)

The hydrochemical facies evolution diagram (HFE-D) of river water or groundwater has been characterized by hydrochemical studies of sea and freshwater types. It is derived from water types, phases, and facies that were categorized to plot major cations and anions using HFE-D diagrams. $Mg^{2+} + SO_4^{2-}$, mixNa^+ + mix$Cl^-$and Mg^{2+}+ mixCl^- water types such as water-rock interaction and ion exchange process. Some samples are Ca^{2+}+SO_4^{2-}, mix$Mg^{2+}Cl^-$and mixNa^+ + mixCl^-in that diagram. The return of irrigation water from surface or groundwater resources has been identified as salinization along the Gulf of Mannar, which may explain the existence of a seawater intrusion from the river mouth. The HFE diagram showed that the ion exchange processes played a primary role in the dynamics of seawater intrusion/salinization of groundwater in the alluvial coastal aquifers.

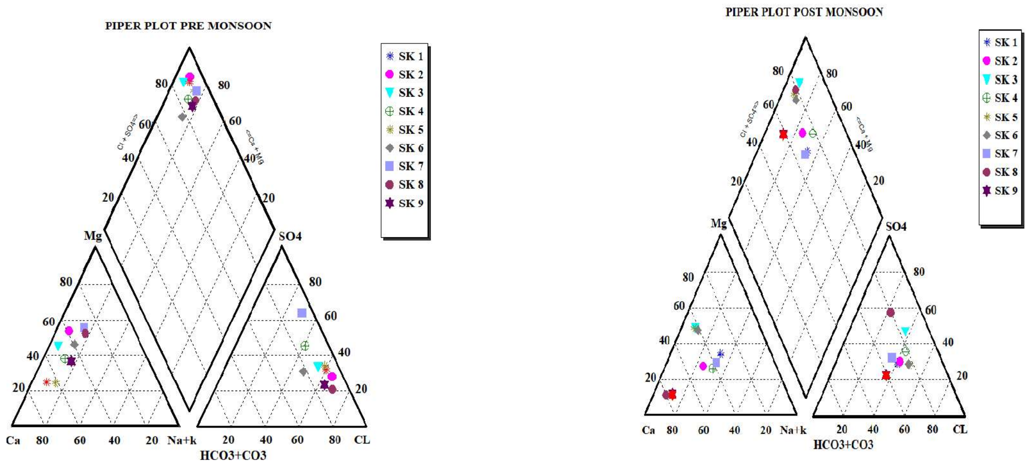

Fig.8: Piper plot pre-monsoon and post-monsoon (2020-2021)

The piper plot Ca, Mg, Na, K; HCO_3, Cl, SO_4 in the combination plotted in the triangle format.

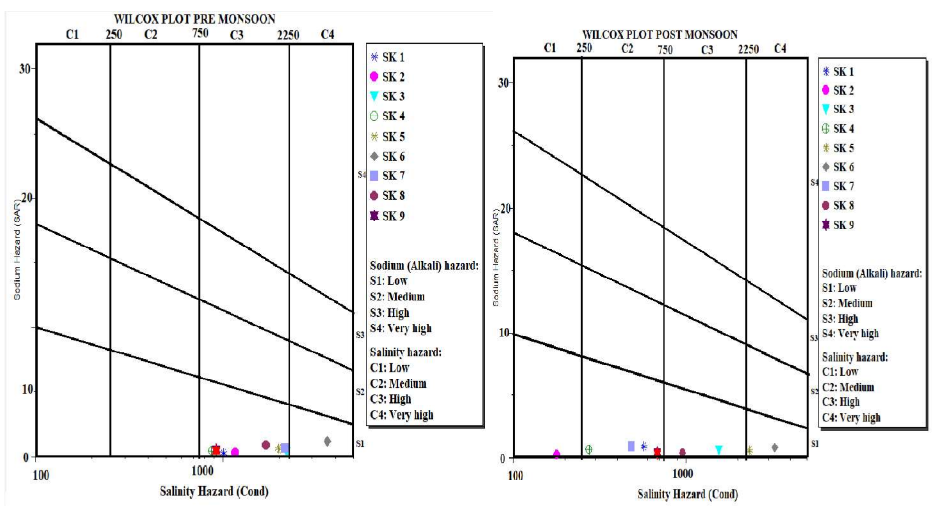

Fig.9: Wilcox plot of pre-monsoon and post-monsoon (2020-2021)

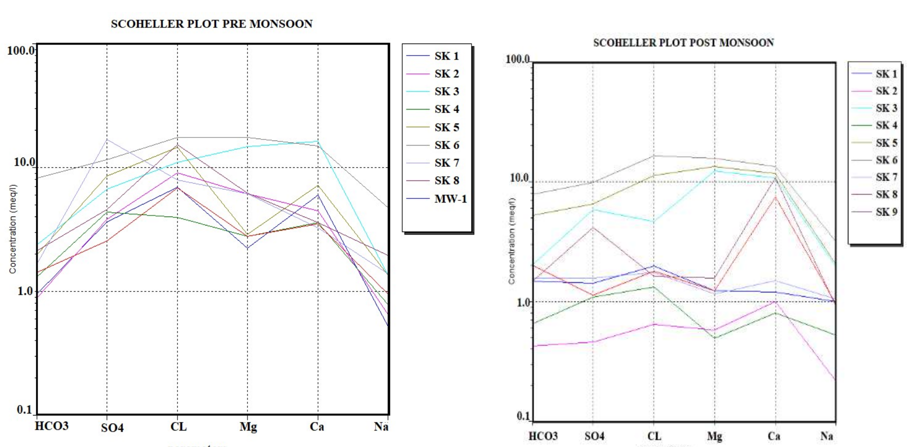

Fig.10: Schoeller plot of pre-monsoon and post-monsoon (2020-2021)

TABLE 1
Water sample location and water type

Sample ID	Latitude	Longitude	Water type
1	9.026588	78.24921	HCO_3
2	9.026588	78.24924	HCO_3-Cl-SO_4
3	9.021099	78.24846	Ca-Mg-Cl-HCO_3
4	8.99481	78.2522	Mg-Ca-SO_4-HCO_3
5	9.004375	78.25084	HCO_3-Cl
6	9.008832	78.2076	Mg-Ca-Cl-SO_4-HCl
7	9.00211	78.1965	Ca-Mg-Cl-SO_4
8	8.99296	78.1954	Mg-Ca-SO_4-HCO_3
9	9.027672	78.23668	Ca-Mg-SO_4-HCO_3

TABLE 2
Pre-monsoon water chemistry data in the study area

Sample ID	pH	EC	TDS	Na	K	Mg	Ca	Fe	Cl	SO_4	HCO_3
1	8.1	1009	718	12	9	32	130	0.01	245	180	110
2	8.1	1165	746	15	8	75	90	0.01	320	184	54
3	7.9	2195	1405	31	14	180	325	0.02	389	321	145
4	7.7	875	560	18	6	34	72	0.01	140	210	80
5	8.1	1455	1274	31	11	35	145	0.02	520	412	120
6	7.11	3626	2321	110	22	213	300	0.02	620	554	502
7	8	975	652	22	13	55	65	0.001	170	234	93
8	7.8	1703	1090	45	6	76	72	0.01	542	219	130
9	7.5	923	591	22	13	34	70	0.01	243	122	87

TABLE 3
Post-monsoon water chemistry data in the study area.

Sample ID	pH	EC	TDS	Na	K	Mg	Ca	Fe	Cl	SO_4	HCO_3
1	7.63	570	365	23	7	15	24	0.01	70	68	90
2	7.35	179	115	5	12	7	20	0.001	23	22	26
3	6.27	1550	992	45	11	150	215	0.02	165	282	124
4	7.27	275	176	12	3	6	16	0.01	47	52	40
5	7.74	2331	1492	47	10	162	235	0.02	402	315	321
6	7.11	3267	2091	73	19	190	270	0.02	585	474	480
7	7.03	484	310	24	9	14	30	0.001	62	75	96
8	7.11	956	612	21	9	19	215	0.01	58	200	90
9	7.02	682	437	22	10	15	150	0.01	64	54	122

TABLE 4
Summary of Hydro chemical Facies Evolution Diagram (HFE-D) fresh/saline intrusion Pre-monsoon and Post-monsoon results in the study area

Year 2020-2021	Pre-monsoon			Post-monsoon		
Station ID	Phase	Facies		Phase	Facies	
1	**Intrusion**	Ca^{2+}	Cl^-	**Fresh**	Mix Na^++Ca^{2+}	Mix Cl^-
2	**Intrusion**	Ca^{2+}	Cl^-	**Intrusion**	Mix Ca^{2+}	Mix Cl^-
3	**Intrusion**	Mix Ca^{2+}	Mix Cl^-	**Intrusion**	Mix Ca^{2+}	Cl^-
4	**Fresh**	Ca^{2+} +Mg^{2+}	Mix HCO_3^-	**Intrusion**	Ca^{2+} +Mg^{2+}	Mix HCO_3^-
5	**Intrusion**	Ca^{2+}	Cl^-	**Intrusion**	Mix Ca^{2+}	Mix Cl^-
6	**Intrusion**	Mix Ca^{2+}	Mix Cl^-	**Fresh**	Mix HCO_3^-	Ca^{2+} +Mg^{2+}
7	**Fresh**	Ca^{2+} +Mg^{2+}	HCO_3^-	**Fresh**	Mix HCO_3^-+ Cl^-	Mix Ca^{2+}
8	**Intrusion**	Ca^{2+}	Cl^-	**Fresh**	HCO_3^-	Ca^{2+} +Mg^{2+}
9	**Intrusion**	Mix Ca^{2+}	Mix Cl^-	**Intrusion**	Mix HCO_3^-	Ca^{2+}


Fig.11: Estuary basin of the Vaippar River

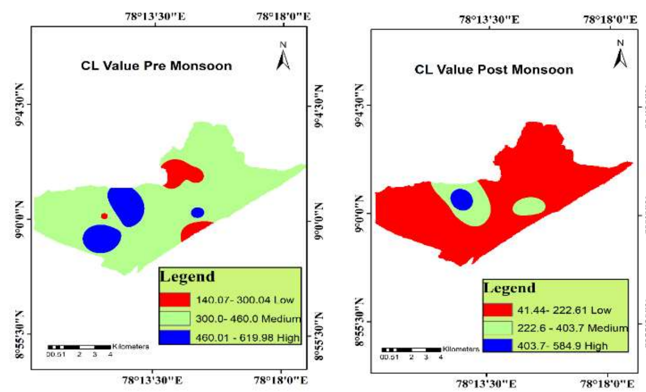

Fig.13 Spatial distribution map of Cl^- value

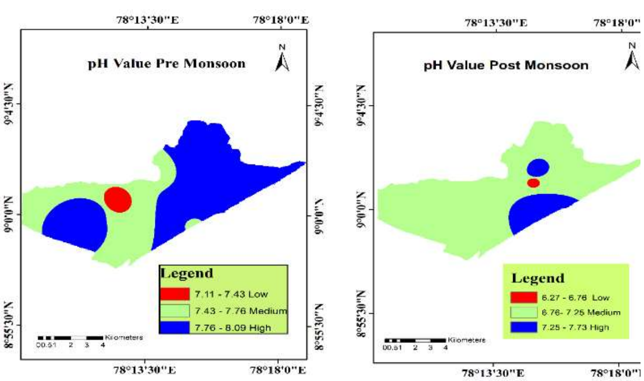

Fig.12: Spatial distribution map of pH ratio

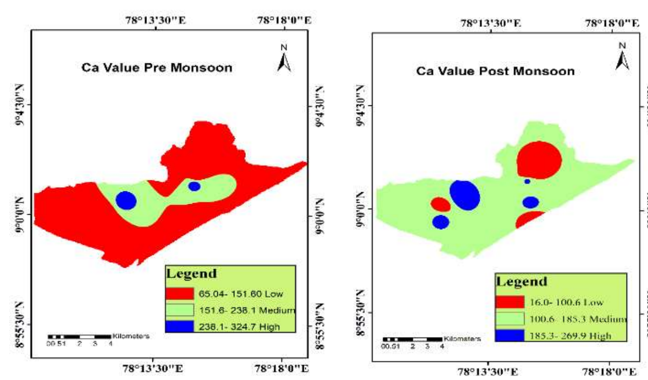

Fig.14 Spatial distribution map of Ca value

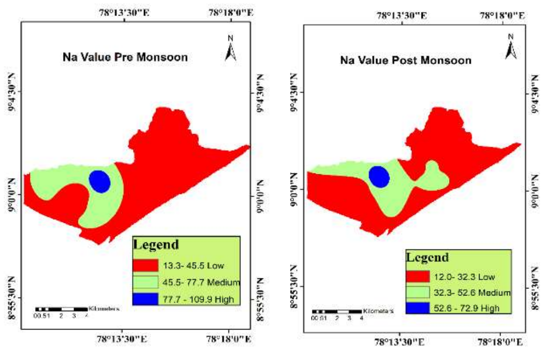

Fig.15 Spatial distribution map of Na value

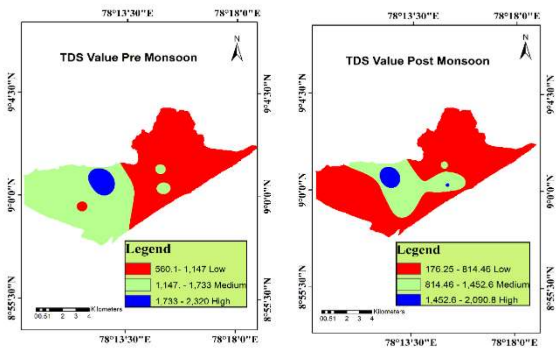

Fig.16: Spatial distribution map of TDS value

HFE diagram pre-monsoon HFE diagram post monsoon

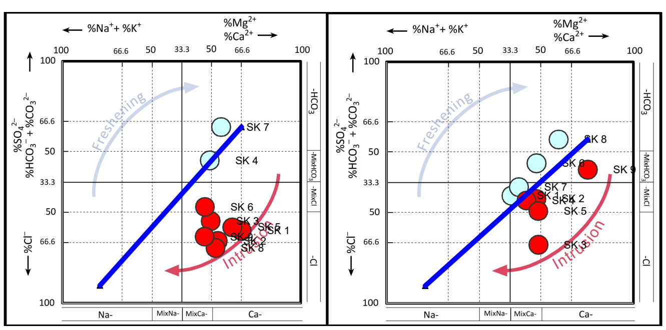

Fig.17: HFE diagram of pre-monsoon and post monsoon

V. Conclusion

The Vaippar basins indicate two environmental depositional segments, encompassing coastal and river settings. At different depths, an enormous volume of fresh water is released and mixed with the ocean. The current study focuses on the interphase quality of seawater and freshwater utilizing the magneto-telluric technique and water geochemistry. The magneto telluric approach is used to map subterranean and deeper aquifers. At a depth of 60m, the intermediate 0.030-0.21 ohm.m was identified as a freshwater outflow zone. A little amount of the precipitation that infiltrates is artificially refilled, along with irrigation and monsoon water. In the study area, the water types wereHCO_3^-, Cl^-, and Ca^{2+}- Mg^{2+}-Cl^- -SO_4^{2-}. The mixing of seawater and freshwater, as defined by the Ca^{2+} -Mg-$Cl^-HCO_3^-$, and Mg-$Ca^{2+}SO_4^{2-}$compositions, was investigated using several methodologies, including the Piper plot, Durov plot, Wilcox plot, and Ternary diagram water quality studies. The diagrams depict water types from the post- and pre-monsoon periods, such as mix Ca^{2+} + mix $Cl^-$and mix Ca^{2+} + mixSO_4^{2-}. Some of the samples contain combinations of Mg^{2+} +SO_4^{2-}, Mg^{2+} +Cl^-, and Ca^{2+} +Cl^-, as shown in the diagram. In the pre-monsoon data, two freshwater samples were identified, while four water samples were identified in the post-monsoon data. The research area presents a serious issue with seawater intrusion and anthropogenic contamination due to a lot of socioeconomic activity depends on groundwater supplies. For both shallow and deep groundwater aquifers, a long-term monitoring programme is necessary in the study area. In regards to climate change and sea level rise, these activities may degrade groundwater quality in the coastal aquifers.

VI. Acknowledgement

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