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Aquifer salinization: A groundwater appraisal of northeast coast of Odisha using water quality index (WQI) and geospatial interpretation

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ABSTRACT

Groundwater is an important source of drinking water supply in the northeast coastal tract of Odisha. Salinization of aquifer is one of the major problems in the coastal aquifers. An attempt has been made to analyze the hydro-geochemistry of groundwater and its suitability through statistical and geospatial data interpretation. A total 60 water samples are collected from coastal villages of Balasore Sadar and Remuna block of the Balasore district of Odisha during pre-monsoon period and analyzed. The water quality parameters like pH, electrical conductivity, total dissolved solid, carbonate, bicarbonate, calcium, magnesium, potassium, sulphate, chloride, fluoride was analyzed using standard analytical procedure (APHA, 2012) for determination of salinity and groundwater facies. The analytical results are compared with WHO and BIS drinking water quality standard. The hydro chemical facies of the study area are determined based on Schoeller's Plot and Langelier-Ludwig diagrams. Scholler's diagram revealed the dominance of Na^+ cation as well as Cl^- anion along the coastal tract. And dominance of Ca^{2+}, Mg^{2+} and HCO_3^- in other localities. Stiff diagrams' results are consistent with Schoeller's plot and Langelier-Ludwig diagram showing three types of groundwater. The result reveals that, Ca^{2+}- HCO_3^- type gradually changes to Na^+- Cl^- type through Ca^{2+}-Mg^{2+}- Cl^- type mixed waters, which might be an indication of change of hydrogeological conditions. The Stiff diagram shows that the water type along the coast is sodium-chloride, which suggests the intrusion of saline water into the deeper aquifer from adjacent seawater. The classification of water based on water quality index (WQI) results majority of the water samples falling under good category and suitable for drinking except samples of Rupsa, Hasanpur, Haldipada bazar, Chakulia (Baharde), Parikhi, Remunabasant market-2, Majhikia and Mala which show poor WQI. Fluoride concentrations also found in some samples above the permissible limit. Iso-concentration maps represent the spatial distribution of concentration of different parameters throughout the study area.

Key words: *Groundwater salinization, Schoeller's Plot, Langelier-Ludwig diagrams,Stiff diagrams, , Water Quality Index.*

Introduction

The growing demands of groundwater resources has subjected to more strain than ever before (Vijayanand *et al.*, 2021; Khatri *et al.*, 2020). Also, the long-term viability of water is under threat due to excess extraction of water in many parts of the world. The encroachment of seawater into coastal aquifers and excess removal of water from aquifer have caused erratic changes in groundwater quality and flow patterns. Groundwater salinization is the typical problem in unconfined coastal aquifer, when excessive groundwater pumping reduces the piezometric head (Buvaneshwari *et al.,* 2020). This results an increased quantity of salt in the root zone, which creates an osmotic impact on plants, forcing them to expend more energy to absorb water from the soil, thereby limiting their ability to develop (Shah *et al.,* 2011). Based on literature reported, the salinity in groundwater is stochastic as several parameters affect its concentration and magnitude. Those parameters include upward instruction from deep aquifers (Vengosh *et al.,* 1999), evaporation rate from soil (Rajmohan *et al.,* 2021), irrigation saline water and wastewater infiltration. Hence, understanding the actual mechanism of groundwater salinization and the affected sources is essential for water resources management and sustainability (Samsudin, 2008). The contamination of ground water in urban environment is a major issue and is complicated by a large number of potential sources of contamination (Jayaprakash *et al.,* 2008). Management of water quality requires the collection and analysis of large water quality dataset which can be difficult to evaluate and synthesize. The Water quality index tool based on aggregation function, which integrates a variety of water quality data into a single quantitative number in a very comprehensive manner (Brown *et al.,* 1970; Tyagi *et al.,* 1972). This will help water users, planners and policymakers to monitor and evaluate the water quality of sources to protect them for the benefit of social welfare, human health and economic growth.

The state of Odisha laying in the eastern part of India is mostly composed of hard rocks and coastal alluvium. It has a 480 Km long coastline against the Bay of Bengal, which is a potential zone of seawater intrusion. The coastal part is densely populated as well as sustains intense agricultural activity. As a result, contamination of the coastal aquifers by geogenic, anthropogenic and seawater intrusion is common.

Study area

The hydrological investigation has been carried out along the northeast coast of Odisha within latitude 21°04′ to 21°58′ North and longitude 86°16′ to 87°29′ East in the district of Balasore at an elevation of 600m above the MSL. The study area is spread over 786Sq. Km (Remuna block 309 Sq. Km and Balasore block for 477Sq. Km) (Fig.1). The major part of the district is underlain by tertiary and quaternary alluvium with basement Precambrian Nilgiri granites (Mahalik and Ananda, 2006) and granitic gneisses with minor pegmatite and quartz veins.

The drainage in the area is Subarnarekha, Panchpara, Budhabalanga, Jambhira, Sono River and their tributaries. Flattering of topography near by the coast, drainage congestion and tidal water ingress into rain land is quite common. The region enjoys humid subtropical climate with an average of 250mm-290mm rainfall during monsoonperiod. During pre-monsoon depth of the water level remains within 6m – 8m below ground level (BGL). In hard rock area and transition zone it may 10m below the ground level.

The study intends to address the degradation of water quality as it relates to salinization of resources and in particular the environmental degradation that occur as result of salinization processes. This can be due to combination of natural and anthropogenic processes, but these can be closely related. Salinization affects agricultural productivity and health condition of local community. Figure 1 shows the location of the study area along Northeast coast.

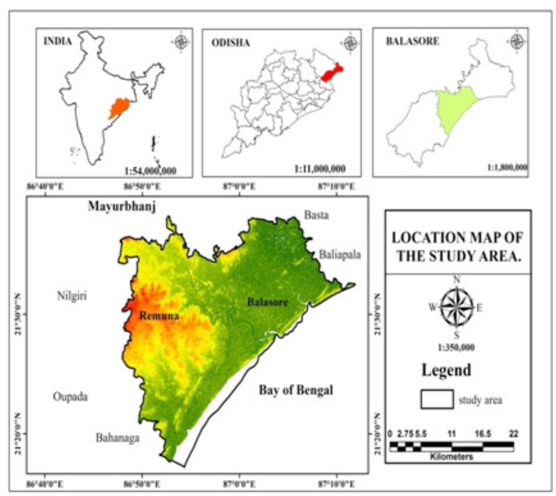

Fig. 1. Location map on the study area

Methodology

The representative ground water samples are obtained from 60 tube wells during pre-monsoon from different locations of coastal blocks (Balasoresadar block and Remuna block) (Fig. 2). The samples were analyzed for PH, EC, TDS major cation and anion by standard analytical procedure (APHA, 2012). The EC and PH are measured in spot using handheld PH and EC meter (HANNAHI-9828 USA). Ca^{2+}, HCO_3^-, Mg^{+2}, Cl^- and TDS by volumetric titration

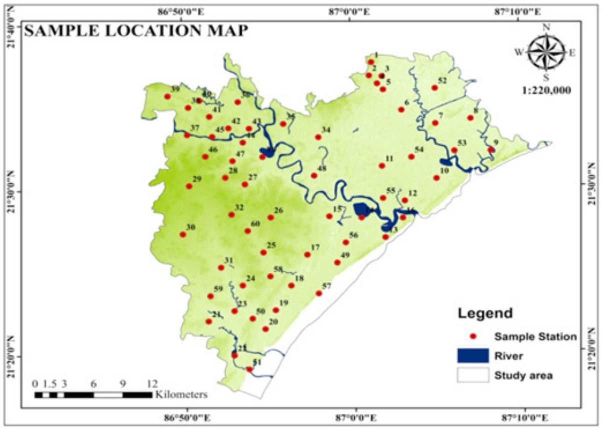

Fig. 2. Sampling Location Map of the study Area.

method. Na^+, K^+ ion is measured by flame photometer while F^- and SO^{2-} determined by spectro-photometric techniques. The ionic balance error (IBE, in percentage) was calculated to check the accuracy of the chemical analyses using Equation-1 (Subba Rao, 2017).

$$IBE = \frac{\sum TCC - \sum TCA}{\sum TCC + \sum TCA} \times 100$$

where STCC and STCA are the total concentrations of cations and anions in meq/l respectively. For all the groundwater samples, the ionic balance errors were around ±5%, conforming reasonably accuracy of analyses.

Results and Discussion

Ground Water Chemistry

Hydrogeochemical analysis is essential to reveal the chemical characteristics of water resources. Based on the reported literature, the salinity in groundwater is stochastic and this is because several parameters affect its concentration and magnitude. From deep aquifers parameters include over exploitation of groundwater from deep aquifers, irrigation of saline water, evaporation rate from soil, inland prawn farming along coast and wastewater infiltration. Hence it is essential to understand the actual mechanism of groundwater salinization and the affected sources and area for water resource management and sustainability. The salinity of the affected area analysed by measuring EC, TDS, Chloride and sodium etc.

The hydrogen ion concentration (pH) varies from 6.70 to 8.40 with an average value of 7.47 indicating mostly alkaline nature of the groundwater. The Electrical conductivity (EC) depends upon temperature, concentration and types of ions present in the water (Das *et al.*, 2011, 2015, 2016). Electrical conductivity (EC) is the measure of capacity to convey the electric current. Worth mentioning, Electrical conductivity (EC) is used to explain the salinity of water; the concentration of dissolved salts is a metric to determine the EC of groundwater. The electrical conductivity from different locations varies from 476.92 µmho/cm to 1361 µmho/cm with an average value of 772.44 µS/cm, whereas the permissible limit is 300 µmho/cm recommended by USPHS. High EC at some place indicate introduction of sewage in groundwater at these sites. The result shows that most of the samples exceeded the permissible limit of salinity, particularly along the coastal tract (Alam *et al.,* 2017). The effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water. The higher the EC, the less water is available to plant (Das, 2022). The total dissolved solids (TDS) ranges from 310 – 885 mg/l with an average value of 504.03 mg/l signifying contributions from both geogenic and non-geogenic sources (Subba Rao *et al.,* 2017). Increased shrimp farming in the agricultural land along the coast causes salinisation of soil as well as salinity of groundwater of the adjacent area (Mahmuduzzaman *et al.,* 2014; World Health Organization, 2017). Continuous use of saline water can be a great threat to human consumption and irrigation. Chief sources of Na^+ are sodic plagioclases, household wastes and irrigation-return-flows (Marghade *et al.,* 2020). The concentration of Cl^- varies from 110 – 255 mg/L with average value of 98.43 mg/l. Anthropogenic sources like domestic wastes, septic tank leakage and irrigation-return-flow could be the possible source of Cl - in groundwater (Laxman *et al.,* 2019) in addition to seawater intrusion. The spatial distribution of salinity, pH, EC,

Table 1. Suitability of ground water based on TDS classification

TDS (mg/l)	Water Class	Number of water samples (Out of 60)
< 300	Excellent	13 (21%)
300-600	Good	43(71%)
600-900	Fair	4(6%)
900-1200	Poor	0
>1200	Unacceptable	0

TDS, sodium and chloride throughout the study area are shown in the iso-concentration maps prepared using Arc GIS (Fig. 3)

To decipher the suitability of groundwater of the study area for drinking purpose, the analytical values of cations and anions are compared with recommended standard of WHO and BIS 10500 (BIS, 2015)(Das *et al*., 2012, 2013) (Table 2).

Hydrochemical facies

The hydrochemical facies of the study area are determined based on Schoeller's Plot and Langelier-Ludwig diagrams (Langelier and Ludwig, 1942). The groundwater type varies from coast towards inland. According to the dominance of ion, the water types can be broadly classified in to into three major types with an increasing concentration of Na and Cl along the coast. This suggests the intrusion of saline water in most of the coastal villages. The variation of water type can be clearly demarcated from the Stiff 's diagram plotted over the study area for a clear understanding.

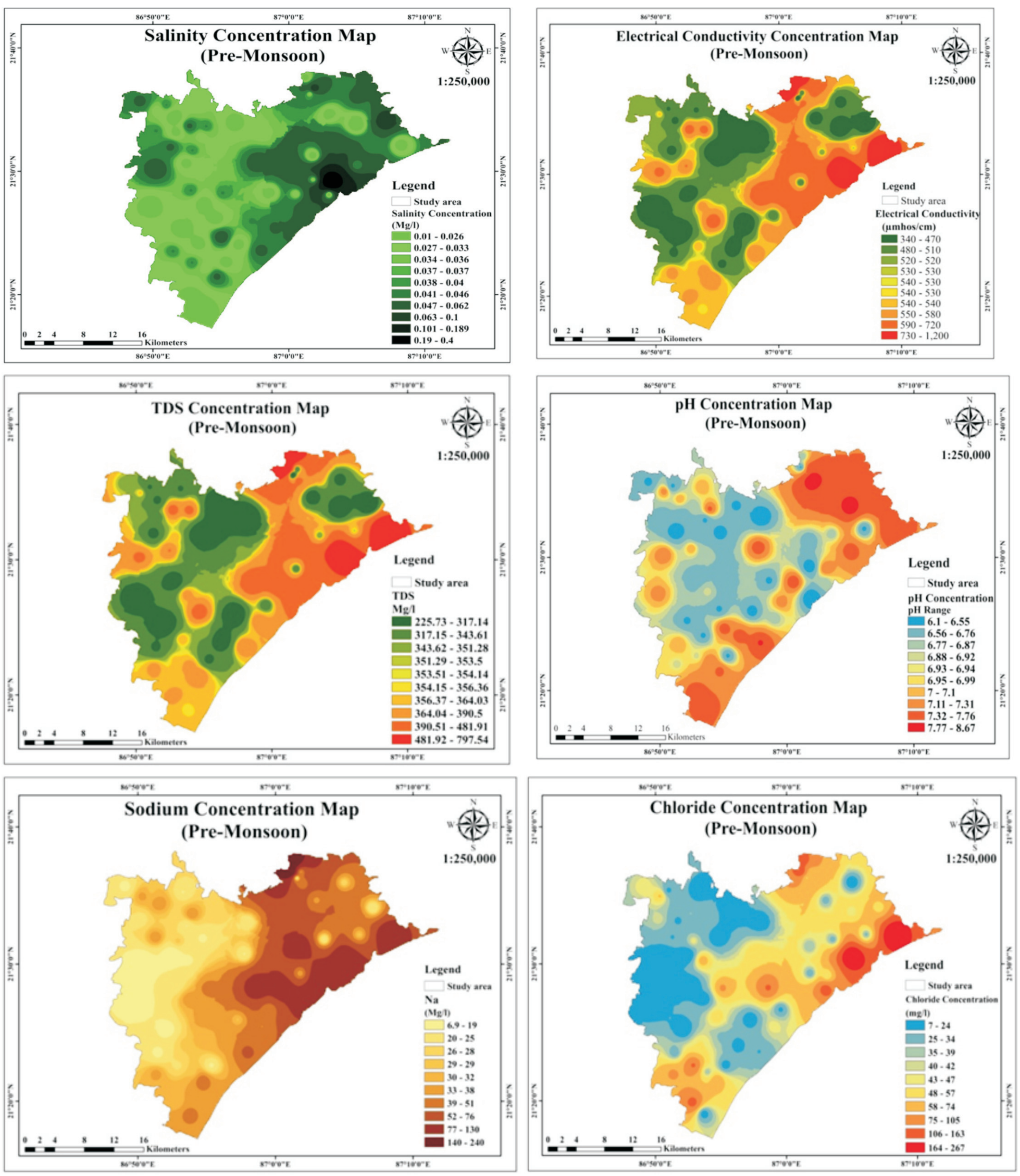

Fig. 3. Spatial distribution of Salinity, pH, EC, TDS, Sodium and Chloride

Table 2. Comparison of water quality of the study area with WHO and BIS 10500 standards

Parameter	Ranges	WHO (2004)	BIS 10500 (ISI.1995)	
			Highest desirable	Maximum desirable
pH	6.7-8.4	6.5-8.5	6.5	8.5
EC	476.92-1361.54	400-2000	-	-
TDS	310-885.00	500-1000	500	2000
Alkalinity	135.00 -315.00	-	200	600
Total Hardness	125.00-350.00	-	300	600
Calcium	30.00 -70.00	100-200	75	200
Magnesium	8.38 -51.64	30-50	30	100
Sodium	22.18-172.28	20-1756	-	-
Potassium	0.58 -14.80	10-12	-	-
Carbonate	6.00 -24.00	-	-	-
Bicarbonate	110.00- 232.00	-	200	600
Chloride	35.00 - 255.00	25-600	250	1000
Fluoride	1.04- 5.48	-	1.0	1.5
Sulphate	15.64 - 78.27	25-250	200	400
Nitrate	15.63-42.32	50	45	

Schoeller's Plot

To assess the evolution of hydrochemical parameters of the study area, major anions and cations are plotted on Scholler's diagram (Fig. 4). The diagram represents the major ion analysis of groundwater in meq/l to demonstrate varieties of hydrochemical water types (Scholler, 1967). It displays and compare the ion concentration of different samples. In this study the Scholler diagram revealed the dominance of Na cation as well as Cl anion in most of the sample locations along the coastal tract. And dominance of Ca, Mg and HCO_3 in other localities. The variation of chemical parameters indicates varied distribution of salts in groundwater. As water goes downward to the main stream, the water chemistry evolves to Na-Cl type. This suggests the saline intrusion along the coastal aquifer.

Ludwig Langelier Plot

The water samples were plotted in Langelier-Ludwig diagram (Fig. 5). In this diagram, the rectan-

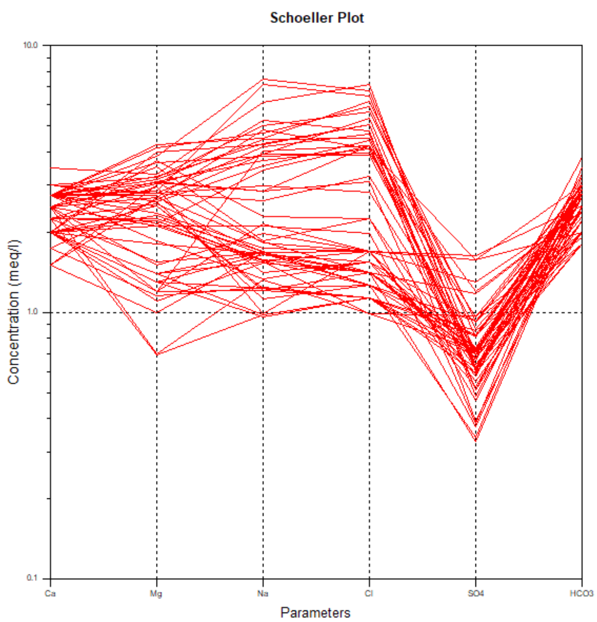

Fig. 4. Scholler's diagram

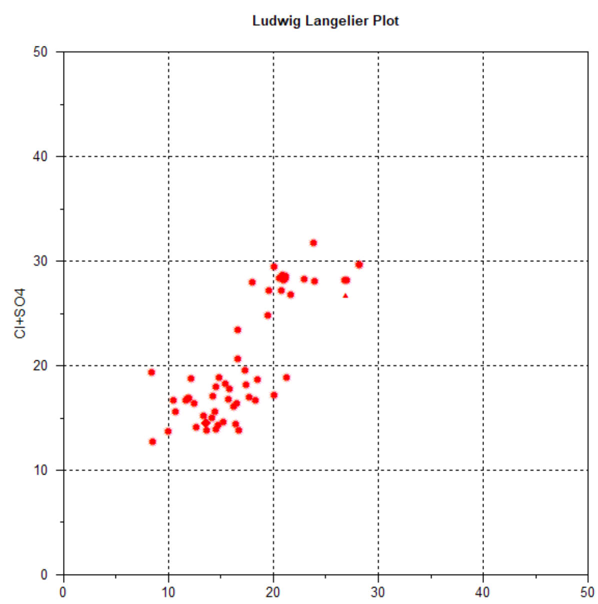

Fig. 5. Langelier-Ludwig diagram

gular coordinates are used to represent patterns and correlations between major cations and anions of samples (Langelier-Ludwig, 1942). The ion concentrations are expressed in meq/l. The alignment of the sample points into the different sectors allows the identification of possible phenomena such as mixing or evolutionary processes of water (Cantasano, 2013)

A high level of Cl^-, Na^+ and Bicarbonate ions in the groundwater samples was observed. Na^+ and K^+ were above Ca^{++} and Mg^{++} (alkaline earth elements) significantly. Thus, most groundwater samples were dominated by the combination of Sodium-chloride type and calcium -bicarbonate type. More precisely, the Langelier-Ludwig (LL) squared diagram allows the determination of what in geochemical practice is indicated as hydrochemical facies, reflecting the effects of chemical interaction with the lithotypes.

Stiff Diagram

The Stiff diagram shows a vertical axis of Sodium-Chloride, calcium-bicarbonate, and magnesium-sulphate (Fig. 6). All the points on the graph, when connected form an irregular polygon shape which can help us identify the water samples with similar quality form identical pattern (Dauda and Habib, 2015). The resulted polygonal-shaped illustrate the solute distribution in groundwater samples. Stiff

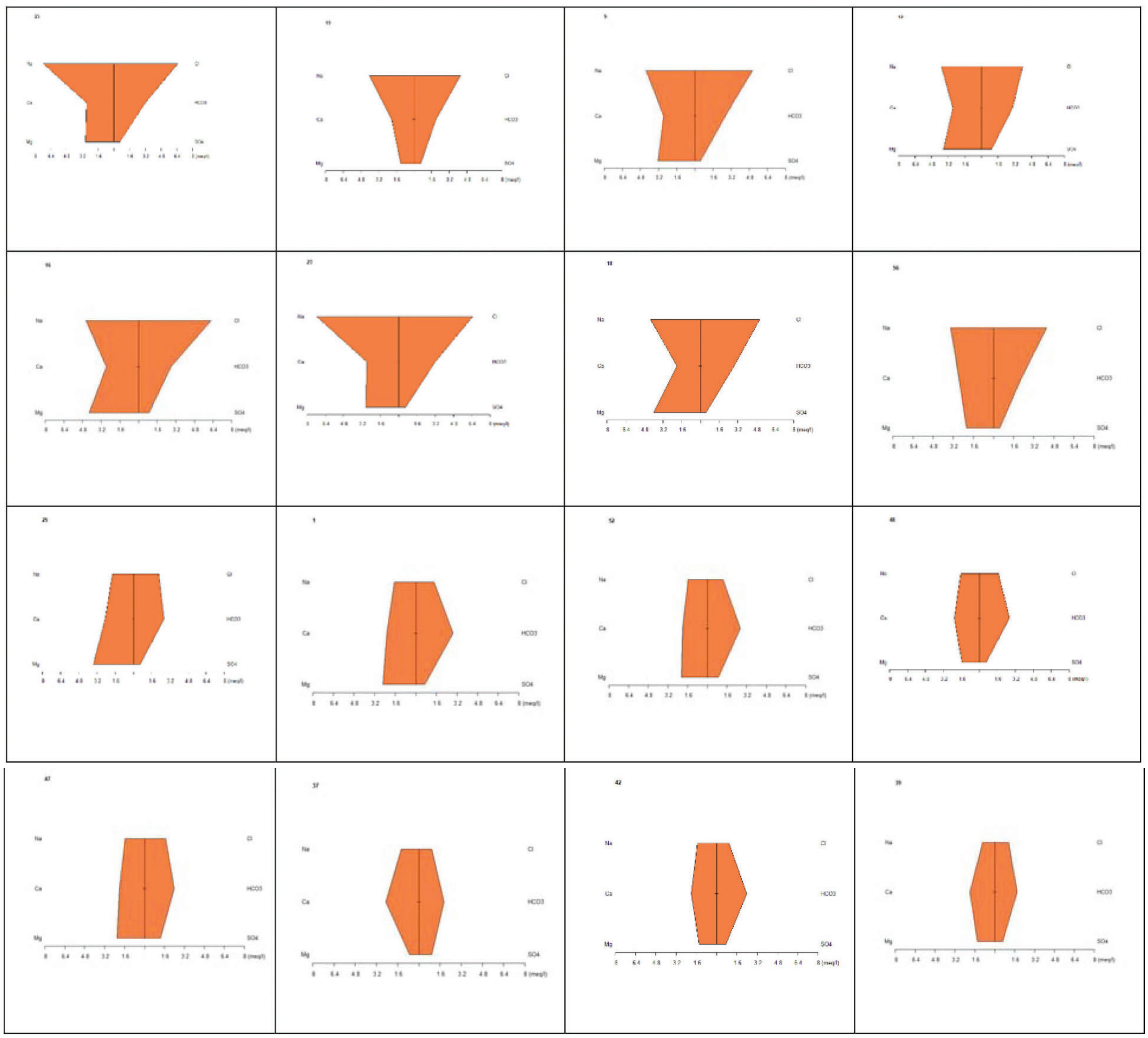

Fig. 6. Stiff diagrams showing variation of water quality

diagrams results are consistent with Schoeller's plot and Langelier-Ludwig diagram showing three types of groundwater. The Stiff diagram shows that the water type along the coast is sodium-chloride, which suggests the intrusion of saline water into the deeper aquifer from adjacent seawater. The variation in chemical parameters indicate varied distribution of salts in groundwater (Subba Rao *et al.*, 2017) throughout the study area (Fig. 7). The study area comprises of coastal transported lateritic soil and sand along the coastal margin and greyish green clay with calcareous nodules (Fig. 8). It suggests that Ca^{2+}- HCO_3^- type gradually changes to Na^+- Cl^- type through Ca^{2+}- Mg^{2+}- Cl^- type mixed waters, which might be an indication of change of hydrogeological

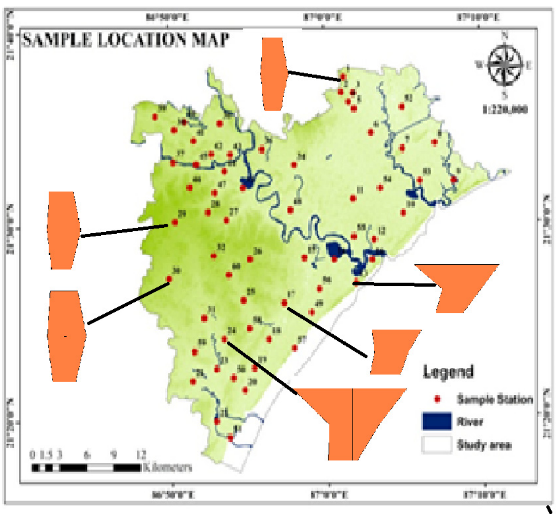

Fig. 7. Map showing variation of water quality from coast to inward

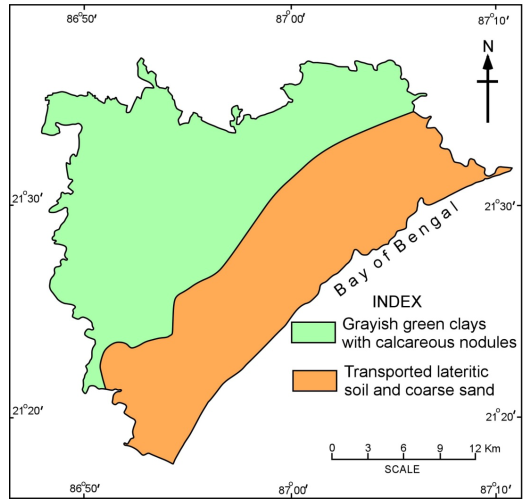

Fig. 8. Lithotype map

conditions or different processes like rock-water interaction, anthropogenic activity (Subba Rao *et al.*, 2019a) or seawater intrusion.

Water Quality Index (WQI)

The chemistry of ground water is often used as a tool for discriminating the drinking water quality. WQI, indicating the water quality in terms of an index number, offers a useful representation of the overall quality of water for public use or any intended use (Das, 2023). It is defined as a technique of rating that provides the composite influence of individual water quality parameters on the overall water quality (Mitra and ASABE Member, 1998). (World Health Organization, 2011) standards for drinking water quality have been used to calculate the WQI.

Table 3. Relative weight of water quality parameters

Parameters	BIS (2012)	Weight (wi)	Relative weight (Wi) $Wi = wi/\Sigma_{i=1}^{n} wi$
pH	6.5-8.5	3	0.071
TDS	500-2000	4	0.095
TH	200-600	3	0.071
TA	200-600	2	0.048
Ca^{2+}	75-200	3	0.071
Mg^{2+}	30-100	1	0.024
Fe	0.3	5	0.119
Cl^-	250-1000	3	0.071
F^-	1-1.5	5	0.119
NO_3^-	45	4	0.095
SO_4^{2-}	200-400	3	0.071
Mn	0.1-0.3	4	0.095
Zn	5.0-15.0	2	0.048
		Σwi = 42	Σwi = 1

WQI, indicating the water quality in terms of an index number, offers a useful representation of the overall quality of water for public use or any intended use. The index assigns a number to a body of water and its sign of quality. The Horton model of water quality index contain four standards of WQI components, i.e., parameter selection, parameter weighing, sub-index calculation and sub-index aggregation. WQI is computed as follows (Horton, 1965).

For this thirteen physico chemical parameters were taken in to consideration such as hydrogen ion concentration, electrical conductivity, total dissolved solids, total alkalinity, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, carbonate, chloride, fluoride, sulphate and nitrate.

Depending on environmental impact and relative influence in overall quality of water, each of the thirteen parameters has been assigned a weight value (wi) between 1 to 5 as presented in Table 3. The maximum weight of 5 assigned to nitrate; weight value 4 assigned to 5 parameters (hydrogen ion concentration, electrical conductivity, total hardness, sulphate and fluoride); the weight value 3 assigned to bicarbonate, chloride and sodium; 2 assigned to 4 parameters (calcium, magnesium, potassium and total dissolve solids) (Mufid, 2012).

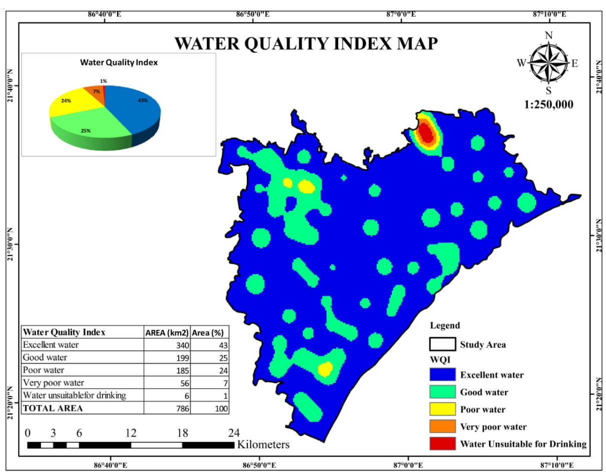

Fig. 9. Spatial distribution of Water Quality Index

The relative weight (Wi) is computed using the following weighted arithmetic index method

$Wi = Wi/\Sigma_{i=1}^{n} Wi$, where, Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters (Brown *et al.*, 1972).

A quality rating scale (Qi) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines of (APHA, 2012) and then multiplied by 100,

$Qi = \left(\frac{Ci}{Si}\right) * 100$, where, Qi is the quality rating, Ci is the concentration of chemical parameter of each water sample and Si is the drinking water standard for each chemical parameter.

The Sub-index values (SI) are determined for each chemical parameter for calculation of WQI, as per the following equation.

$SIi = Wi \times Qi$, where, SIi is the sub-index of the i^{th} parameter and Qi is the rating based on the concentration of the i^{th} parameter.

The overall Water Quality Index (WQI) is calculated by sub-index aggregation as follows:

$$WQI = \sum SIi$$

Water Quality Indices for all the sampling locations are calculated for pre-monsoon, monsoon and post-monsoon of (2015-2016) and (2016-2017). Accordingly, computed WQI values are classified into five categories. From the calculated value, the Water Quality Index of Rupsa, Hasanpur, Haldipada bazar, Chakulia (Baharde), Parikhi, Remunabasant market-2, Majhikia, Mala have WQI range more than 100 (>100). This demonstrates the poor water type (Fig. 9) represents the spatial distribution of Water Quality Index of the study area.

Conclusion

From the hydro-geochemical analysis of 60 groundwater samples, it is reveals that the groundwater in

Table 4. Water classification based on WQI and % of samples in each class

WQI range	Water type	Nos. of sample	% Of sample
<50	Excellent water	—	—
50-100	Good water	51	85
100-200	Poor water	9	15
200-300	Very poor water	—	—
>300	Water unsuitable for drinking	—	—

the study region is acidic to slightly alkaline in nature. The analytical results are compared with WHO and BIS drinking water quality standard. High percentage of chloride and EC of groundwater samples confirms saline water intrusion. The hydrochemical facies of the study area are determined based on Schoeller's Plot and Langelier-Ludwig diagrams. Scholler's diagram revealed the dominance of Na^+ cation as well as Cl^- anion along the coastal tract. And dominance of Ca^{2+}, Mg^{2+} and HCO^-_3 in other localities. Occurrence of Ca, Mg and HCO_3 indicate temporary hardness, alkalinity and alkaline earth and weak acid. About 55 water samples show high concentration of fluoride than that the recommended upper limit by WHO and BIS. Stiff diagrams' results are consistent with Schoeller's plot and Langelier-Ludwig diagram showing three types of groundwater. The result reveals that,change of groundwater types from Ca-HCO_3 (fresh water) ® Ca-Mg-Cl ® Na-Cl (saline water) (Figs. 5 and 6) as well as increase of TDS in seaward direction indicates the effect of seawater intrusion in the study area. excess of Na/Cl ratio over seawater (0.88) in 41 out of 60 cases, further supports seawater intrusion in study area (Rajendiran *et al.*, 2021). The Stiff diagram also shows that the water type along the coast is sodium-chloride, which suggests the intrusion of saline water into the deeper aquifer from adjacent seawater. The classification of water based on water quality index (WQI) results majority of the water samples falling under good category and suitable for drinking except samples of Rupsa, Hasanpur, Haldipada bazar, Chakulia (Baharde), Parikhi, Remunabasant market-2, Majhikia and Mala which show poor WQI. From the water quality classification majority of the samples are falling under good water category except few are under poor condition due to pollution activities from the industries and population growth. Therefore, periodic monitoring, rainwater harvesting and artificial recharge of groundwater should be undertaken by government and non-government agencies for the improvement of water quality.

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