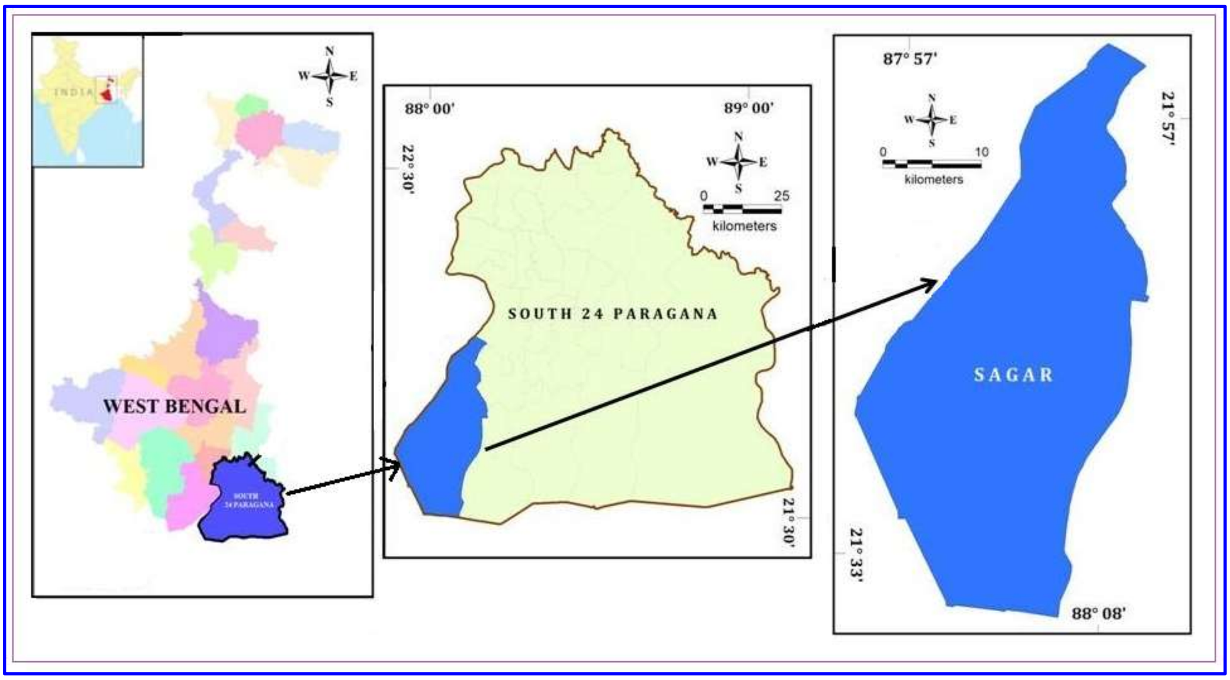

SEA WATER INTRUSION IN COASTAL AREA OF THE SUNDARBANS: A STUDY IN AND AROUND GANGA SAGAR ISLANDS, WEST BENGAL

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CONTENTS

Executive Summary

This study examines the critical problem of sea water intrusion (SWI) in the coastal aquifers of Sagar Island, the largest island of the Indian Sundarbans. The region faces major environmental challenges, including coastal erosion, salinity intrusion and groundwater overexploitation due to population growth and climate change. It shows the interplay between natural processes and human activities that exacerbate groundwater salinization. The report evaluates the hydrochemical properties, assesses the risks of Saline Water Intrusion (SWI) and examines the suitability of the groundwater for drinking and irrigation purposes.

The study area, Sagar Island, covers the southern part of South 24 Parganas district in West Bengal and comprises an area with a flat topography and Quaternary alluvial sediments. The hydrogeological setting of the study area reveals three aquifer systems: Aquifer-I (4–41 mbgl) is localized and saline, Aquifer-II (55–185 mbgl) is brackish to saline, and Aquifer-III (200–320 mbgl) is a confined freshwater aquifer isolated by thick clay layers. Freshwater is found only below 200 mbgl, overlain by saline aquifers, with piezometric levels ranging from 3.10 to 5.78 mbgl seasonally.

Using advanced hydrochemical methods such as Piper and Durov diagrams, Gibbs plots and ion ratio analyzes, the study shows that deeper aquifers (Aquifer III) have a sodium-bicarbonate facies ($Na\text{-}HCO_3$), indicating minimal seawater influence, while the surface waters, especially near the intertidal zones, show a sodium-chloride (Na-Cl) dominance, suggesting saltwater intrusion during high tides or natural calamities. Ionic ratios (Mg^{2+}/Ca^{2+} <1 and Na^+/Cl^- >1) further confirm freshwater dominance in deeper aquifers. The mixing rate (R_{mix}) ranges from 0.019% to 3.98%, classified as low risk for SWI.

For drinking water suitability, groundwater pH ranges from neutral to alkaline (7.91–8.97), with sporadic exceedance of BIS limits (8.5). Total dissolved solids (TDS) exceed desirable limits (500 mg/L) in 95% of samples but remain below permissible thresholds (2000 mg/L). without exceeding the permissible limits. Mostly major ions are within safe limits, for important parameters such as chloride, nitrate, sulfate, fluoride or heavy metals such as arsenic and iron according to the 2012 BIS standards. Surface waters, especially saline ones, have significantly higher TDS and EC values, making them unsuitable for drinking without treatment.

In terms of suitability for irrigation, the study uses indices such as sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP) and residual sodium carbonate (RSC), in addition to USSL and Wilcox diagrams, to classify groundwater as acceptable to doubtful for irrigation. With EC values predominantly in the C3 category (750–2250 µS/cm) and high levels of sodium, long-term use of this groundwater could affect soil permeability and crop yields, indicating the need for alternative water sources such as rainwater harvesting or surface water management.

In conclusion, deep aquifers (Aquifer-III) remain unaffected by seawater intrusion, but surface water salinization is evident due to tidal influence. Groundwater is generally safe for

drinking, though TDS and pH require monitoring. For agriculture, high sodium and salinity levels necessitate alternative water management strategies, such as rainwater harvesting and the use of salt-tolerant crops.

The study recommends strengthening of ongoing groundwater monitoring network, promoting sustainable water use practices, and conducting further research on climate change impacts. This study provides critical insights for policymakers to mitigate salinity threats and ensure water security in the ecologically sensitive Sundarbans region.

1.0 GENERAL INTRODUCTION

1.1 Introduction

Groundwater studies have been conducted worldwide with regard to several concerns, including climate change, seawater intrusion, and water overexploitation. Generally, coastal aquifers exhibit over-abstraction of groundwater to face the demand of various human activities such as agricultural and urban activities. Particularly, population and economic growth contribute to a more intensive use of land and a greater pressure on natural resources and ecosystems. This in turn increases the potential threat to the quantity and quality of groundwater [Faye et al, 2004; Nejib et al 2017].

Coastal aquifers are subject to the inflow of seawater, which represents the main limitation for groundwater uses [Wen et al, 2020; Radhapyari et al, 2021]. Saltwater intrusion can be considered a very serious hazard to coastal areas that threatens fresh water supplies needed for livelihood [Vahidipour et al, 2021]. It is plausible to point out that a partial intrusion of seawater into coastal aquifers can take place naturally. Despite the natural processes like tidal waves and tsunami also cause sweater intrusion in the shallow and deep coastal aquifers. For unconfined aquifers, the groundwater extraction rate accelerates SWI, leading to an increase in aquifers' salinization [Singh et al, 2020]. Whereas, for confined aquifers salinization is unlikely due to the isolation facilitated by impermeable geological formation. However, the critical component involving the hydro-chemical investigation of the aquifers remained missing in both the shallow and deep aquifers. It depends on the geological conditions of the reservoirs and the variations in sea level due to global climate changes [Foster et al, 2016]. In this case, the amplification of the phenomenon may be caused by the excessive use of freshwater [Dörfliger et al, 2013]. Overcoming this hazard is a major challenge for groundwater management and sustainability.

The present study focuses on the groundwater issues of Sundarbans, the only mangrove forest of the globe, which is presently under threat of severe coastal erosion due to relative sea level rise. Environmental degradation caused by severe cyclones, sea level rise, coastal salinity increases and storm surge followed by coastal erosion, flood and earthquake are common in the Sundarban area. Islands in the Sundarban are losing their areas over the years due to coastal erosion and accretion problem. Wide scale reclamation, deforestation and unsustainable resource exploitation practices have together produced changes in the physical and biological dynamics of the coastal system.

This study is an attempt to show the relationship between hydrochemical variations and the pattern of seawater intrusion. For that purpose, this study uses concepts from the recently published Indices, assessment of Mixing rate, correlation between constituents, facies analysis and interpretation of Ionic ratios. Its results are quantified and translated to map format using a Geographical Information System (GIS). Along with the seawater intrusion assessment, the present report brings about the information concerning ground water quality in terms of suitability of its use for domestic and agricultural field.

1.2 Study area

Indian Sundarban covers an area of 9629 sq. km and is consisting of 102 islands of which 54 are inhabited (4493 sq.km.). In sundarban, groundwater occurs within 160 mbgl are brackish to saline in nature, whereas fresh potential aquifer exists within 250 to 400 mbgl depth.

The Sagar Island forms part of the Ganges delta and is the largest island of Indian Sundarban (Fig.1). The island is located in the southern part of South 24 Parganas district in West Bengal state and lying between 21°36' to 21°56' North Lattitude and 88°02' to 88°11' East longitude. It receives annual rainfall to the tune of 1900 mm.

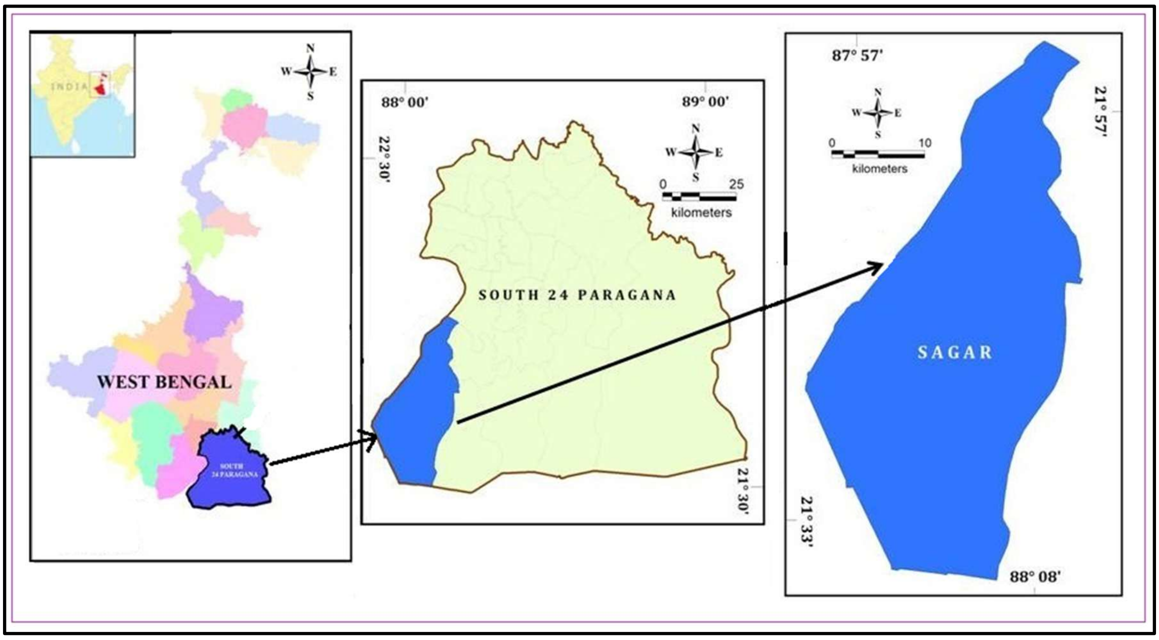

FIGURE 1: MAP OF THE STUDY AREA, SAGAR ISLAND, WEST BENGAL

1.3 Hydrogeological Information

Sagar island is underlain by the recent alluvium comprising of sand, silt and clay deposited by Ganga River. Groundwater exploration indicates that fresh water bearing aquifers are occurring in confined condition within the depth range of 205 to 325 m bgl and is overlain by saline aquifers. The fresh and saline aquifers can be separated by 20-25 m thick impervious clay layers.

Piezometric level varies from 3.58 to 5.78 m bgl and 3.10 to 5.09 during pre-monsoon and post-monsoon periods respectively. As the top aquifers within 160 m bgl depth are saline, island is suffering from salinity hazards in groundwater. Following table shows brief Aquifer characteristics of the study area.

TABLE 1: AQUIFER CHARACTERISTICS OF STUDY AREA

Physiography	Flat topography with mean elevation of 4 m above mean sea level.
Geology	Quaternary alluvial sediments
Major Aquifers	Younger Alluvium
Aquifer Disposition: Three Aquifer Systems	**Aquifer–I** : 4 - 41 mbgl, occurence is localized & not regional
	Aquifer–II : 55 – 185 mbgl
	Aquifer–III : 200 - 320 mbgl

Geological Map along with Aquifer Disposition details of study area is shown in fig. 02.

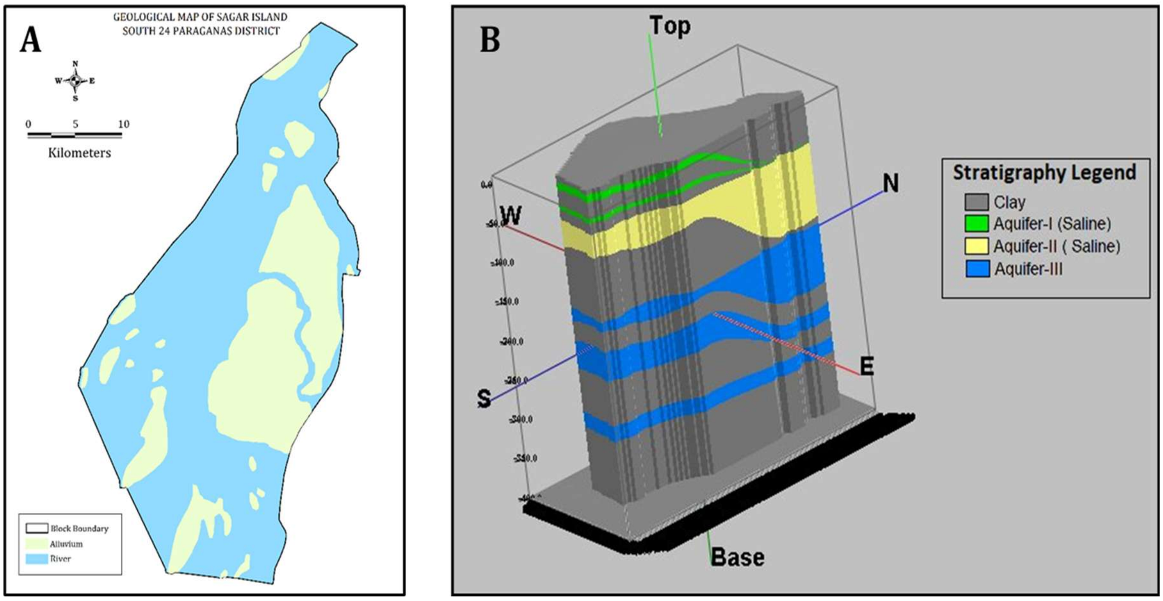

FIGURE 2: GEOLOGICAL MAP OF SAGAR ISLAND. B. AQUIFER DISPOSITION

The surface Geophysical investigation was carried out at Kachuberia area, Bamankhali area, Krishnanagar area, Rudranagar area & Ganga Sagar area of Sagar Island, South 24 parganas District, West Bengal. The attributes of geophysical study on the basis of interpreted values of VES (Vertical Electrical Sounding) data and borehole electrical logging data have been presented in Table: 02. Total depth of investigation was considered 300.00 mbgl. in all locations. From the geophysical study it is concluded that clay & brackish water formation have been identified down to the depth of i) 75.00 mbgl at Kachuberia area, ii) 123.00 mbgl. at Bamankhali area, iii) 173.00 mbgl. at Krishnanagar area, iv) 152.00 mbgl. at Rudranagar area & v) 167.00 mbgl at Ganaga Sagar area. Below that fresh water formation has been identified with intercalation of clay horizons down to the depth of 300.00 mbgl except Kachuberia area, where deeper brackish water formation starts below the depth of 280.00 mbgl. Even though top aquifer is having potential groundwater bearing zones, on account of high salinity it is not being explored and is not used for drinking as well as irrigation.

TABLE 2: INTERPRETED RESULTS OF VES DATA OF SAGAR ISLAND

Location	Co-ordinates	Resistivity in ohm-m					Thickness in metre				Lithology
		P1	P2	P3	P4	P5	H1	H2	H3	H4	
Kachuberia	21.8407N, 88.1389E	1.7	1.1	6.5	25.5	3.8	3.9	56.1	15.0	205.0	0.00-75.00 mbgl. brackish formation, below fresh formation down to 280.0 mbgl. Again brackish formation starts.
Bamankhali	21.8246N, 88.1249E	1.5	1.0	7.4	38.0	--	3.5	97.5	22.0	---	0.00-123.00 mbgl. brackish formation, below fresh formation.
Krishnanagar	21.7776N, 88.0926E	1.1	0.9	6.8	35.0	--	3.3	138.7	31.0	----	0.00-173.00 mbgl. brackish formation, below fresh formation.

Location	Co-ordinates	Resistivity in ohm-m					Thickness in metre				Lithology
		P1	P2	P3	P4	P5	H1	H2	H3	H4	
Rudranagar	21.7444N, 88.1036E	2.2	1.3	7.5	42.0	--	4.1	120.9	27.0	----	0.00-152.00 mbgl. brackish formation, below fresh formation.
Ganga Sagar	21.6460N, 88.0723E	2.1	1.2	7.4	41.5	--	3.9	135.6	27.5	----	0.00-167.00 mbgl. brackish formation, below fresh formation.

1.4 Methodology

1.4.1 Sampling & Physicochemical analysis

Groundwater samples were collected from twenty-two (22) representative tube wells during pre-monsoon periods located more or less uniformly throughout the island. In addition, seven (07) samples were also collected from Ponds and Cannels situated at the Island and four (04) samples were collected from Sea Rivers and Creeks surrounding the Island. Before sampling the sample bottles were soaked in 1:1 dilute hydrochloric acid for one day and then washed 2 or 3 times with distilled water. The bottles were also rinsed three times with the water samples before collection. The collected samples were brought to the lab and chemical analyses were carried out. After that EC and pH were measured using portable meter. Then the water samples were filtered using 0.45 µm millipore filter paper before commencing the geochemical analysis. Groundwater level was measured using steel measuring tape. Blanks and standards were running simultaneously for maintaining the accuracy during analysis. EC, pH and temperatures were measured, while collecting the groundwater samples. The list of sample location has been presented as Table 03 and the map of Study area is presented in fig. 03. None of the abstraction structure tapping the saline Aquifer I and II has been identified at the study area. Hence all the ground water samples collected are from comparatively Fresh and Deeper Aquifer III. These samples are originated from Aquifer more than 200 meter deep.

In general, sodium and chloride are the dominant ions of seawater/saline water, while calcium and bicarbonate are commonly the major ions of fresh water [Chadha, 1999]. Therefore, high levels of Na and Cl ions in coastal groundwater may indicate a significant effect of seawater mixing and the occurrence of saline water [Mondal et al. 2010], while considerable amounts of HCO_3 and Ca indicates the contribution of the water–rock interaction. In this context, the Chadha's diagram [Chadha, 1999] is obtained by plotting (Ca + Mg) − (Na + K) vs. HCO_3 − (SO_4 + Cl), which allows to identify the origin of salinization in groundwater. The obtained plot is divided into four fields [Hajji et al, 2022, Chidambaram et al 2018]:

I. Recharge water,
II. Reverse ion exchange water,
III. Seawater effect, and
IV. Base ion exchange water.

TABLE 3: SAMPLE LOCATION OF GANGA SAGAR ISLAND

S. No.	Sample Code	District	Block	Location	Source	Type of sample	Latitude	Longitude	Well Depth in mtrs.
1	FSW-01	S24 Parganas	Sagar	Kochuberia, School	Pond	Fresh Surface Water	21.86608	88.14850	-
2	FSW-02	S24 Parganas	Sagar	Mandirtala	Pond	Fresh Surface Water	21.82056	88.09987	-
3	FSW-03	S24 Parganas	Sagar	Krishnanagar Tankpar	Pond	Fresh Surface Water	21.77565	88.09319	-
4	FSW-04	S24 Parganas	Sagar	Chakphuldubi	Pond	Fresh Surface Water	21.79122	88.10581	-
5	FSW-05	S24 Parganas	Sagar	Rudranagar BDO Office	Pond	Fresh Surface Water	21.73080	88.10499	-
6	FSW-06	S24 Parganas	Sagar	Purshottampur	Pond	Fresh Surface Water	21.67563	88.11341	-
7	SSW-01	S24 Parganas	Sagar	Purshottampur	Canal	Saline Surface Water	21.66812	88.10499	-
8	SSW-02	S24 Parganas	Sagar	Kochuberia LCT Jetty	River	Saline Surface Water	21.83812	88.13342	-
9	SSW-03	S24 Parganas	Sagar	Chemaguri	Creek	Saline Surface Water	21.68511	88.12511	-
10	SSW-04	S24 Parganas	Sagar	Gangasagar, Sea	Sea	Saline Surface Water	21.63304	88.07461	-
11	SSW-05	S24 Parganas	Sagar	Kamalpur	Canal	Saline Surface Water	21.72518	88.12666	-
12	GW-01	S24 Parganas	Sagar	Kochuberia, PHED	GW/WS	Groundwater	21.85975	88.14191	314.15
13	GW-02	S24 Parganas	Sagar	Pakhirala, ICDS	HP/TW	Groundwater	21.83812	88.13342	210.29
14	GW-03	S24 Parganas	Sagar	Pakhirala, PHED	GW/WS	Groundwater	21.84266	88.13306	261.25
15	GW-04	S24 Parganas	Sagar	Patharpratima	HP/TW	Groundwater	21.82635	88.15499	251.78
16	GW-05	S24 Parganas	Sagar	Mandirtala, PHED	GW/WS	Groundwater	21.80793	88.10529	272.30
17	GW-06	S24 Parganas	Sagar	Naraharipur PHED	GW/WS	Groundwater	21.75303	88.09336	236.89
18	GW-07	S24 Parganas	Sagar	Sagar College	HP/TW	Groundwater	21.75295	88.09340	268.01
19	GW-08	S24 Parganas	Sagar	Kamalpur PHED	GW/WS	Groundwater	21.71577	88.10725	283.73
20	GW-09	S24 Parganas	Sagar	Rudranagar PHED	GW/WS	Groundwater	21.73081	88.10499	274.93
21	GW-10	S24 Parganas	Sagar	Manasadwip PHED	GW/WS	Groundwater	21.69690	88.11499	279.0
22	GW-11	S24 Parganas	Sagar	Chemaguri, PHED	GW/WS	Groundwater	21.67729	88.12504	257.0
23	GW-12	S24 Parganas	Sagar	Gangasagar Beguakhali	GW/WS	Groundwater	21.67732	88.05907	210.16
24	GW-13	S24 Parganas	Sagar	Gangasagar, PHED	Mark-II	Groundwater	21.66248	88.08019	215.32
25	GW-14	S24 Parganas	Sagar	Rudranagar,Pri. Sch.	HP/TW	Groundwater	21.73674	88.10542	220.18
26	GW-15	S24 Parganas	Sagar	Radhakrishnapur	HP/TW	Groundwater	21.71813	88.08101	277.75
27	GW-16	S24 Parganas	Sagar	Radhakrishnapur Mayagoalini Ghat	HP/TW	Groundwater	21.72724	88.06405	284.15
28	GW-17	S24 Parganas	Sagar	Adhikarichak	HP/TW	Groundwater	21.72617	88.09494	220.46
29	GW-18	S24 Parganas	Sagar	Khasramkarchar PHED	GW/WS	Groundwater	21.76085	88.11610	260.39
30	GW-19	S24 Parganas	Sagar	Rudranagar, Agri. Farm	HP/TW	Groundwater	21.72718	88.10671	210.85
31	GW-20	S24 Parganas	Sagar	Gangasagar, Light	HP/TW	Groundwater	21.63670	88.07987	200.96

S. No.	Sample Code	District	Block	Location	Source	Type of sample	Latitude	Longitude	Well Depth in mtrs.
				House					
32	GW-21	S24 Parganas	Sagar	Gangasagar	Mark-II	Groundwater	21.63503	88.07536	208.74
33	GW-22	S24 Parganas	Sagar	Gangasagar, PHED	GW/WS	Groundwater	21.63680	88.07520	215.18

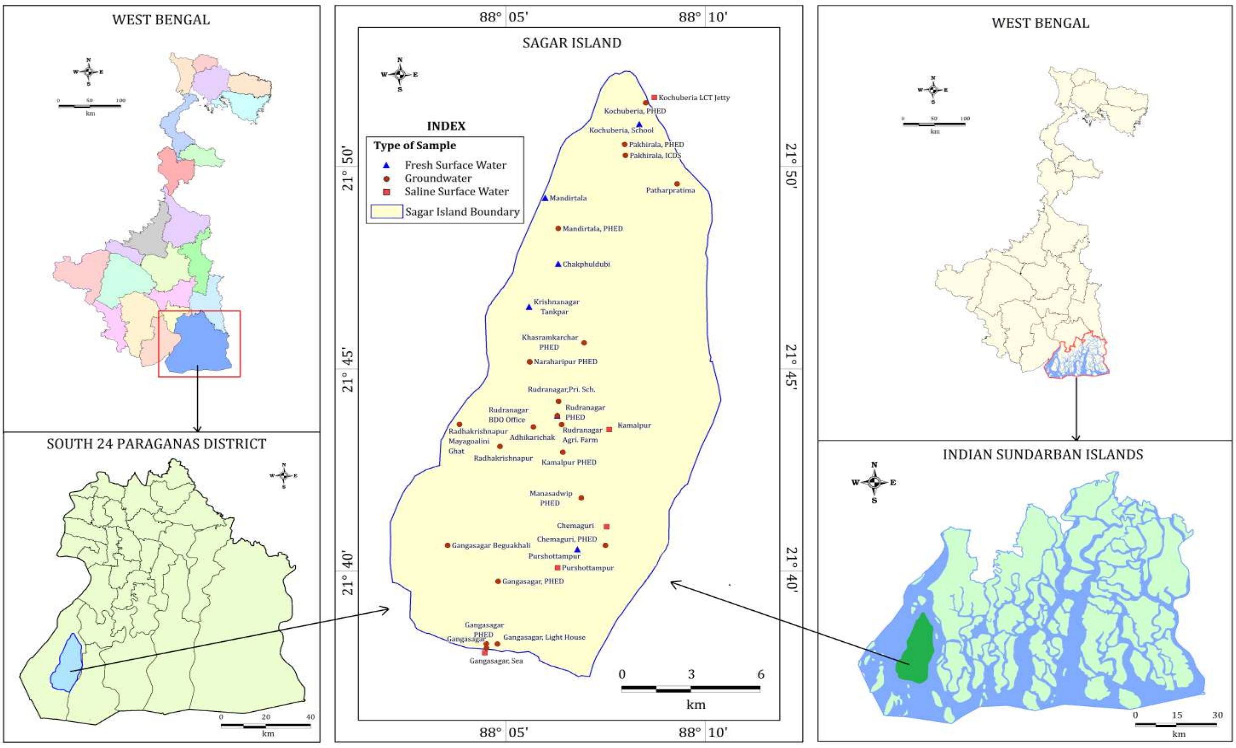

FIGURE 3: WATER QUALITY SAMPLE LOCATION MAP OF SAGAR ISLAND

1.4.2 Correlation between Hydrochemical Parameters

Several diagrams have been used worldwide to represent the relationship between the major element and other parameters such as EC. The plots used for assessing the seawater intrusion as well as to characterize the origin of salinity in groundwater are as follows:

SN	Correlation Plot/Ratio	Assessment point	References
1.	Cl and Cl/HCO_3 ratio	Assess seawater intrusion in coastal areas	Kim et al, 2003
2.	Cl/HCO_3 ratio	Indicator of salinization by seawater intrusion	Chidambaram et al 2018
3.	Ca/Mg ratio	Most significant natural tracers of seawater intrusion in coastal aquifers	Pulido-Leboeuf, 2003; Ouhamdouch et al, 2021
4.	SO_4/Cl ratio	Natural tracer of marine intrusion phenomenon in coastal aquifers	Telahigue et al, 2020
5.	Correlation between Cl and EC	Highlights the effect of seawater intrusion	Hajji et al, 2022

2. HYDROCHEMICAL FACIES ANALYSIS AND CLASSIFICATION

2.1 Hydrochemical facies analysis with Piper and Durov diagrams

Chemical characteristics of groundwater depends on several factors such as the lithology of the geological strata in which groundwater is flowing (*i.e.,* the aquifer), time of residence of water in the aquifer, and environmental conditions. The major ion compositions of groundwater samples of the studied area do not vary much. Samples are generally Na^{+}-K^{+}- rich (100%) with HCO_3^{-} is found as dominant type of anion (Fig. 04). The Piper Trilinear diagram shows that the as per cationic concentration groundwater chemistry was mainly characterized by Sodium Potassium type irrespective of groundwater or surface water source. As per anionic concentration all groundwater samples are HCO_3^{-} - type. Surface water samples from both saline water bodies or fresh water bodies are typically Cl^{-} type. From the Piper plot all the groundwater samples have also been classified as Na^{+}-HCO_3^{-} or Mixed type whereas Surface water samples purely classified as similar ion compositions of Na-Cl type, which indicates saline water influence in the region. Piper Diagram clearly indicates that the ground water samples are originated from a depth of 200 meter or more and all are of similar groundwater characteristics. These samples are collected from abstraction structures tapping Aquifer III (deeper) and this aquifer is less likely to be affected with sea water intrusion unlike Aquifer I and II. But the surface water bodies specially located at banks or near sea area have been affected by the tidal influence and become characterised as potent site salinity hazards throughout the study area. The discussed fact of the study area has been supported by data plotted on Durov diagram (Fig. 05).

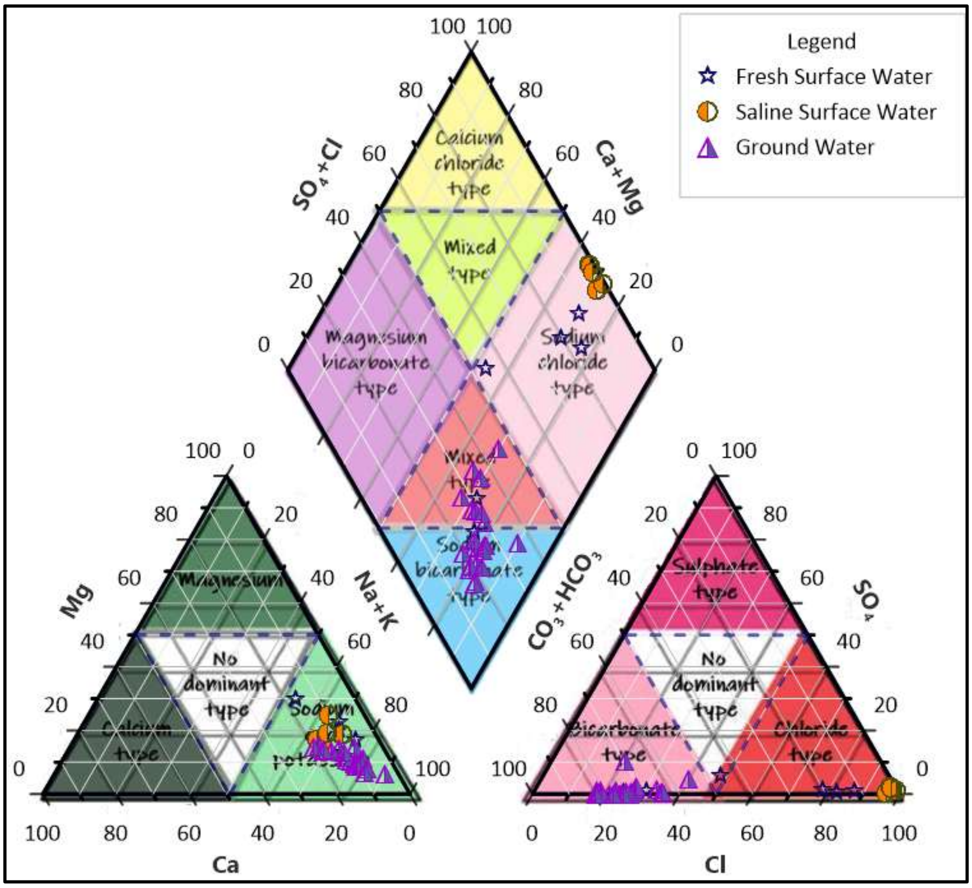

FIGURE 4: PIPER TRILINEAR DIAGRAM OF SAGAR ISLAND STUDY AREA FOR HYDROGEOCHEMICAL FACIES

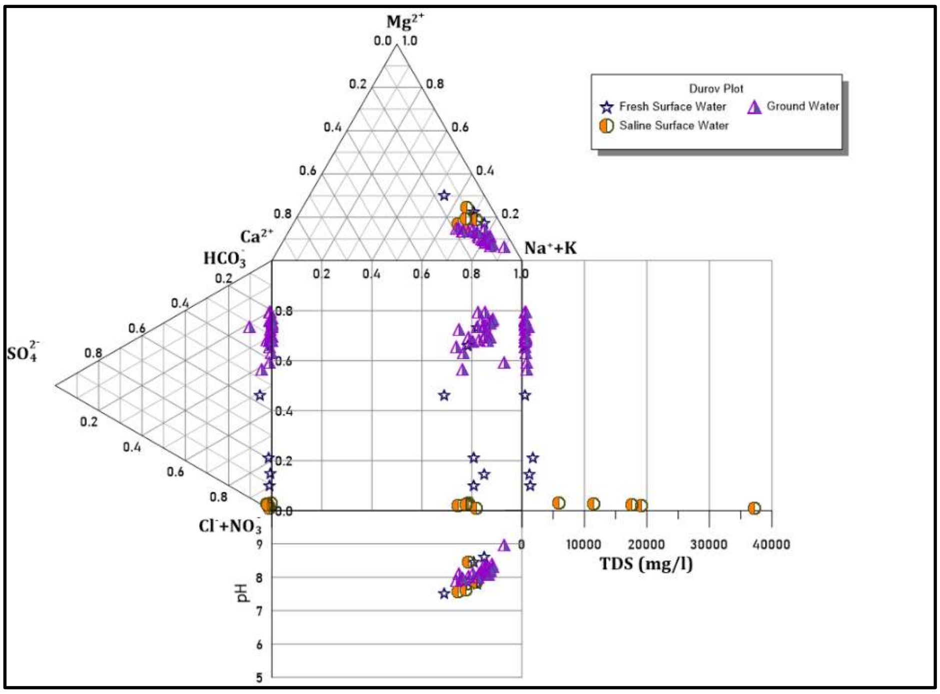

FIGURE 5: DUROV PLOT OF SAGAR ISLAND STUDY AREA

2.2 Gibbs Diagram

This has also been evidenced from the distribution of samples in Gibbs Plot (Fig. 06) that the chemical compositions of groundwater in study area are mainly affected by rock-water interaction and evaporation sedimentation. Most of the groundwater samples are obtained from areas with ratios of $Na^+/(Na^++Ca^{2+})$ or $Cl^-/(Cl^-+HCO_3^-)$ mostly greater than 0.5 signifies the dominance of sea-water interactions and weathering of rock forming minerals. Samples with $Na^+/(Na^++Ca^{2+})$ or $Cl^-/(Cl^-+HCO_3^-)$ ratios greater than 0.5 with high TDS levels between that the groundwater chemistry has been controlled not only by rock weathering interaction and/or atmospheric precipitation but also by evaporation at places.

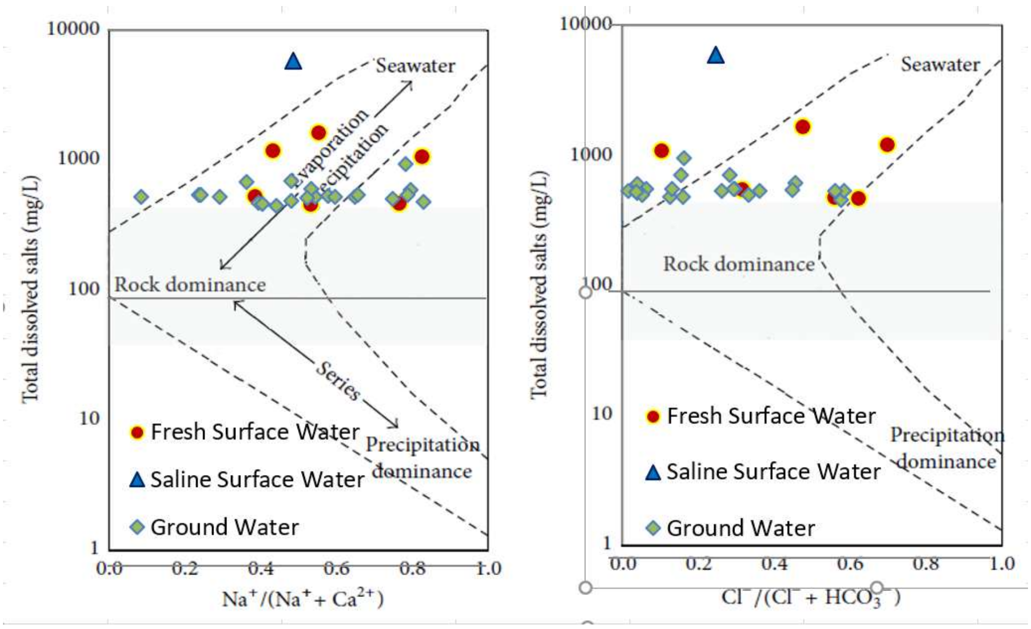

FIGURE 6: GIBBS DIAGRAM OF THE SAMPLES FROM STUDY AREA OF SAGAR ISLAND

3. SEAWATER INTRUSION INDICATORS

The salinization of coastal aquifers due to sea water intrusion can be summarized as the mixing between the recharge water or fresh water (prevailing calcium bicarbonate facies) and the sea water (prevailing sodium chloride facies). Through chemical reactions and dominance of some cations and anions this can alter the groundwater chemistry. The dynamics of sea water intrusion can be recognized by the evolution of the chemistry of the major ions over time.

3.1 Facies identification of groundwater in the study area

Chadha's diagram (Chadha 1999) was used to delineate the hydrochemical facies of groundwater. The water samples are plotted in different sub-felds on the Chadha's diagram (Fig. 07). According to Chadha's diagram, majority of the samples fall in the sub-field 8 delineating base ion exchange water ($Na-HCO_3$ as dominant facies). All the ground water samples of the study area occupied in sub-field 8 indicating no intrusion or mixing with sea water in the deeper aquifer. This interpretation correlates with the result of ionic ratio and mixing rate calculation. However, few surface water samples fall in the sub-field 7 indicating Na-Cl dominance facies which may be due to the interaction of sea water with surface water during high tide.

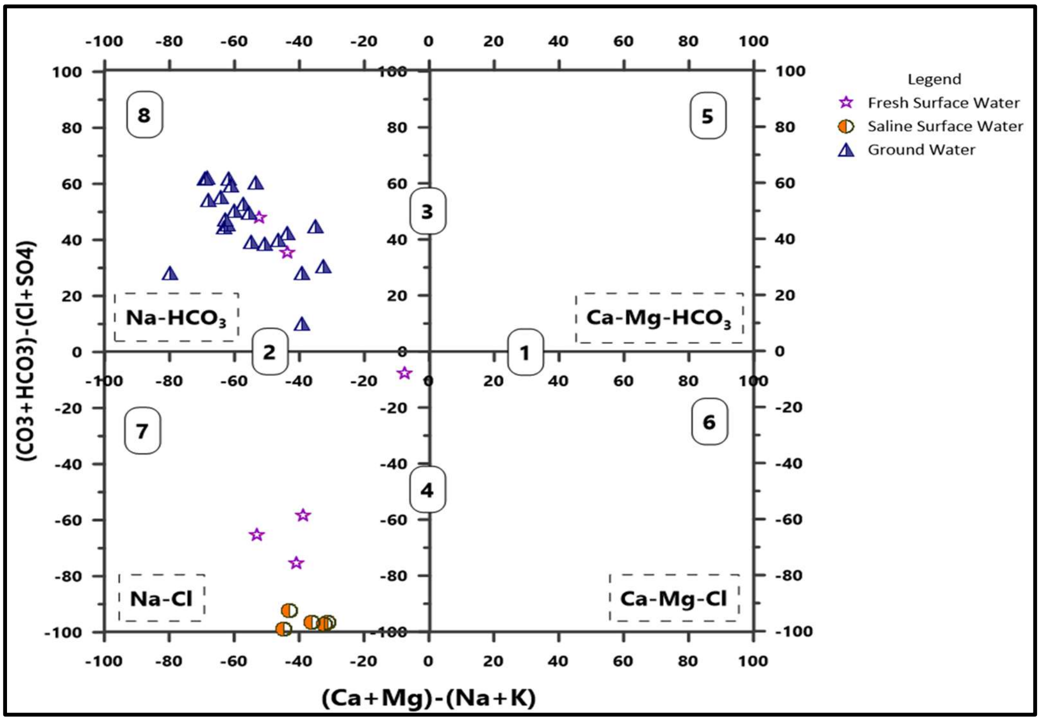

FIGURE 7: CHADHA'S DIAGRAM IN THE STUDY AREA: (5) RECHARGE WATER, (6) REVERSE ION EXCHANGE WATER, (7) SEA WATER EFFECT, (8) BASE ION EXCHANGE WATER

3.2 Correlation between parameters

3.2.1 Correlation between EC and Cl

The correlation between Cl and EC (Fig. 08 and 09) was used to identify the correlation between the two constituents. The strong correlation was found between both the type ($R^2 = 0.9011$) in all samples. The evolution from freshwater to seawater and the interaction between the two can also be defined from the relationship. In the present study majority of the sample group fall in the Freshwater and mixing zone and Marine intrusion effect was not identified in the deeper aquifer samples.

3.2.2 Correlation between Cl and Cl/HCO_3

Based on the Cl vs. Cl/HCO_3 ratio was used to assess seawater intrusion in coastal areas (Fig. 08). The vertical dotted line, corresponding to the Cl concentration of 65 mg/L, indicates the limit after which a strong seawater effect is found. In the present study, this relationship shows that groundwater in the deeper coastal aquifer is not affected by seawater intrusion and falls in the freshwater zone.

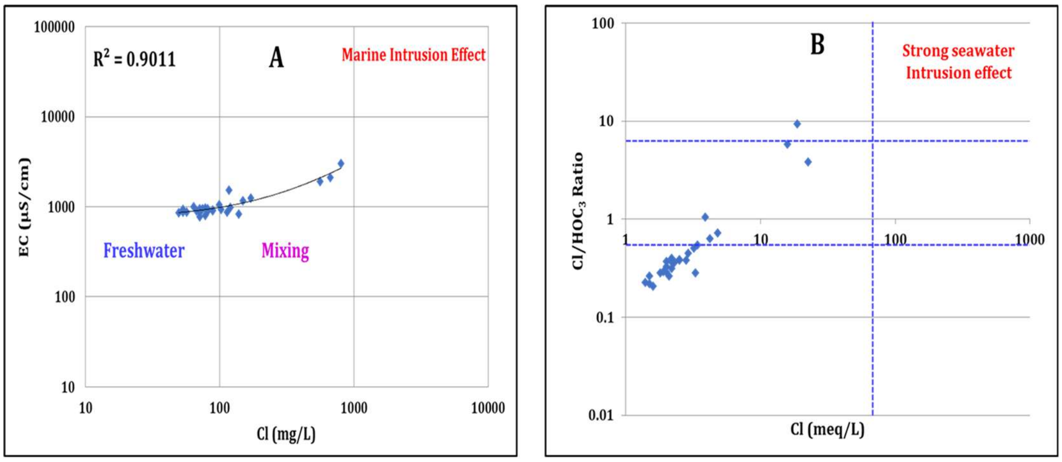

FIGURE 8: A. EC VS. CL PLOT IN THE STUDY AREA. B. RELATIONSHIP CL/HCO3 VS. CL IN GROUNDWATER OF THE STUDY AREA

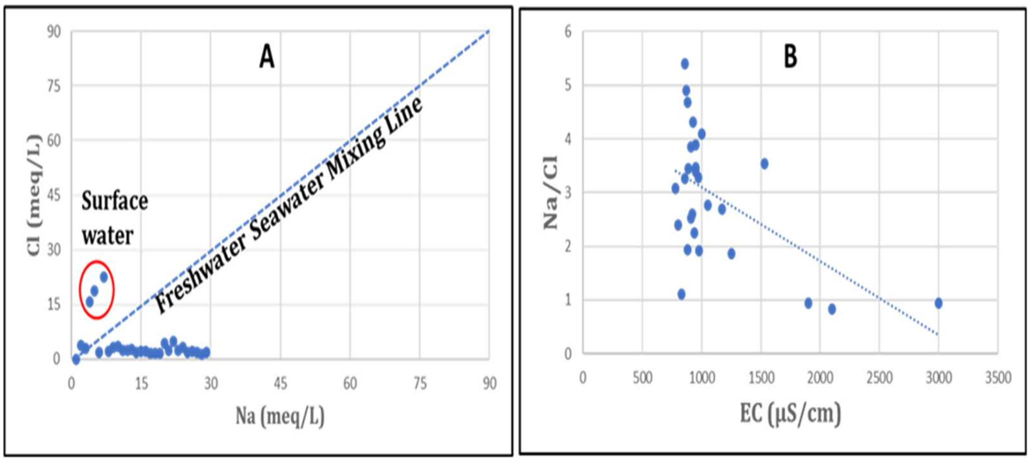

FIGURE 9: A. CROSS PLOT BETWEEN NA+ VS CL- B. EC VS NA+/CL-

3.3 Ionic ratio to understand the SWI

The potential salinization sources are categorized by distinguishable geochemistry and most used ionic ratios (IRs) related to hydrogeochemical processes [Maurya et al, 2019; Reghunath et al, 2002] as shown in Table. 04 Generally, calcium (Ca^{2+}) is dominated in groundwater, whereas magnesium (Mg^{2+}) in seawater and IR of Mg^{2+}/Ca^{2+} >5 indicates Sea Water Intrusion (SWI) [Bhagat et al, 2021]. All of the samples have IR (Mg^{2+}/Ca^{2+}) >1, which indicates the groundwater is free from salinization. The range of IR (Na^{+}/Cl^{-}) 0.86–1 is used as a direct indicator of SWI because of the long-term residence and dominance of Na^{+} and Cl^{-} ions in seawater. All the groundwater samples have IR (Na^{+}/Cl^{-}) >1. However, 3 samples were found to fall above the Freshwater Seawater Mixing line (Fig. 09) which are surface water and suggests the probability of inundation or mixing with sea water in high tide condition.

TABLE 4: SUMMERY OF VARIOUS RATIO TO EXPRESS POTENTIAL SOURCES OF CONTAMINATION OF GROUNDWATER

SN	Location	Type	Mg/Ca	Na/Cl	K/Cl	Ca/ HOC_3+SO_4
1	Kochuberia, School	SW	1.86	1.10	0.09	0.33
2	Mandirtala	SW	0.86	2.25	0.04	0.21
3	Tank at Tankparth	SW	2.70	0.94	0.04	0.46
4	Chalphuldubi	SW	2.24	0.83	0.03	0.92
5	Adj to BDO Office	SW	1.00	3.09	0.11	0.16
6	Purshottampur	SW	2.84	0.94	0.03	0.39
7	Kochuberia, PHED	GW	0.86	2.39	0.05	0.23
8	Pakhirala, ICDS	GW	0.78	1.93	0.03	0.28
9	Pakhirala, PHED	GW	0.81	1.92	0.04	0.26
10	Patharpratima	GW	0.92	2.52	0.04	0.19
11	Mandirtala, PHED	GW	1.18	2.59	0.04	0.17
12	Narharipur, PHED	GW	0.92	2.77	0.04	0.16
13	Sagardwip College	GW	0.90	3.46	0.05	0.14
14	Kamalpur, PHED	GW	0.90	3.40	0.04	0.14
15	Rudranagar PHED	GW	1.00	3.89	0.05	0.11
16	Mansashadwip PHED	GW	1.00	4.32	0.06	0.15
17	Chemaguri, PHED	GW	0.80	4.68	0.07	0.13
18	Gangasagar, Mark-II	GW	1.00	4.90	0.06	0.12
19	Gangasagar, PHED	GW	1.60	2.69	0.05	0.07
20	Rudranagar, Pri. Sch.	GW	1.88	3.44	0.04	0.13
21	Radhakrishnapur	GW	0.82	1.87	0.03	0.31
22	Radhakrishnapur	GW	1.57	3.44	0.04	0.11
23	Adhikarichak	GW	1.17	3.55	0.06	0.13
24	Rudranagar, PHED	GW	1.00	4.08	0.05	0.14
25	Rudranagar, Agri. Farm	GW	0.89	3.28	0.04	0.16
26	Gangasagar, Light House	GW	1.14	3.26	0.04	0.13
27	PHED Guest House	GW	1.00	5.41	0.06	0.11
28	PHED Guest House WS	GW	0.75	3.85	0.05	0.12

3.4 Mixture with seawater estimation

The assessment of Mixing rate (R_{mix}) between freshwater and seawater has been done with the use of Chloride (Cl) as conservative tracer. The equation for the calculation of Mixing rate (R_{mix}) is based on the mass conservation is presented below:

$$Rmix = (Clsample - Clfreshwater)/(Clseawater - Clfreshwater) \times 100 \ (1)$$

Where,
Cl_{sample} = Chloride concentration in the water sample,
$Cl_{freshwater}$ = Chloride concentration in freshwater (as the average chloride concentration of samples having Electric Conductivity < 1000 $\mu S/cm$ = 46 mg/L
$Cl_{seawater}$ = Chloride concentration in seawater (=19,000 mg/L)

The calculated mixing rate (R_{mix}) in the study area ranges from 0.019% to 3.98% (Fig. 10). The degree of risk of seawater intrusion phenomenon is evaluated according to the R_{mix} values mentioned in Table: 05. All the samples in the study area (both Surface water samples and Ground water) have revealed low risk of seawater intrusion as well as a low degree of contamination risk.

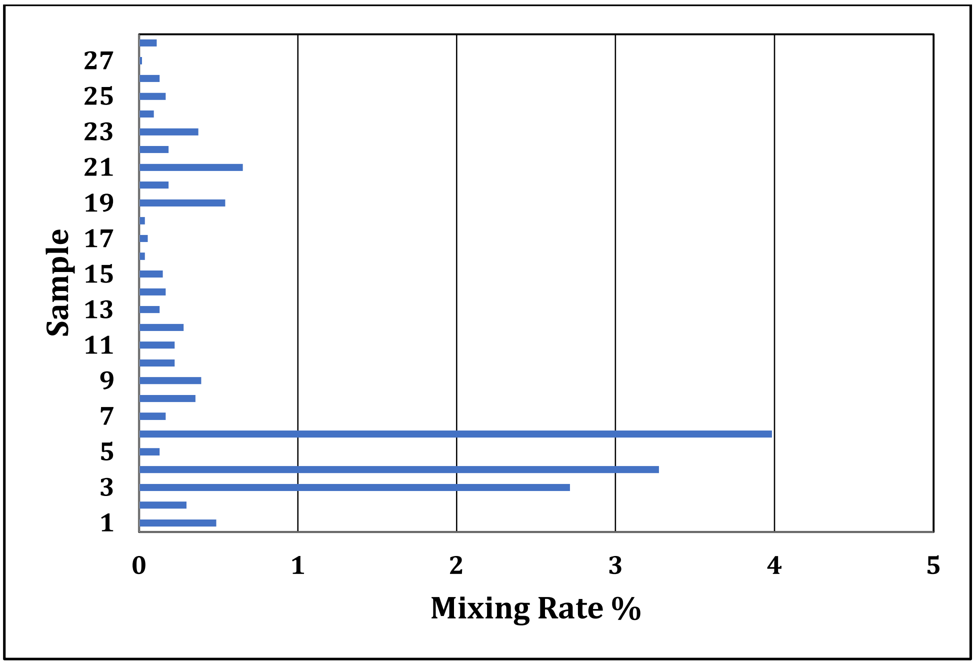

FIGURE 10: RMIX EVALUATION AND SPATIAL DISTRIBUTION

TABLE 5: SPECIAL RANKING OF SEAWATER HAZARD

R_{mix} %	No. of Sample	% of Sample	Seawater Intrusion Risk
0-5	29	100%	Low
5-10	-	-	Medium
10-15	-	-	High
15-20	-	-	Very High

4. HYDROCHEMISTRY AND ASSESSMENT FOR DRINKING WATER SUITABILITY

4.1 Groundwater quality scenario of Sagar Island

Geochemistry of ground water is mainly dependent upon several factors like, soil or rock through which rain water percolates, depositional history of the rock types, composition of the rock types, climate of the area, role of microorganisms, topography of the area and the role of human activities etc. The summary statistics of basic groundwater quality has been presented in Table: 06.

4.1.1 Hydrogen Ion Concentration (pH)

In Sagar Island, the pH content of ground water varies from 7.91 to 8.97 (Pakhirala ICDS), which indicates that ground water is almost neutral to alkaline in nature. For Fresh surface water pH ranges from 7.51 – 8.61 (Tankparh) and for Surface saline water the range observed was 7.57 – 8.46 (Purusottampur). Few water samples were found to have pH values exceeded the permissible limit of 8.5 by BIS 2012.

4.1.2 Electrical Conductivity

The range of Electrical Conductivity as well as TDS values indicates wide variation in dissolved constituents in groundwater of Sagar Island. The maximum conductivity value of 1530 µS cm^{-1} at 25°C for groundwater has been observed at Adhikari Chak whereas maximum conductivity value of 3000 µS cm^{-1} at 25°C has been observed for fresh surface water body of Purusottampur area. For Sea, River, Canal and Creeks usual very high value of Electrical Conductivity has been observed in the range of 10 to 57 mS cm^{-1} at 25°C and as well as TDS observed in the range 5935 to 37173 mg/L. As per the salinity hazard classes No analyzed groundwater samples were found unsuitable (i.e., EC >2250 µS cm^{-1}). Only one pond was to have Electrical Conductivity in this category. The high EC value of pond water is attributed by ingress of saline water. High concentration of TDS can cause water to become corrosive, salty or develop a brackish taste. 88% of the analyzed groundwater samples (Total 23 locations) and 100% fresh surface water samples showed TDS values ranged higher than Desirable Limit of 500 mg/L (BIS: 2012).

4.1.3 Distribution of Major Cations

a) Calcium, Magnesium

The alkaline earth metals Calcium and Magnesium are two important cations in ground water which have been analyzed. Ca concentration varies from 10 to 44 mg/L in ground water and 20 to 50 mg/L in fresh surface water. Accordingly, Mg concentration varied from 07 to 26 mg/L in ground water and 12 to 86 mg/L in surface water. The maximum concentration for Calcium was detected at groundwater of Radhakrishnapur, and at Adhikari maximum concentration for groundwater Magnesium was detected. None of the samples from both the category exceeded the acceptable limit for Calcium and Magnesium respectably.

b) Sodium, Potassium

Groundwater Na concentration ranges from 121 mg/L to 269 mg/L and in fresh surface water Na concentration observed in the range 99 mg/L to 489 mg/L. Normal range K was reported for both surface and groundwater samples of the study area.

TABLE 6: SUMMARY STATISTICS OF CHEMICAL QUALITIES OF VARIOUS WATER SAMPLES OF SAGAR ISLAND

Constituents		Ground Water			Fresh Surface Water			Saline Surface Water		
		Min	Max	Avrg	Min	Max	Avrg	Min	Max	Avrg
pH		7.91	8.97	8.19	7.51	8.61	8.03	7.57	8.46	7.86
EC $\mu S\ cm^{-1}$ at 25°C		800	1530	975	780	3000	1592	10000	57000	29080
Total Hardness (as $CaCO_3$)		65	200	109	100	480	248	1500	9500	5100
Calcium (as Ca)		10	44	22	20	50	32	300	1200	780
Magnesium (as Mg)		7	26	13	12	86	41	182	1580	765
Sodium		121	269	174	99	489	264	1730	11140	5206
Potassium		3	8	4	4	26	16	5	500	161
Carbonate alkalinity (as $CaCO_3$)		0	39	8	0	15	5	0	21	4
Bicarbonate alkalinity (as $CaCO_3$)		329	708	415	122	397	274	177	287	211
Total alkalinity (as $CaCO_3$)	mg/L	300	580	354	125	325	233	145	235	180
Chloride		50	170	87	71	801	390	3541	22234	10954
Nitrate		4	34	22	14	29	22	28	42	33
Sulphate		0	83	8	3	23	12	16	351	220
Fluoride		0.20	0.79	0.35	0.23	0.75	0.49	0.42	1.00	0.74
PO_4		0.05	0.48	0.22	0.1	1.1	0.38	0.17	1.49	0.51
SiO_2		7	21	13	8	15	11	9	21	15
TDS		488	1002	601	506	1729	957	5935	37173	18267
Iron		0.22	0.97	0.50	0.22	1.23	0.79	1.2	16.12	10.29

4.1.4 Distribution of Major Anions

Chloride, Carbonate/Bi-carbonate, Sulphate and Nitrate are the major anions present in ground water of Sagar Island.

a) Chloride

Chloride content of ground water varies from 50 to 170 mg/L in groundwater and 71 to 801 mg/L in fresh surface water**.** Ground water is charecterised by moderate level Chloride and sodium contents points towards fresh nature. Saline water bodies are charecterised by the presence of very high chloride concentration in the range 3541 to 22234 mg/L. None of the analysed groundwater sample showed Chloride concentration higher than the Acceptable or Permissible Limits of Chloride as per BIS (2012).

b) Total Alkalinity

Enrichment of bicarbonate concentrations of ground water by and large coincides with the direction of ground water flow. The value of total alkalinity in groundwater of Sagar Island ranges from 300 to 580 mg/L and for surface water it ranges from 125 to 325 mg/L.

All groundwater samples and 80% of fresh surface water samples of Sagar Island, showed total alkalinity value higher than acceptable limit but none found value higher than the Permissible limit by BIS 2012.

c) Nitrate, Sulphate and Fluoride

As per BIS (2012), the Permissible Limit of Nitrate in drinking water is 45 mg/L. In Sagar Island none of the analysed sample either groundwater or surface water showed higher concentration than the permissible limit for Nitrate. The maximum concentration was found at Groundwater of Gangasagar Light house area. Seepage of sewage wastes and nitrogen fertilizer are the major sources of nitrate contamination in groundwater.

None of the analysed sample (groundwater or fresh surface water) showed higher concentration of Sulphate or fluoride as prescribed by BIS, 2012.

4.1.5 Hardness of Ground Water

Calcium and Magnesium, Carbonate and Bicarbonate are the important constituents that give a measure to hardness of ground water. The hardness (temporary hardness) as $CaCO_3$ in the ground water of Sagar Island ranges from 65 to 200 mg/L. For surface water the hardness ranged from 100 to 480 mg/L.

The quality of groundwater in terms of Total Hardness as $CaCO_3$ has been found as soft to hard. The detail distribution is as follows (Table 07). As per BIS (2012), the Permissible limit of Hardness in drinking water is 600 mg/L none of the sample was found to have Hardness more than the Permissible Limit.

TABLE 7: HARDNESS CLASSIFICATION OF GROUNDWATER OF SAGAR ISLAND

Water Class	TH as CaCO3 in mg /L	No. of Samples
Soft	<75	04
Moderately Hard	75–150	15
Hard	150–300	03
Very Hard	>300	0

4.2 Evaluation of drinking water suitability

- The water quality data of the study area revealed that quality of groundwater used for Water Supply, Drinking and other Domestic Purposes in and around the study area is very much suitable for drinking purposes. Only Sporadic occurrence of high pH at one location has been encountered. Details in Table: 08.
- Occurrences of Iron exceeding the permissible limit of 1.0 mg/L were not observed as per the samples analysed. But other agencies/ department have reported occurrence of Iron above permissible limit at the study area.
- According to Arsenic Task Force and Fluoride Task Force, Govt. of West Bengal, Sagar Block has not been identified as arsenic or fluoride effected block.
- Sagar Block has been identified as salinity affected block. Surface water data from current support this finding. But the aquifer used for water supply or drinking purposes from where the samples have been collected is having depth more 300 meters mostly. This zone is found to be not affected by salinity.

TABLE 8: DRINKING WATER SUITABILITY OF GROUNDWATER SAGAR ISLAND IN REGARDS OF PHYSICO CHEMICAL PARAMETERS

Constituents		Acceptable Limit	Permissible Limit	No. of Samples beyond Acceptable Limit	Samples beyond Acceptable Limit (%)	No. of Samples beyond Permissible Limit	Samples beyond Permissible Limit %)
pH	mg/L (ppm)	6.5-8.5	No Relaxation	01	4.5	01	4.5
Total Hardness (as $CaCO_3$)		200	600	0	-	0	-
Calcium (as Ca)		75	200	0	-	0	-
Magnesium (as Mg)		30	100	0	-	0	-
Total alkalinity as $CaCO_3$		200	600	22	100	0	-
Chloride		250	1000	0	-	0	-
Nitrate		45	No Relaxation	0	-	0	-
Sulphate		200	400	0	-	0	-
Fluoride		1	2	0	-	0	-
TDS		500	2000	21	95.4	0	-
Iron		1	No Relaxation	0	-	0	-

TABLE 9: DRINKING WATER SUITABILITY AS PER THE HEAVY METAL CONTAMINATION OF SAGAR ISLANDS

Constituents		BIS 2012 Limit as per drinking water suitability		Ground Water		GW Samples beyond Permissible Limit		Fresh Surface Water		Saline Surface Water	
		Acceptable Limit	Permissible Limit	Min	Max	Number	%	Min	Max	Min	Max
Total Arsenic (as As)	mg/L (ppm)	0.01	No Relaxation	Traces	0.009	00	00	Traces	0.007	Traces	0.009
Mercury (as Hg)		0.001	No Relaxation	Not Detected		00	00	Not Detected		Not Detected	
Iron (as Fe)		1.0	No Relaxation	0.03	0.97	00	00	0.22	1.23	2.33	16.12
Manganese (as Mn)		0.1	0.3	0.02	0.06	00	00	0.03	0.20	0.03	0.20
Copper (as Cu)		0.05	1.5	Traces	0.03	00	00	Traces	0.01	Traces	0.03
Zinc (as Zn)		5	15	0.01	0.24	00	00	0.02	0.22	0.05	0.20
Lead (as Pb)		0.01	No Relaxation	Not Detected		00	00	Not Detected		Not Detected	
Total Chromium (as Cr)		0.05	No Relaxation	Not Detected		00	00	Not Detected		Traces	0.01
Nickel (as Ni)		0.02	No Relaxation	Not Detected		00	00	Not Detected		0.01	0.02
Cadmium (as Cd)		0.003	No Relaxation	Not Detected		00	00	Not Detected		Not Detected	
Strontium (as Sr)		No BIS/ WHO Guideline		0.03	0.14	-	-	0.07	0.21	0.32	0.46
Cobalt		No BIS/ WHO Guideline		Not Detected		-	-	Not Detected		Traces	0.01

Heavy Metal:

Heavy metal contamination of water resources not always necessarily to a degree that creates public health hazards, but many times the degree of occurrence adversely affects domestic, agricultural, municipal or industrial purposes. Trace elements are generally present in small concentration in natural water system. Their occurrence in groundwater and surface water can be due to natural sources such as dissolution of naturally occurring minerals containing trace elements in the soil zone or the aquifer material or due to human activities such as mining, fuels, smelting of ores and improper disposal of industrial wastes. Investigation of heavy metals is very essential since slight changes in their concentration above the acceptable/ maximum permissible levels, whether due to natural or anthropogenic factors, can result in serious environmental and subsequent health problems.

Groundwater has served as the principal source of water supply at Sagar Island and surrounding area. Due to utilisation of groundwater as a veritable source of drinking water supply at the study area, it becomes necessary to access critically their quality and portability for human consumption. Based on this background this study includes the monitoring of heavy metal of groundwater, fresh and saline surface water resources of Sagar Island area.

Apart from Total Iron, concentration of various Heavy Metals *viz.* Total Arsenic, Mercury, Manganese, Copper, Zinc, Lead, Total Chromium, Nickel, Cadmium, Strontium and cobalt have been analysed from groundwater, fresh surface water and saline surface water of Sagar Island, West Bengal. Drinking water suitability as per Occurrence of various metals has been furnished in above Table: 09.

As per BIS (2012), the Permissible Limit of Iron in drinking water is 1.0 mg/L. In Sagar Island, Iron content ranged between 0.22 to 0.97 mg/L. The maximum Concentration was found at Rudranagar. None of the analyzed groundwater sample was found to have Fe concentration more than permissible limit. For Fresh Surface water the observed range was 0.22 to 1.23 mg/L (Purusottampur area). 43% of fresh water samples were found Fe contaminated. For saline water resources Fe found in the range of 2.33 to 16.12 mg L^{-1} and all the sources were found with high level of Fe contamination.

Range of total Arsenic concentration was found from traces to 09 µg L^{-1} for groundwater and traces to 07 µg L^{-1} for fresh surface water. The highest concentration was observed at Rudranagar Primary School, Sagar. All of the analysed groundwater samples are found safe as per BIS 2012 Limit.

Manganese concentration in groundwater was observed in the range of 0.02 to 0.06 mg L^{-1} (at Pakhirala ICDS, Sagar Island) and in the range of 0.03 to 0.20 mg L^{-1} for fresh surface water. No analysed samples were found having Mn concentration above the permissible limit of 0.3 mg L^{-1}.

Highest concentration of Copper was observed as 03 µg L^{-1} at Kamalpur, Sagar Island. None of the analysed sample showed Copper concentration higher than the permissible limit of 1.5 mg L^{-1} (BIS 2012) both for groundwater and fresh surface water samples.

Zinc concentration was observed in the range of traces to 0.241 mg L^{-1} (Adhikari Chak, Sagar Island). None of the samples was found having Zn concentration higher than the permissible limit of 15 mg L^{-1}.

Total Chromium, Nickel and Cobalt were not detected from groundwater or fresh surface water resources but observed in Sea/ Creek/ River water in the range of traces to 0.01 mg L^{-1}, 0.01 to 0.02 mg L^{-1} and Traces to 0.01 mg L^{-1} respectively. All the detected concentrations were found in safe range as per BIS 2012.

Strontium concentration of the groundwater was observed in the range of 0.03 to 0.14 mg L^{-1} for groundwater, 0.07 to 0.21 mg L^{-1} for fresh surface water and 0.32 to 0.46 for saline water.

Mercury, Lead and Cadmium were not detected from any type of resources *i.e.* groundwater fresh surface water or saline surface water.

Apart from high Iron level of fresh and saline surface water bodies none of analysed heavy metals was observed at an unsafe level or in the range higher than the permissible limit set by BIS for drinking water suitability (2012). Low level occurrence of various heavy metals in fresh water resource also favours the use of the same for irrigation and other domestic purposes and minimises potential risks to public health and ecosystems, especially due to heavy metals, which are considered dangerous because of their potential toxicity and persistence in the environment.

5. SUITABILITY ASSESSMENT FOR IRRIGATION

5.1 Irrigation parameters

The concentrations of different parameters were interrelated, and irrigation indexes like soluble sodium percentage (SSP), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium hazard (MH), Permeability Index (PI), and Chloroalkaline Index (CAI) were calculated to assess groundwater quality. USSL salinity, Wilcox, permeability index, and Gibbs diagrams were drawn with the help of Grapher free software to assess irrigation quality of collected water samples.

5.1.1 Exchangeable Sodium Percentage (ESP)

Sodium is an important cation and when excess of sodium is present in irrigation water, affects the soil structure and crop yield. Sodium percent in water is used to evaluate quality of groundwater for irrigation purpose. Sodium percentage is calculated by the formula, given below (Wilcox, 1955) and the concentrations are expressed in meq/L.

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

Sodium percentage against electrical conductivity of groundwater is plotted in Wilcox diagram (Fig. 11A) indicates that values in the sagar islands shows that the range for groundwater is from 66.24 to 90.84 meq/l, whereas in surface water in pond and canal ranges from 49.60 to 81.24 meq/L and in river/ sea water ranges from 68.01 to 87.62 meq/L.

5.1.2 Salinity and alkalinity hazard

The dissolved salt content plays an important role in irrigation. Based on EC, irrigation water is classified as excellent, good and permissible, unsuitable [Ragunath, 1987]. Sodium Adsorption Ratio (SAR) determines sodium or alkali content present in water, which is used for irrigation. Sodium adsorption ratio is calculated by sodium, calcium and magnesium ions and it is expressed in meq/l. The alkali hazards involved in the use of water for irrigation is determined by the absolute and relative concentrations of cations. If the proportion of sodium is high the alkali hazard is high and if calcium and magnesium predominate the hazard is low. Alkali soils are formed by accumulation of exchangeable sodium and are characterized by the poor tilt and low permeability. The U.S. Salinity Laboratory has recommended the use of a parameter "the sodium adsorption ratio (SAR)" as it is more closely related to the adsorption of sodium by the soil. SAR is formulated by Richards (1954), which is used to calculate sodium adsorption ratio and expressed as

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

The EC and salinity values of groundwater samples are plotted in USSL classification (United States Salinity Laboratory, Freeze and Cherry, 1979) (Fig. 11B). Based on Sodium Adsorption Ratio (SAR), the values in the Sagar islands shows that the range for groundwater is from 4.58 to 13.37 meq/L, whereas in surface water in pond and canal ranges from 3.03 to 23.12 meq/L and in river/ sea water ranges from 29.75 to 68.56 meq/L.

5.1.3 Residual sodium carbonate (RSC)

Residual sodium carbonate is used to indicate alkalinity hazard in irrigation water. When there is an increase in sodium concentration in groundwater, it will help to precipitate calcium and magnesium on soil. The carbonate and bicarbonate concentration higher than calcium and magnesium concentration is suitable for irrigation purposes. RSC was calculated by Raghunath in (1987) and the concentrations are expressed in meq/L.

$$RSC = (HCO_3 + CO_3) - (Ca + Mg)$$

Residual sodium carbonate values in the Sagar islands shows that the range for groundwater is from 3.10 to 7.67 meq/L, whereas in surface water in pond and canal ranges from -17.57 to 4.79 meq/L and in river/ sea water ranges from -96.93 to -21.94 meq/L.

5.1.4 Permeability index (PI)

Permeability index was given by Donean in (1964), which is calculated with calcium, sodium, magnesium and bicarbonate concentrations, where concentrations are expressed in meq/L.

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} * 100$$

The permeability index of groundwater of study area ranges from 92.64 to 115.74 meq/l, whereas in surface water in pond and canal ranges from 59.46 to 103.04 meq/l and in river/ sea water ranges from 68.47 to 88.33 meq/l.

5.1.5 Magnesium Hazard (MH)

This is evaluated by the equation given by Szabolcs and Darab [26], where the concentration of each cation was expressed in meq/L

$$MH = \frac{(Mg * 100)}{(Ca + Mg)}$$

5.2 Evaluation of irrigation water quality

Since all agricultural water used in the study area is supplied from groundwater, it is necessary to evaluate the quality of irrigation water in the study area. Many factors affect the quality of irrigation water including temperature, pH, salinity and alkalinity. The water quality for irrigation water is generally evaluated using salt damage and alkali damage. Increased salinity of groundwater increases kinematic viscosity, leading to an increase in friction resistance. Consequently, the seepage speed and permeability coefficient decrease, preventing water from reaching the branches and leaves of plants to reduce crop yields. Irrigation with high salinity water induces the accumulation of salt in soils and leads to secondary salinization of the soil, causing changes in the chemical composition of soil solutions. This reduces the stability of the overall soil structure and leads to degradation of soil physical properties, affecting the extension of plant roots, seed germination and the movement of water through the soil. When the alkalinity of groundwater is too high, soil organic matter content is reduced and soil nutrient conditions are worse, affecting plant growth.

- As per the USSL diagram (USSL, 1954) (Fig. 11 and Table 10) Samples were within C3 and 1 was within C4, indicating permissible to high salinity hazards in the ground water.
- The Wilcox diagram [Wilcox, 1948] shown in Fig. 11A represents the relationship between EC and %Na. In general, the %Na value of groundwater used for irrigation should be less than 60% [Li et al., 2016]. As shown in the Table 09 samples were found to be unsuitable for irrigation. The results of the present study show that majority of the sample points are in the C3S1 and C3S2 regions.
- Irrigation suitability interpretation- Groundwater used for irrigation in the area is of permissible to doubtful in nature as per the Irrigation suitability Indices. Hence, surface water should be explored and rain water harvesting as well as water conservation structures to be practised.
- With long-term irrigation with ground water may impart a detrimental effect on the permeability of land.

TABLE 10: SUMMARIZED RESULT TO ASSESS THE SUITABILITY OF THE GROUNDWATER FOR IRRIGATION

Parameter	Range	Water Class	No. of samples	Reference
SAR	< 10	Excellent	25	Richards, 1954
	10 to 18	Good	3	
	18 to 26	Moderate	Nil	
	> 26	Unsuitable	Nil	
ESP	< 50	Good	1	Wilcox, 1955
	> 50	Unsuitable	27	
RSC	< 1.25	Good	4	Raghunath, 1987
	1.25 to 2.50	Moderate	Nil	
	> 2.50	Unsuitable	24	
MH	< 50	Good	12	Szabolcs and Darab, 1964
	> 50	Unsuitable	16	
Salinity hazards (EC in µS/cm)	<200	C1- Excellent or low	Nil	Wilcox, 1955
	200-750	C2- Good or medium	Nil	
	750-2250	C3- Permissible or high	27	
	2250-5000	C4- Unsuitable or very high	1	
PI	> 75	Good	27	Donean,1964
	25 to 75	Moderate	1	
	< 25	Unsuitable	Nil	

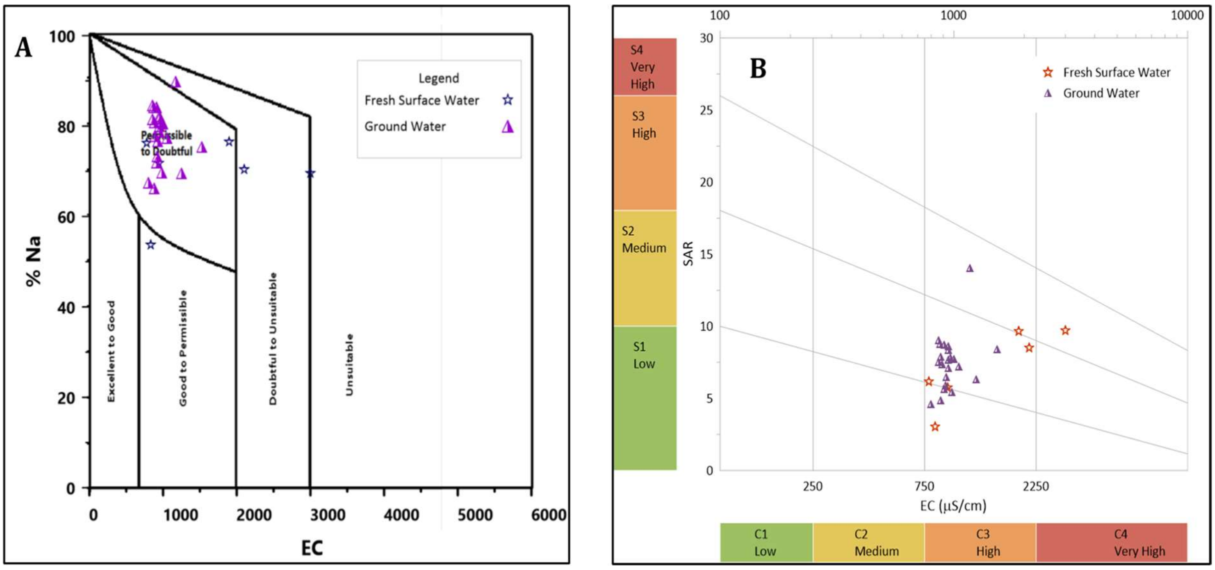

FIGURE 11: A. WILCOX DIAGRAM AND B. UNITED STATES SALINITY LABORATORY (USSL) DIAGRAM FOR ASSESSING THE IRRIGATION WATER QUALITY OF THE STUDY AREA

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion and Recommendation

In the present study, the chemical characteristics of groundwater in Sagar Island were analysed via multiple approaches, and the ingress of seawater in the coastal aquifer has been evaluated with various methods. The suitability of the groundwater in respect of drinking and irrigation has also been examined. The conclusions drawn are as follows:

- According to Chadha's diagram, majority of the samples fall in the sub-field 8 delineating base ion exchange water (Na-HCO3 as dominant facies) and does not and indicate any intrusion or mixing with sea water in the deeper aquifer. However, few surface water samples fall in the sub-field 7 indicating Na-Cl dominance facies which may be due to the interaction of sea water during high tide situation or during various natural calamities like cyclones or super cyclones.
- The correlation study between different constituents and IR analysis also confirms that groundwater in the deeper coastal aquifer is not affected by seawater intrusion and falls in the freshwater zone.
- The calculated mixing rate (Rmix) in the study area ranges from 0.019% to 3.98% which also revealed low risk of seawater intrusion as well as a low degree of contamination risk at deeper aquifer of the study area.
- The water quality data of the study area revealed that quality of groundwater used for Water Supply, Drinking and other Domestic Purposes in and around is suitable for drinking purposes.
- Sagar Block has been identified as salinity effected block and average EC value in the ground water was 975 µS cm^{-1} at 25°C. As per the USSL diagram almost all Samples were found within C3 group, indicating permissible to doubtful in respect of use in irrigation.
- As per the Wilcox diagram majority of the sample points are in the C3S1 and C3S2 regions. Long-term use of ground water in irrigation may impart a detrimental effect on the permeability of land. Hence before using for irrigation proper management is prescribed.
- At present the study deals with very limited aspects of monitoring of groundwater and surface water interaction of the study area. No aspects of fresh water resource management, from hydrogeological point of view, has been incorporated in study. Establishment of centers for monitoring and analyzing spatial variation of surface and groundwater chemical quality at a definite time interval is strongly recommended for inclusion as an aspect of the future study. Sustainable development for groundwater resources, conserving the environment and getting aware of the possible challenges should also be considered. Hence it is recommended another in depth research project should be taken up as a future scope of research 0for better understanding the unique hydrogeological features of Sagar Island and surrounding study areas.

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