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Groundwater quality assessment and GIS based mapping of selected areas of Mangrol Coast, Gujarat (India)

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ABSTRACT

Groundwater is one of the most valuable natural resources that are essential for life on earth. Groundwater has become a necessary resource due to increase in its usage for drinking, water supply, irrigation and industrial uses etc. The main purpose of the present investigation was to assess groundwater quality and create maps based on spatial distribution of selected parameters in coastal area of Mangrol, Gujarat. GIS is an effective tool for groundwater quality mapping as a database system in order to prepare maps based on concentration of various parameters by using ArcGIS 10.1 software. The results obtained showed that the composition of groundwater is largely affected by seawater intrusion, especially at Site 2 (Mangrol Beach). Site 3 (Bara Road) showed lower values for selected parameters and is comparatively better than other sites. TDS was highest by 1242 mg/l (site 10) in August, 2014 while hardness was 633.3 mg/l at Site 2 in September 2014 (Table 3.2). Site 2 and Site 10 (HodiChakla) showed higher concentrations of the selected parameters as they are closely located nearby shoreline of Mangrol. In September 2014, the concentration of calcium hardness was at its peak by a value 490 mg/l at Site 2 while highest amount of magnesium hardness (272.3 mg/l) was recorded in January 2015 (Table 3.6) at the same site. Groundwater quality maps are generated which being easily interpretable, could serve as a communication tool to aware local people and governmental and non-governmental organizations. We conclude that groundwater quality of Mangrol coastal area is under threat from saline water intrusion, geology of the environment, urbanization and influence of the seasons. Continuous monitoring and regulations related to groundwater use must be in-force ideally to prevent further degradation and sustainable utilization of groundwater in the study area.

Keywords: Water Quality, GIS Mapping, Quality Analysis, Sea water intrusion, Hardness.

INTRODUCTION

Groundwater is one of the most valuable natural resources that are essential for life on earth. Groundwater has become a necessary resource in last few decades due to increase in its usage for drinking, water supply, irrigation and industrial uses etc. Water scarcity is becoming acute problem in several parts of India, especially in arid and semi-arid regions. India is water stressed and is likely to be water scarce by 2050 [1]. The total water requirement of India by 2050 has been estimated at 1,450 km3 per year [2]. This is significantly more than the current estimate of utilizable water resources potential of 1,122 km^3 per year. As a result of population growth, industrialisation, urbanisation, agriculture and other anthropogenic activities, quality of groundwater is deteriorating day by day [3]. To fulfil the ever increasing demand of water there is high dependence on borehole water both for domestic and industrial usage [4]. Water quality assessment is very necessary to check the notability of drinking water as per the guidelines given by Bureau of Indian Standards. The possible reasons for groundwater contamination are prevailing drought prone conditions, discharges of untreated sewage wastes, irrigation runoffs and industrial effluents [5]. Temporal changes of recharged water, hydrological conditions and human factors may cause periodic changes in groundwater quality [6]. Various methods discussed in literature on drinking water quality and prescribed limits provided by different regulatory bodies could be used without considering uncertainties involved [7]. Information on the status and changing trends in water quality is necessary to formulate ideal guidelines for decision makers [8]. Ascertaining the quality is quite necessary before its use for various purposes for our own benefits [9]. Quality of water is identified in terms of its physical, chemical and biological parameters [10] as it sheds light on geochemical evolution of groundwater [55]. The chemical and physical characteristics of ground water determine its usefulness [11]. Monitoring of groundwater quality has become indispensable because clean water is necessary for human health and the integrity of aquatic ecosystems [9]. Field investigators point towards groundwater as vital source of water and sole input to coastal water [12, 13, 14]. Climate change is likely to affect ground water due to changes in precipitation and evapotranspiration. The decrease in precipitation will affect recharge of the coastal aquifers while increase in temperature will heighten water demand affecting recharge of the coastal aquifers [15]. Scientific findings on how coastal and oceanic chemicals interact with the ecosystem possess challenges to our understanding [16]. Increased saltwater intrusion will carry a significant socio-economic burden and is likely to touch upon national economies and local livelihoods [17]. Ghosh [18] analysed the effects of human activities and sea-level changes on spatial and temporal behaviour of salt-water and freshwater flow through the Godavari Delta of India. Saline intrusion into coastal aquifers has become a major concern [19] because it constitutes the commonest of all the pollutants to freshwater. Therefore, understanding of saline intrusion is essential for the management of coastal water resources [20]. Sherif et al., [21] had investigated the possible effect of climate change on seawater intrusion in coastal aquifers.

India has a very long coastline of about 7500 km and almost 25% of country's population lives in coastal areas. The coastal aquifers of India ranges from that of Jurassic to Recent and is seen almost all along the coast, right from Gujarat to West Bengal. Sea water intrusion is reported in Gujarat and Tamil Nadu while salinity of groundwater in other coastal areas is mostly associated with naturally occurring geologic activities. The overdependence on groundwater to meet ever increasing demands has resulted in overexploitation of groundwater resources in several states of India including Punjab, Haryana, Gujarat, Rajasthan, Uttar Pradesh, Tamil Nadu [22,23,24]. When the groundwater is drawn from coastal aquifer having connection with sea, there are further chances of mixing resulting into contamination [25]. Subsidized fuels, heavy pumping and excessive use of groundwater has caused faster depletion of water tables near coasts. Gujarat state is situated in western part of India and has nearly 1600 km long coastline. Droughts are frequent in north Gujarat, Saurashtra and Kachchh regions due to poor and erratic rainfall [26].

GIS is an effective tool for groundwater quality mapping as a database system in order to prepare maps based on concentration of various parameters. Remote sensing data from aircraft or satellite has become an increasingly valuable tool for understanding subsurface water condition [27]. It is very useful and easy to feed data into a GIS environment for integration with other types of data and further analysis [28]. Combination of remote sensing and GIS techniques has been proved to be an efficient tool in groundwater studies throughout the world [29,30,31,32,33]. The present investigation was carried out to provide an overview of groundwater quality based on selected parameters namely pH, electrical conductivity, total dissolved solids, total hardness, calcium-magnesium hardness and turbidity. The spatial distribution of groundwater quality parameters in the study area were mapped by using Arc GIS 10.1 software.

Table 1: Selected Sites of the Study Area and Its Geo-Coordinates

Site	Name of the site	Latitude	Longitude
1	Mangrol Port	21°6'32.025" N	70°6'25.057" E
2	Mangrol Beach	21°6'24.530" N	70°6'16.920" E
3	Bara Road	21°6'17.677" N	70°6'48.721" E
4	Jalaram Nivas-Fish Market	21° 6'32.132"N	70°6'7.818" E
5	Eidgaah	21°6'39.734" N	70°6'1.072" E
6	Baai Area	21°6'40.484" N	70°6'10.067" E
7	Maktupur Road	21°6'53.547" N	70°5'55.183" E
8	Gawaro Area	21°6'47.872" N	70°5'44.904" E
9	Fish Market	21°6'35.987" N	70°6'8.675" E
10	Hodi Chakla	21°6'28.598" N	70°6'21.845" E

1.2 Study Area:

Mangrol is situated in lower part of western Gujarat, between North latitudes 21^{o} 7' 12'' and East longitudes 70^{o} 7' 12''. The approximate limits of the three principal geological formations (Deccan Trap lava flows, Gaj beds and Miliolite limestone) encountered in the study area [34]. There are limestone aquifers underlying Mangrol coast. It is characterized by semi-arid climate. The main occupations of the local people are fisheries, farming, horticulture practices and animal husbandry along with other. The Mangrol port came into existence after 1990. The study area is been least researched for its groundwater quality since past few years. Study area along the coast covered ten different sites namely Mangrol Port (Site 1), Mangrol Beach (Site 2), Bara Road (Site 3), Jalaram Nivas-Fish Market (Site 4), Eidgaah (Site 5), Baai Area (Site 6), Maktupur Road (Site 7), Gawaro Area (Site 8), Fish Market (Site 9) and Hodi Chakla (Site 10). Water depth at Site 4, 5 and Site 8 was 15-17 meter whereas areas around Site 2 were with 50-55 metres depth for groundwater. Rest of the sites were with more than 20 meters depth of groundwater.

Fig. 1: Google Image of the Mangrol Coastal Area, Junagadh (Gujarat)

EXPERIMENTAL SECTION

2.1 Field Sampling:
Groundwater samples were collected for the period of six months from August 2014 to January 2015. Month wise sampling and analysis was carried out to know the possible fluctuations in the parameters. The geographical coordinates of the different locations were identified using Google earth.

2.2 Mapping:
Google earth images, Arc GIS 10.1 software and GPS (Garmin GPS Map 62) were used in collecting information and final mapping of the parameters. Krigging was carried out from the spatial analysis tools available in Arc GIS software.

2.2.1 GIS Techniques and Krigging:
Geo-referencing Google Earth Image was carried out by using Arc GIS software where geographical coordinates of the study areas were used for spatial reference of the image in Arc Catalogue. WGS 1984 Geographic Coordinates System was applied to the base map. Geo-referred Google image was used and point features were created as shape file using Create Feature option available in Editor. Sampling sites were marked by point feature option. Krigging was performed by opening Arc Toolbox and selecting Spatial Analyst Tool of which Interpolation option was selected for creating maps. Final maps were created by selecting layout view. Krigging is a geo-statistical tool that is effectively used to predict spatial distribution of chemical parameters of groundwater [35].

2.2.2 Data Analysis
All the data sets have been compiled using Microsoft excel and its functions. Each parameter was estimated for three times and average value was considered as final result. Standard deviation (±) was also calculated and presented in tables.

2.3 Methods:
Following parameters were determined from the groundwater samples collected from selected sites around Mangrol coast. The methods used for groundwater quality analysis were as per the standard methods mentioned in the book by SK Maiti [36].

2.3.1 pH
pH of the water and samples were determined by using ELICO LI 127 pH meter.

2.3.2 Electrical Conductivity (EC) and Total Dissolved Solids (TDS):
Electrical Conductivity (EC) of the samples was determined by using ELICO EC-TDS meter (CM 183, Make-India) where the electrode was directly dipped into well diluted and filtered solutions to get direct digital display of the result at 25˚C.

2.3.3 Turbidity:
Turbidity of the sample was measured by Nephalometric method using CL 52D model of ELICO. Sample was poured into the cell and turbidity was read directly from digital display of the instrument along with the regular adjustment with distilled water as a blank. Values were recorded in NTU- Nephalometric Turbidity Unit.

2.3.4 Total Hardness (TH):
The total hardness of the water samples was determined by EDTA titration method**.** In which 30 ml of well mixed sample was taken in a conical flask and pH of solution was adjusted up to 10. A pinch of Eriochrome black-T was added and titrated with 0.01M EDTA till wine red solution changes to blue. The volume of EDTA consumed was noted and similarly a reagent blank with distilled water was run to calculate the hardness of the water samples. All samples were diluted to 30 and then estimated by titration.

$$Total\ Hardness\ = \frac{CxDx1000}{mlofsample}$$

Where, C = ml of EDTA required, D = 1M

2.3.5 Calcium Hardness (Ca):
The calcium hardness of the water samples was determined by EDTA titration methods. In which 30 ml of well mixed sample was taken in a conical flask and pH of solution was adjusted up to10. A pinch of Murexide was added and titrated with 0.01M EDTA till pink solution changes to purple. The volume of EDTA consumed was noted and similarly a reagent blank with distilled water was run to calculate the hardness of the water samples. All samples were diluted to 30 and then estimated by titration.

$$Calcium\ Hardness = \frac{Cx1000x1.05}{mlofsample}$$

Where, C = volume of Titrant

2.3.6 Magnesium Hardness (Mg):
Mg Harness as $CaCO_3$ mg/l is the difference between Total Hardness and Calcium Hardness.

$$Mg\ Harness\ as\ CaCO3\ mg/l\ =\ (Total\ Hardness - Calcium\ Hardness)$$

RESULTS AND DISCUSSION

The monthly variation in selected groundwater quality parameters of Mangrol coastal area is presented in Table 3.1 to 3.6 and average data of 6 months is shown in Table 3.7.

3.1 pH:
All the groundwater samples showed near to neutral pH (7). The values were in the range of 6.54 to 8.17 during study period (August 2014 to January 2015) (Table 3.1 to 3.6). This value is in accordance with the prescribed limit set by Bureau of Indian Standards (BIS) for drinking water. Highest pH value was recorded at Site 8 (Gawaro Area) (8.17) in the month of January 2015 (Table 3.6) followed by Site 3 (8.14) and Site 4 (Jalaram Nivas-Fish Market) (8.12) in the month of November 2014 (Table 3.4). The lowest pH of 6.54 was observed in the month of September 2014 (Table 3.2) at Site 1 (Mangrol Port) and it was 6.58 at Site 10 (Hodi Chakla) in October 2014 (Table 3.3) while slightly increased pH value was recorded in the month of September 2014 (6.63) at Site 10. pH of groundwater samples mostly remained near to neutral (pH 7) and slightly alkaline (pH>7) while it was slightly acidic (pH <7) during September and October (monsoon). Comparable findings were also recorded at Perungudi, Southern part of Chennai by Ambica et al., [37] where they recorded the 6.6 pH of the groundwater similarly Soni and Pujari [38] recorded pH 8.1 of the groundwater in Kovaya located near coastal area of Gujarat. Fluctuations in pH values during different seasons of the year are attributed to factors like dilution of seawater by freshwater influx, reduction of salinity and temperature [39, 40, 41].

3.2 Electrical Conductivity (EC):
Electrical conductivity indicates the total dissolved solids in water. Electrical conductivity in waterways is affected by diverse factors like soil profile, land use, land cover, flow, surface runoff, groundwater inflow, temperature and evaporation. In present investigation, the electrical conductivity of the samples collected over study period ranged from 391.87µS to 1653µS (micro Siemens). High temperature favors the conductivity values resulting to change in its cation and anion concentration which indicates the presence of high amount of dissolved solids in ionized form. EC was highest at Site 10 (HodiChakla) (1653µS) in October 2014 followed by 1635.33µS at the same Site (Hodi Chakla) and 1627µS at Site 7 (Maktupur Road) in the month of October 2014 respectively. Lowest electrical

conductivity of 391.87 µS and 424.4µS was recorded in December 2014 (Table 3.6) at Site 8 (Gawaro Area) and Site 7 (Maktupur Road) respectively while Site 5 showed 428.6 µS in the month of December 2014. Similar results were obtained at coastal areas of South Chennai by Kumar [42], where they observe the EC of groundwater as 3140 µS towards Buckingham canal. Comparable findings were also recorded by Olufemi et al., [43] from borehole water sample in EtiOsa (Nigeria) with the highest conductivity of 1511µS. Soni and Pujari [38] also observed EC by 1112 µS of the groundwater sample in Kovaya located near coastal area of Gujarat. Mirza et al., [44] had also reported EC value 2082.11 µS in Satkhira district of southwest coastal zone of Bangladesh.

Table 3.1: Water Quality Analysis of the Samples Collected from Selected Areas of Mangrol Coast in August, 2014

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	BIS Desirable Limit	BIS Permissible Limit
pH	7.04 ±0.04	7.16 ±0.02	7.11 ±0.02	7.13 ±0.03	7.12 ±0.02	7.08 ±0.03	7.13 ±0.02	7.24 ±0.02	7.15 ±0.01	7.06 ±0.02	6.5-8.5	-
EC (µS)	1341.33 ±4.16	1454 ±4.00	1570 ±5.00	915 ±6.56	1231 ±6.08	1313.67 ±5.51	1486.67 ±5.51	551.33 ±6.66	1564 ±4.36	1635.33 ±8.39	-	-
TDS (mg/l)	903.33 ±4.93	1232 ±2.65	881.33 ±3.21	459.67 ± 5.51	604 ±6.08	782 ±2.65	735.67 ±2.08	284.67 ±2.08	846.67 ±3.79	1242 ±2.65	500	2000
Turbidity (NTU)	1.43 ±0.04	1.22 ±0.03	1.21 ±0.03	1.08 ±0.04	1.22 ±0.02	3.12 ±0.03	1.22 ±0.03	1.1 ±0.17	1.08 ±0.04	1.22 ±0.03	1	5
TH as $CaCO_3$ **(mg/l)**	453.3 ±5.8	510.0 ±10.0	466.7 ±5.8	436.7 ±5.8	413.3 ±5.8	430.0 ±10.0	383.3 ±5.8	423.3 ±15.3	520.0 ±10.0	496.7 ±5.8	200	600
Ca Hardness as $CaCO_3$ **(mg/l)**	399.0 ±10.5	423.5 ±12.1	402.5 ±6.1	332.5 ±12.1	399.0 ±10.5	413.0 ±16.0	357.0 ±10.5	371.0 ±16.0	350.0 ±12.1	381.5 ±6.1	75	200
Mg Hardness as $CaCO_3$ **(mg/l)**	54.3	86.5	64.2	104.2	14.3	17.0	26.3	52.3	170.0	115.2	30	100

Table 3.2: Water Quality Analysis of the Samples Collected from Selected Areas of Mangrol Coast in September, 2014

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	BIS Desirable Limit	BIS Permissible Limit
pH	6.54 ±0.02	6.67 ±0.07	7.03 ±0.03	7.13 ±0.03	7.05 ±0.02	6.87 ±0.01	7.03 ±0.02	7.14 ±0.04	6.92 ±0.02	6.63 ±0.03	6.5-8.5	-
EC (µS)	1493.67 ±5.51	1554.33 ±8.39	1334.33 ±4.93	787.67 ±2.08	1066.33 ±6.66	1313 ±6.08	1335.33 ±6.66	1555.67 ±3.79	1502.67 ±7.23	1614 ±6.08	-	-
TDS (mg/l)	1081.33 ±2.31	1114.67 ±8.08	922 ±6.93	431.33 ±7.51	564.67 ±2.89	812.33 ±4.04	698 ±1.73	792 ±3.46	773.67 ±4.62	962 ±3.46	500	2000
Turbidity (NTU)	0.52 ±0.03	0.52 ±0.02	0.42 ±0.03	0.53 ±0.05	0.64 ±0.06	0.43 ±0.04	0.54 ±0.06	0.45 ±0.07	0.54 ±0.06	0.71 ±0.02	1	5
TH as $CaCO_3$ **(mg/l)**	236. 7 ±5.8	633.3 ±16.0	226. 7 ±11.5	230.0 ±10	236.7 ±5.8	323.3 ±11.5	346.7 ±15.3	390.0 ±10.0	360.0 ±10.0	543.3 ±15.3	200	600
Ca Hardness as $CaCO_3$ **(mg/l)**	178.5 ±10.5	490 ±16.0	136.5 ±10.5	157.5 ±10.5	136.5 ±10.5	259.0 ±6.1	245.0 ±26.4	203.0 ±16.0	192.5 ±16.0	287.0 ±6.1	75	200
Mg Hardness as $CaCO_3$ **(mg/l)**	58.2	143.3	90.2	72.5	100.2	64.3	101.7	187.0	167.5	256.3	30	100

Table 3.3: Water Quality Analysis of the Samples Collected from Selected Areas of Mangrol Coast in October, 2014

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	BIS Desirable Limit	BIS Permissible Limit
pH	6.85 ±0.03	6.86 ±0.04	6.95 ±0.02	7.1 ±0.02	7.09 ±0.03	6.62 ±0.02	7.07 ±0.02	7.05 ±0.03	6.93 ±0.02	6.58 ±0.01	6.5-8.5	-
EC (µS)	1223.67 ±5.51	1425 ±7.81	1453.33 ±5.51	946.33 ±3.21	1244.67 ±5.51	1323.33 ±4.93	1627 ±4.36	703.67 ±5.51	1477.67 ±3.79	1653 ±4.36	-	-
TDS (mg/l)	913.67 ±5.51	995.33 ±8.39	930.67 ±3.79	488 ±4.36	630.33 ±6.66	865 ±7.81	828 ±4.36	337.33 ±4.93	813.67 ±5.51	1104.67 ±7.23	500	2000
Turbidity (NTU)	0.62 ±0.03	0.63 ±0.04	0.51 ±0.02	0.53 ±0.05	0.72 ±0.02	0.53 ±0.04	0.41 ±0.02	0.52 ±0.02	0.32 ±0.03	0.51 ±0.02	1	5
TH as $CaCO_3$ **(mg/l)**	473.3 ±20.8	303.3 ±5.8	343.3 ±11.5	270.0 ±10.0	316.7 ±15.3	440.0 ±10.0	310.0 ±10.0	243.3 ±15.3	253.3 ±11.5	373.3 ±5.8	200	600
Ca Hardness as $CaCO_3$ **(mg/l)**	318.5 ±6.1	234.5 ±12.1	332.5 ±6.1	227.5 ±16.0	248.5 ±16.0	332.5 ±6.1	294.0 ±10.5	220.5 ±10.5	238.0 ±16.0	311.5 ±6.1	75	200
Mg Hardness as $CaCO_3$ **(mg/l)**	154.8	68.8	10.8	42.5	68.2	107.5	16.0	22.8	14.0	61.8	30	100

3.3 Total Dissolved Solids (TDS):

Total dissolved solids has a direct relation with EC and thus as expected, TDS was also higher in the groundwater samples exhibiting high EC. TDS values were recorded in the range of 248.07 mg/l to 1242 mg/l. In August 2014, total dissolved solids concentration was 1242 mg/l at Site 10 (Hodi Chakla) followed by 1232 mg/l at Site 2 (Mangrol Beach) in the same month while 1114.67 mg/l in September 2014 at Site 2. High TDS values exceeding 1000 mg/l [38] and misbalance of anion and cation ratio [45] is commonly observed characteristic in coastal aquifers. Lowest concentrations were recorded in the month of December 2014 at Site 8 (248.07 mg/l) followed by 271.1 mg/l in December 2014 at Site 5 (Eidgaah) while third lowest concentration was 285.07 mg/l in the same month at Site 4 (Jalaram Nivas-Fish Market). The total dissolved solids are mainly composed of carbonates, bicarbonates, chlorides, phosphates and nitrates of calcium, magnesium, sodium, potassium, manganese, organic matter, salt and other particles. Geochemical characteristics of the ground are major determinants for varying TDS levels in groundwater. Based on taste, water with total dissolved solids content of less than 500 mg/L is regarded as good quality water [46] but water with extremely low TDS may taste flat and insipid. The values of TDS obtained in the present investigation are similar to values 1679 mg/l to 2841 mg/l previously recorded by Gummadi et al., [47] in Andhra Pradesh, Kumar [42] by 2,104 mg/l in Thivanmiyur coastal areas of South Chennai. Similarly Senthikumar et al., [48] by 1117 mg/l in post-monsoon and 1809 mg/l in pre-monsoon season in Cuddalore area of Tamil Nadu and Mirza et al., [44] had also reported TDS value of 1098.38 mg/l in Satkhira district, southwest coastal zone of Bangladesh.

Table 3.4: Water Quality Analysis of the Samples Collected from Selected Areas of Mangrol Coast in November, 2014

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	BIS Desirable Limit	BIS Permissible Limit
pH	7.63 ±0.15	7.88 ±0.02	8.12 ±0.02	8.11 ±0.02	8.03 ±0.03	7.72 ±0.02	8.03 ±0.02	8.14 ±0.03	7.84 ±0.01	7.72 ±0.02	6.5-8.5	-
EC (µS)	834 ±4.36	983.67 ±3.79	710.6 ±2.25	742.27 ±3.07	629.33 ±3.21	734 ±6.08	633.77 ±5.41	501.43 ±3.96	763.67 ±5.51	1030.33 ±3.21	-	-
TDS (mg/l)	625.67 ±7.23	661.67 ±3.21	485.97 ±3.49	524.87 ±5.22	365.07 ±4.31	520.33 ±4.93	465.07 ±4.32	350.53 ±3.11	577.8 ±2.03	717.67 ±5.51	500	2000
Turbidity (NTU)	0.42 ±0.02	0.32 ±0.03	0.33 ±0.04	0.53 ±0.05	0.53 ±0.04	0.63 ±0.04	0.51 ±0.02	0.43 ±0.04	0.41 ±0.02	0.42 ±0.03	1	5
TH as $CaCO_3$ **(mg/l)**	243.3 ±5.8	326.7 ±5.8	213.3 ±15.3	150.0 ±10.0	216.7 ±5.8	233.3 ±15.3	163.3 ±5.8	210.0 ±10.0	183.3 ±11.5	306.7 ±5.8	200	600
Ca Hardness as $CaCO_3$ **(mg/l)**	157.5 ±10.5	192.5 ±12.1	175.0 ±6.1	119.0 ±12.1	178.5 ±10.5	175.0 ±16.0	147.0 ±10.5	143.5 ±6.1	150.5 ±6.1	262.5 ±10.5	75	200
Mg Hardness as $CaCO_3$ **(mg/l)**	85.8	134.2	38.3	31.0	38.2	58.3	16.3	66.5	32.8	44.2	30	100

Table 3.5: Water Quality Analysis of the Samples Collected from Selected Areas of Mangrol Coast in December, 2014

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	BIS Desirable Limit	BIS Permissible Limit
pH	6.93 ±0.03	6.97 ±0.02	7.42 ±0.03	7.17 ±0.02	7.16 ±0.02	7.48 ±0.02	7.72 ±0.03	7.73 ±0.04	7.29 ±0.01	6.85 ±0.05	6.5-8.5	-
EC (µS)	519.33 ±4.93	636.33 ±3.21	487 ±4.36	477.27 ±2.37	428.6 ±4.68	484.5 ±4.77	424.4 ±6.29	391.87 ±5.74	491 ±6.08	562 ±6.08	-	-
TDS (mg/l)	310.33 ±6.66	429.33 ±4.93	299.6 ±4.68	285.07 ±3.93	271.1 ±4.29	387.43 ±4.86	366.73 ±3.81	248.07 ±2.61	298.93 ±3.52	424.33 ±6.66	500	2000
Turbidity (NTU)	0.32 ±0.03	0.53 ±0.04	0.73 ±0.05	0.51 ±0.02	0.52 ±0.03	0.63 ±0.04	0.62 ±0.03	0.32 ±0.02	0.43 ±0.04	0.33 ±0.05	1	5
TH as $CaCO_3$ **(mg/l)**	163.3 ±5.8	170.0 ±10.0	120.0 ±17.3	133.3 ±15.3	120.0 ±17.3	233.3 ±11.5	233.3 ±15.3	116.7 ±5.8	140.0 ±10.0	220.0 ±10.0	200	600
Ca Hardness as $CaCO_3$ **(mg/l)**	126.0 ±10.5	98.0 ±6.1	84.0 ±10.5	91.0 ±16.0	73.5 ±10.5	182.0 ±6.1	175.0 ±16.0	70.0 ±16.0	94.5 ±10.5	157.5 ±10.5	75	200
Mg Hardness as $CaCO_3$ **(mg/l)**	37.3	72.0	36.0	42.3	46.5	51.3	58.3	46.7	45.5	62.5	30	100

Table 3.6: Water Quality Analysis of the Samples Collected from Selected Areas of Mangrol Coast in January, 2015

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	BIS Desirable Limit	BIS Permissible Limit
pH	7.64 ±0.02	7.42 ±0.03	7.76 ±0.02	7.82 ±0.03	7.93 ±0.02	7.48 ±0.01	7.77 ±0.02	8.16 ±0.02	7.84 ±0.03	7.66 ±0.02	6.5-8.5	-
EC (µS)	903.67 ±5.51	1103.33 ±4.93	1179 ±4.36	1057.67 ±2.08	1144.67 ±5.51	1249 ±6.08	1096.33 ±6.66	487.33 ±4.93	945.67 ±3.79	1105.33 ±8.39	-	-
TDS (mg/l)	854.67 ±7.23	868.33 ±3.79	734.33 ±5.51	530.67 ±3.79	574.33 ±4.93	979 ±2.65	587.67 ±7.23	394.33 ±4.93	535 ±7.81	983.67 ±5.51	500	2000
Turbidity (NTU)	0.18 ±0.07	0.26 ±0.02	0.11 ±0.02	0.12 ±0.05	0.11 ±0.02	0.05 ±0.03	0.41 ±0.02	0.06 ±0.03	0.17 ±0.02	0.03 ±0.03	1	5
TH as $CaCO_3$ **(mg/l)**	556.7 ±5.8	573.3 ±5.8	256.7 ±15.3	350.0 ±10.0	370.0 ±15.3	550.0 ±10.0	250.0 ±5.8	270.0 ±10.0	306.7 ±11.5	453.3 ±11.5	200	600
Ca Hardness as $CaCO_3$ **(mg/l)**	367.5 ±10.5	301.0 ±6.1	192.5 ±12.1	262.5 ±10.5	220.5 ±18.2	371.0 ±12.1	227.5 ±16.0	136.5 ±10.5	203.0 ±6.1	357.0 ±10.5	75	200
Mg Hardness as $CaCO_3$ **(mg/l)**	189.2	272.3	64.2	87.5	149.5	179.0	22.5	133.5	103.7	96.3	30	100

3.4 Turbidity (in NTU):

There was as such no turbidity observed in the groundwater samples except during month of August 2014. Values of turbidity ranged from 0.02 to 3.12 NTU over study period. In August 2014, it was 3.12 NTU at Site 6 followed by 1.43 NTU at Site 1 and with the same value of 1.22 NTU at Site 2, 5, 7 and Site 10. Turbidity was near to negligible in January by 0.02 NTU (Site 10), 0.04 NTU (Site 6) and 0.05 NTU (Site 8). Comparative values were reported (0.1NTU) in Perungudi, southern part of Chennai by Ambica et al., [37]. Overall, the values of turbidity were well below desirable limit prescribed by BIS (except in August 2014). Turbidity in water is due to colloidal and extremely fine suspended matters [49].

3.5 Total Hardness (TH) as $CaCO_3$:

The values of total hardness were observed in the range of 116.7 mg/l to 633.3 mg/l. Maximum hardness was observed at Site 2 (633.3 mg/l) in September 2014 while it was 573.3 mg/l in January 2014 at same site. It was 556.7 mg/l in January 2015 at Site 1. In December 2014, there was drastic change in the trend of total hardness which was reduced to 116.7 mg/l at Site 8. Concentration of total hardness was 120 mg/l at Site 3 (Bara Road) and Site 5 followed by 133.3 mg/l at Site 4. Similar findings were also recorded by Soni and Pujari [38] where they observed total hardness of 800 mg/l during monsoon in Kovaya, coastal area of Gujarat while Champidi et al., [50] observed 1690 mg/l of hardness in Erasinos basin of eastern Attica. Pandian and Kumar [51] had also reported hardness content of the groundwater sample by 3391 mg/l in Tuticorin of Tamil Nadu. Hardness in water is due to natural accumulation of salts in contact with soil and varied geological formations. It may enter from the direct pollution caused by human activities and agricultural runoff as well. Other major sources of hardness include sewage, run-off from soils, limestone leachates, building materials with calcium oxide, textile and paper discharges containing magnesium [11] which results in variety of dissolved polyvalent metallic ions dominant in water. The water hardness may also be discussed in terms of carbonate (temporary) and non-carbonate (permanent) hardness [52]. In the present study, samples analyzed over study period showed total hardness concentration in the permissible limits (600 mg/l) prescribed by BIS.

3.6 Calcium Hardness as $CaCO_3$:

Concentration of calcium hardness (as $CaCO_3$ Hardness) in groundwater samples varied from 70 mg/l to 490 mg/l. In September 2014, the concentration of calcium hardness was at its peak i.e. 490 mg/l at Site 2 followed by 423.5 mg/l while at Site 6 considerably higher concentration of about 413 mg/l was recorded in August 2014. In December 2014, calcium hardness was relatively lower i.e. 70 mg/l at Site 8 and 73.5 mg/l at Site 5 followed by 84 mg/l at Site 3. Similar findings were also recorded by Soni and Pujari [38] with hardness of 516 mg/l during monsoon in coastal area of Gujarat, Champidi et al., [50] also observed higher value of 7400 mg/l in Erasinos basin of eastern Attica while Srinivas et al., [53] had recorded 1067 mg/l of calcium hardness in Kanyakumari of Tamil Nadu. Similar findings are reported by Pandian and Kumar [51] where they found calcium hardness value of 965 mg/l in Eppodumventran, Tuticorin of Tamil Nadu. High concentration of Ca and Mg may be attributed to seawater influx and fertilizer application on nearby land. Hardness of water is not a specific constituent and caused by dissolved polyvalent-metallic ions [54] which is variable and complex mixture of cations and anions.

3.7 Magnesium Hardness:

Magnesium hardness (as $CaCO_3$ Hardness) in groundwater was far more than the BIS permissible limit for drinking water quality standard in most of the samples. Magnesium Hardness concentration ranged from 10.8 mg/l to 272.3 mg/l. At Site 2, highest amount of Mg hardness (272.3 mg/l) was recorded in January 2015 followed by Site 10 (256.3 mg/l) in September 2014, whereas at Site 1 its concentration was 189.2 mg/l in January 2015. Magnesium hardness declined in October 2014 which accounted to 10.8 mg/l at Site 3 and 14.0 mg/l at Site 9 followed by Site 5 in August 2014 with a value of 14.3 mg/l. Alike readings were obtained by Champidi et al., [50] where they observed magnesium hardness by 1297 mg/l in Erasinos basin of eastern Attica. Olufemi et al., [43] also reported magnesium hardness by a value 108 mg/l at SP/07 in Lagos aquifer of Nigeria. Values of magnesium hardness were also recorded by Soni and Pujari [38] as 470 mg/l in coastal area of Gujarat, Sundaram and Mariappan [54] as 196 mg/l in Kanyakumari of Tamil Nadu while Pandian and Kumar [51] observed 2405.2 mg/l at Pudukottai, Tuticorin of Tamil Nadu.

Table 3.7: Average Values of Water Quality Parameters of the Samples Collected from Mangrol Coast during August 2014 to January, 2015 (Used for Mapping)

Parameters	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
pH	7.11	7.16	7.40	7.41	7.40	7.21	7.46	7.58	7.33	7.08
EC (µS)	1052.6	1192.8	1122.4	821.0	957.4	1069.6	1100.6	698.6	1124.1	1266.7
TDS (mg/l)	781.5	883.6	709.0	453.3	501.6	724.3	613.5	401.2	641.0	905.7
Turbidity (NTU)	0.58	0.58	0.55	0.55	0.62	0.90	0.62	0.48	0.49	0.54
TH as $CaCO_3$ **(mg/l)**	354.4	419.4	271.1	261.7	278.9	368.3	281.1	275.6	293.9	398.9
Ca Hardness as $CaCO_3$ **(mg/l)**	257.8	289.9	220.5	198.3	209.4	288.8	240.9	190.8	204.8	292.8
Mg Hardness as $CaCO_3$ **(mg/l)**	96.6	129.5	50.6	63.3	69.5	79.6	40.2	84.8	89.1	106.1

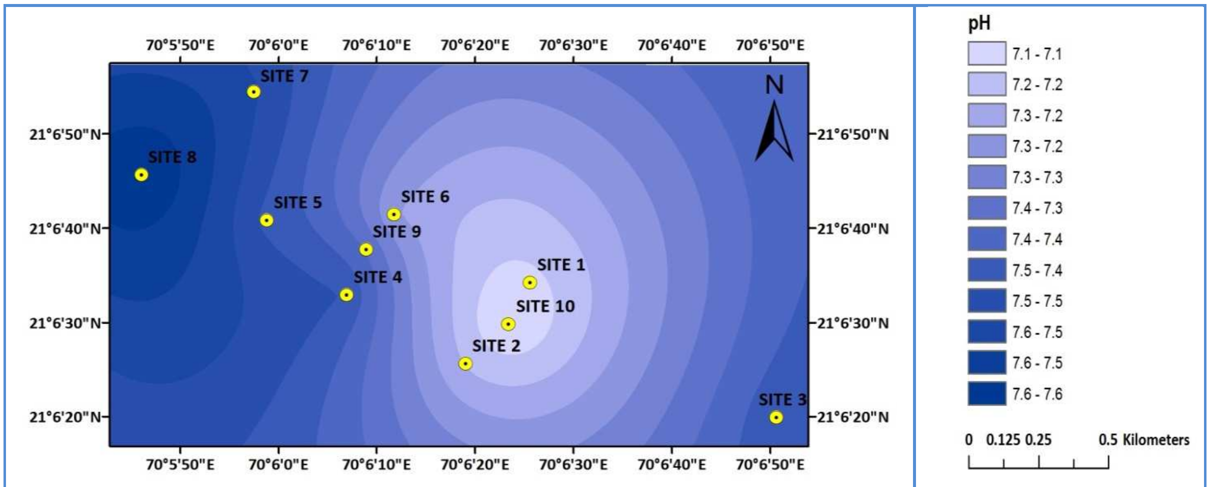

Fig. 3.1: Average Levels of pH at Selected Areas of Mangrol Coast

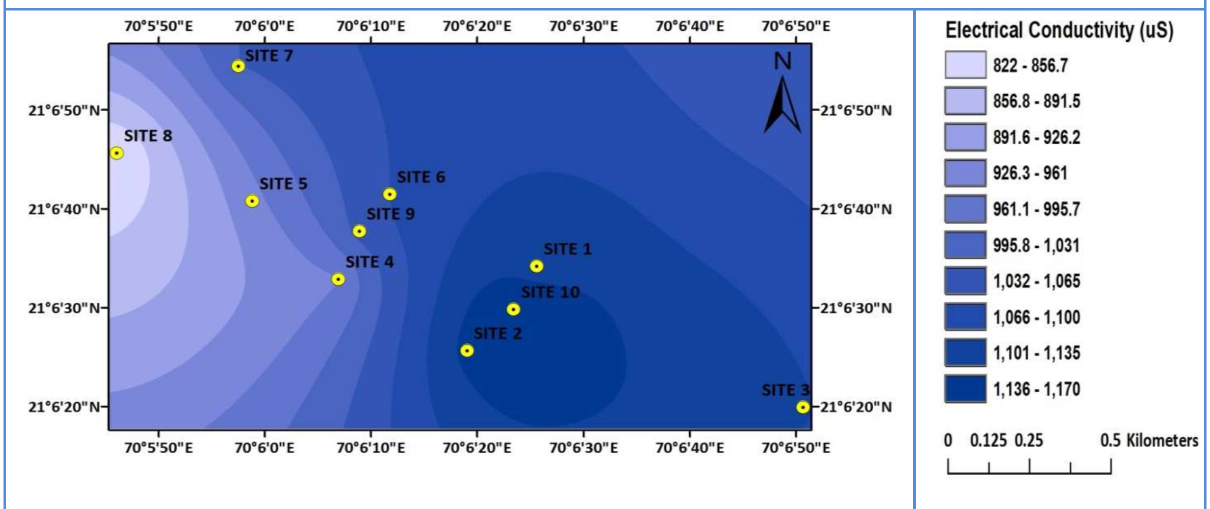

Fig. 3.2: Average Levels of Electrical Conductivity (µS) at Selected Areas of Mangrol Coast

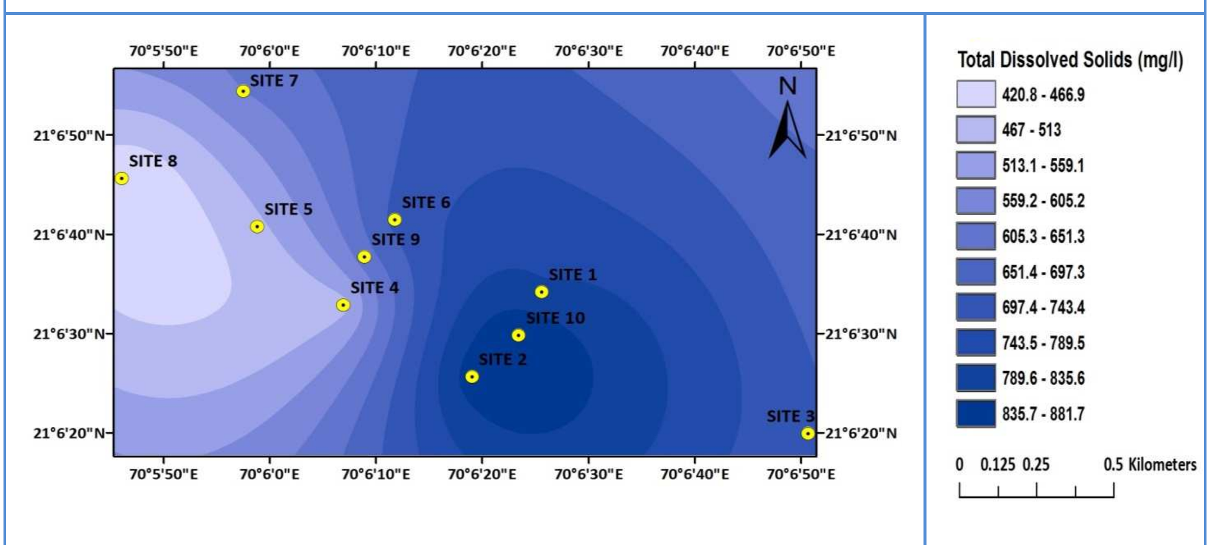

Fig. 3.3: Average Levels of Total Dissolved Solids (mg/l) at Selected Areas of Mangrol Coast

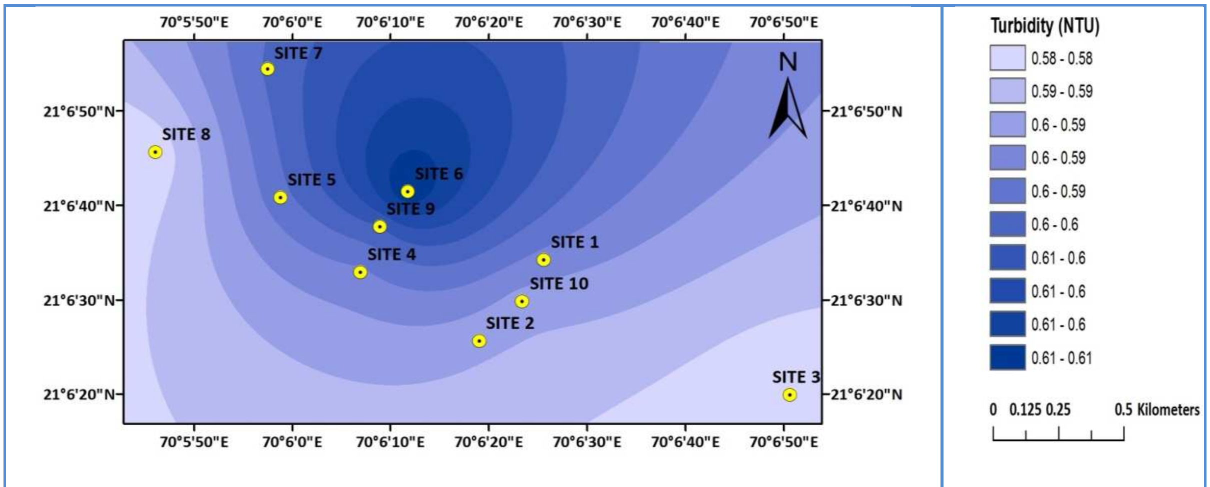

Fig. 3.4: Average Levels of Turbidity (NTU) at Selected Areas of Mangrol Coast

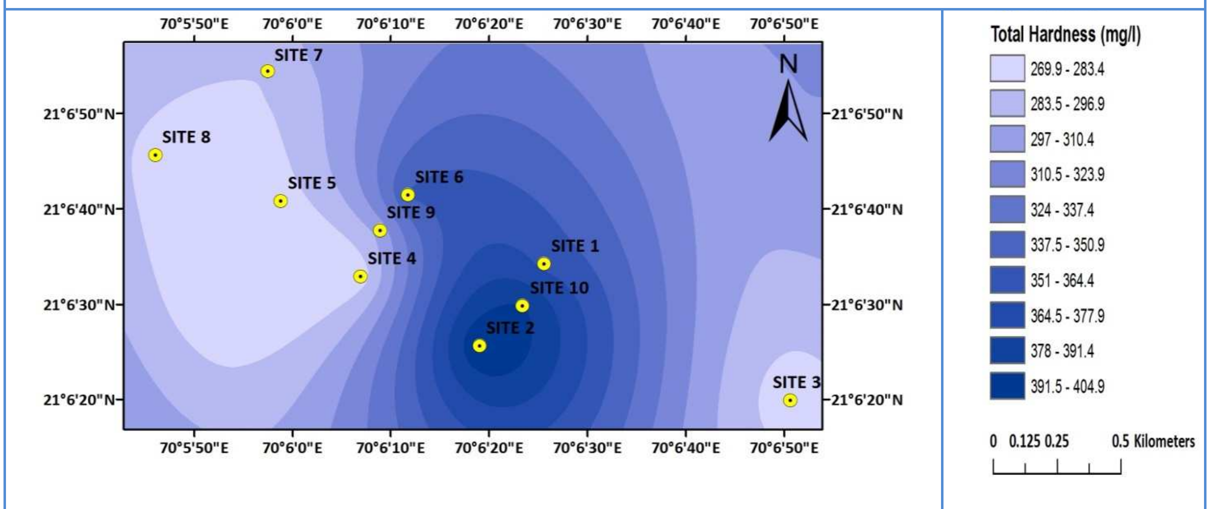

Fig. 3.5: Average Levels of Total Hardness (mg/l) at Selected Areas of Mangrol Coast

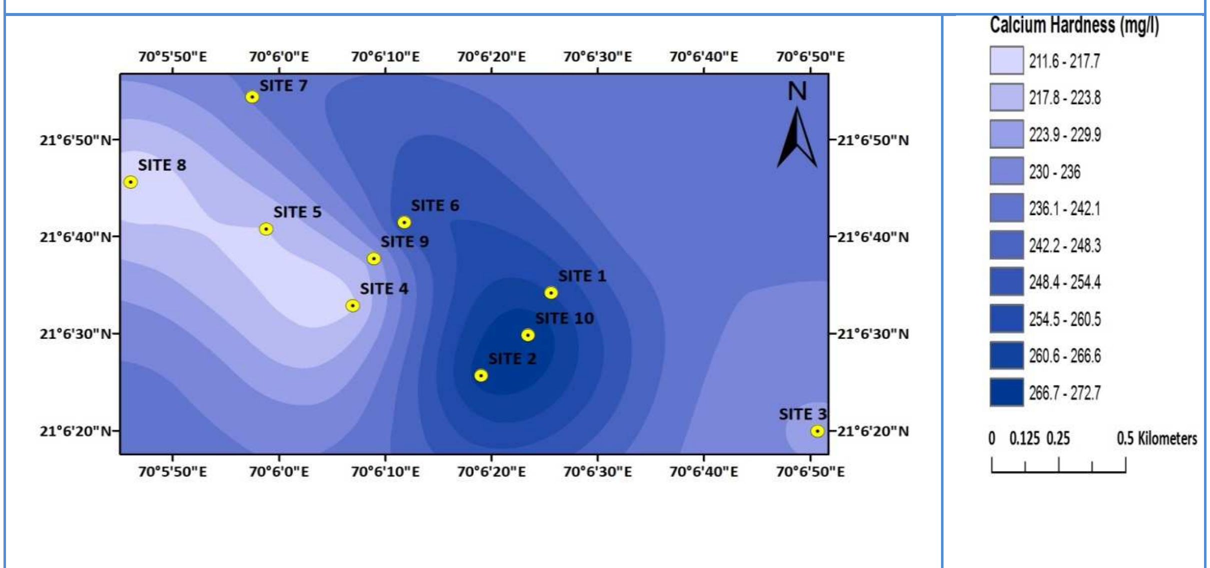

Fig. 3.6: Average Levels of Calcium Hardness (mg/l) at Selected Areas of Mangrol Coast

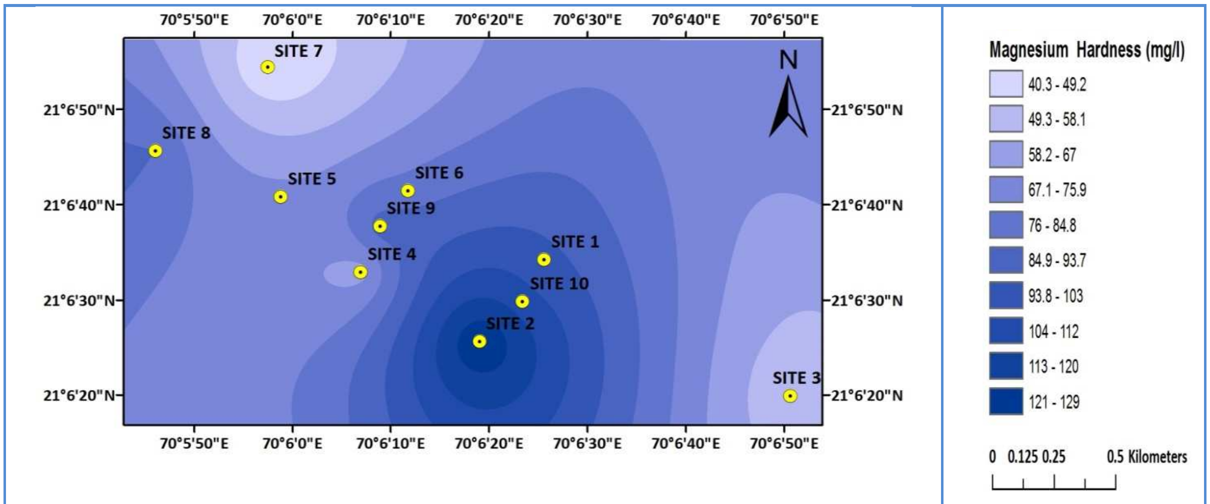

Fig. 3.7: Average Levels of Magnesium Hardness (mg/l) at Selected Areas of Mangrol Coast

CONCLUSION

Main purpose of the present investigation was to assess groundwater quality and create maps based on spatial distribution of selected parameters in coastal area of Mangrol, Gujarat. The results obtained showed that the composition of groundwater is largely affected by seawater intrusion, especially at Site 2 (Mangrol Beach). Many samples remained hard throughout the study area from August 2014 to January 2015. Highest pH value was recorded at Site 8 (Gawaro Area) (8.17) in January 2015 and while EC was highest at S Site 10 (Hodi Chakla) (1653 µS) in October 2014. In August 2014, total dissolved solids concentration was 1242 mg/l at Site 10 (Hodi Chakla) followed by 1232 mg/l at Site 2 (Mangrol Beach) in the same month while hardness was 633.3 mg/l at Site 2 (Mangrol Beach) in September 2014. In December 2014, there was drastic change in the trend of total hardness which was reduced to 116.7 mg/l at Site 8. Site 2 and Site 10 (Hodi Chakla) showed higher concentrations of the selected parameters as they are closely located nearby shoreline of Mangrol. Site 4 (Jalaram Nivas-Fish Market) and Site 8 (Gawaro Area) showed lower values for selected parameters and were comparatively better than other sites. Finally results of the study revealed that the quality of ground water varies widely from place to place in Mangrol coast area. Groundwater level also plays an important role in these variations.

Groundwater quality maps were generated which being easily interpretable, could serve as a communication tool to aware local people and governmental and non-governmental organizations. The monitoring programs using remote sensing and GIS are needed to detect and understand the potential of threats on larger scale. These techniques are very much effective, cheaper and valuable tools in groundwater monitoring at coastal level. We conclude that groundwater quality of Mangrol coastal area is under threat from saline water intrusion, geology of the environment, urbanization and influence of the seasons. There is an urgent need to take appropriate measures for safe and sustainable use of groundwater. Our study also concludes that the groundwater of Mangrol coastal area needs proper treatment before its use for drinking purpose. Continuous monitoring and regulations related to groundwater use must be in force ideally to prevent further degradation of the groundwater quality in the study area.

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