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Hydrogeochemical Evaluation of Mahanga Block, Cuttack District, Odisha, India

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Abstract Water quality analysis in the Mahanga block of Cuttack district indicate that, ground water quality is controlled by natural geochemical processes such as mineral weathering, dissolution/precipitation reaction, ion-exchange process. The chemical parameters such as Ca, Mg, Na, K, Cl, HCO_3, and SO_4 of groundwater play a significant role in classifying and assessing water quality. With respect to drinking water quality in comparison to BIS (1991) standards, TDS, TA, TH, Ca, Mg, Cl, F, NO_3 are found to exceed the highest desirable limits in some cases but not the maximum permissible limit. With respect to irrigation indices such as residual sodium carbonate (RSC), percent sodium (%Na), permeability index (PI), potential soil salinity (PSS), sodium adsorption ratio (SAR), the groundwater are suitable for irrigation purpose. The relative concentrations such as Ca/Mg, Na/Cl, $Cl/(HCO_3+CO_3)$ and base exchange index are used to assess the salinity of groundwater in the study area.

Keywords: *groundwater quality, Mahanga block, residual sodium carbonate, irrigation, permeability index, Doneen diagram, magnesium hazards*

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1. Introduction

Although man has been using groundwater prior to the dawn of civilization, the importance of quality was felt much afterwards. To be used for a particular purpose such as for domestic, irrigation and industrial, water must satisfy certain quality specifications as suggested by various national and international agencies. The problem like quality deterioration takes place both due to geogenic and anthropogenic reasons. The anthropogenic quality deteriorations take place due to mismanagement of solid and liquid wastes as a result of rapid growth in population, industrial and mining activities of a particular place and agricultural activities. Mahanga block, which is located in the extreme north- eastern part of the Cuttack district, Odisha is present on an alluvial plain of Mahanadi delta. Like any other delta region, there is no dearth of groundwater but the qualitative aspects need to be studied to judge their suitability for various use. Moreover in Mahanadi delta, salinity of groundwater is a great concern for the local people since saline aquifers occur at different depths sandwitched between fresh water aquifers up to tens of kilometres inlands causing uncertainity in getting fresh water. Keeping these aspects in view, an attempt has been made to evaluate the groundwater quality in the Mahanga block of Cuttack district, Odisha.

2. Study Area

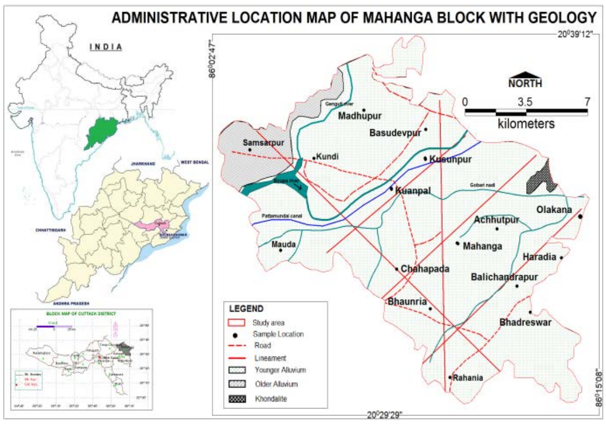

Figure 1. Llocation map of Mahanga block

The study area is Mahanga block of Cuttack district is located at a distance of 41 km from Cuttack city, in the Mahanadi Delta area of eastern part of Cuttack district, Odisha (Figure 1). The area extends between north latitudes 20°C] 29'29" to 20°39'12" and east longitudes 86°02'47" to 86°15'08" with a study area of 206.44 sq km. The Mahanadi delta zone has a tropical to sub-tropical climate and the average annual rainfall in Mahanga block is 1716.4 mm. The average temperature in this region varies between 22°C and 44°C in summer and between 10.5°C and 30.2°C during winter season. The most important economic activity of this area is agriculture and the major crops are paddy, sugarcane, maize, ragi, oil seeds, pulses and vegetable etc. The irrigation system is mostly fed by the surface water through canal system. A large canal named Pattamundai canal flows through the area irrigating the crop lands. The distributaries of the Mahanadi river like Genguti and Birupa rivers control the main drainage system of the area. The area of study, which forms a part of the Mahanadi delta occupies upper and mid-deltaic plains.

3. Geology and Hydrogeology

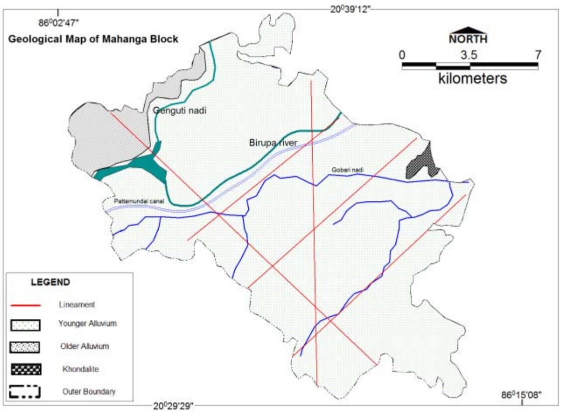

Figure 2. Generalised geological map of study area

Geologically, the study area is a part of the Peninsular India formed by the Archaean basement of Eastern Ghats Supergroup. During the drifting of the Indian Plate from Antarctica and Australian plate in the end of the Mesozoic period, the subsidence of the East coast basin took place where the deposition of deltaic sediment has been going on till now (Mahalik, 2000). The alluvial deposits in this area mainly form flood plain and palaeo channel deposits, gravels and patches of kankar formations belongs to the Tertiary to Quaternary age. The geology of the study area is shown in Figure 2 where residual hill is represented by khondalite, which is also present as basement. In addition to the Precambrian basement rocks, two alluvial deposits of contrasting characters and agesbelonging to two distinct formations namely younger alluvial formation and older alluvial formation also occur in the study area. The older alluvial sediments which are grey to brown in colour, unfossiliferous containing lots of calcareous concretions occur mainly in the upper part of the Mahanadi delta. These are potential source of groundwater occurrence with a yield capacity of 10-15 lps. The younger alluvium consisting of clay, sand, gravels and pebbles occupies major part of the deltaic plain as mid-deltaic plain & lower deltaic plain of Mahanadi delta. They occur as narrow strips of limited thickness along the course of major river channels such as Birupa, Genguti and other streams and streamlets in the unconsolidated terrain. The thickness of the alluvial deposits ranges from 30 to 400 m. The clay fraction of these alluvial soil ranges from 40–45% containing predominantly montmorillonite. The alluvial deposits are fertile and very suitable for agricultural activities because of their adsorption and retention of water and plant nutrients. These younger alluvium are also potential source of ground water occurrence with a yield capacity of 30 to 50 lps. The depth of water level in the study area varies from 1.5 mbgl to 4.5 mbgl. The depth to water table map of the study area is given in Figure 3. A very significant occurrence in the alluvial terrain is that of a lateritic horizon which is present at a depth varying from 18.22 to 42.86 m bgl at Basudevpur and from 42.69 to 45.77 m bgl at Kuhunda areas. The same lateritic horizon has been reported by Shukla (2011) at different depths in the Mahanadi delta in other areas.

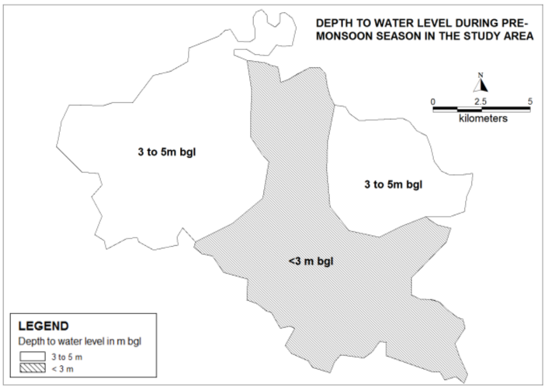

Figure 3. Depth to water table map of the study area

4. Materials and Method

A total number of 15 samples were collected from all over the block during Pre-monsoon (May-2009) from tube wells (09) and dug wells (06). All the chemical constituents were analysed following standard methods (APHA, 1985, Jain et al., 1987, 89). Temperature, electrical conductivity (EC) and pH were measured on the spot using a portable water analysis kit. Alkalinity was determined by acid titration with 0.01 N HCl. Chloride was determined by acid titration with $AgNO_3$. Major cations and anion elements such as Ca, TH, HCO_3 and CO_3 were determined by adopting standards method of titration. Spectrophotometer was used to determine concentration of SO_4 and flame photometer for Na and K. Ion analyzer was used for the determination of nitrate and fluoride. The normalized inorganic charge balance was used to estimate overall analytical uncertainty and it was found to be within the limit.

5. Hydrogeochemistry

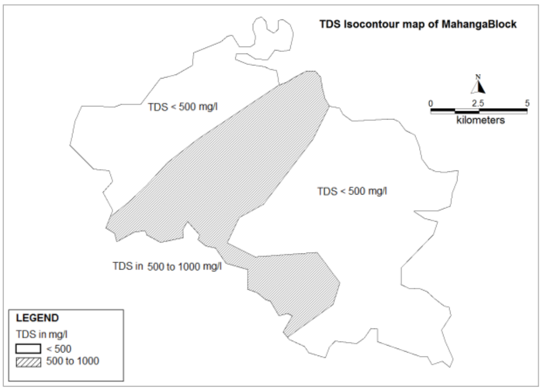

Figure 4. Isoconcentration map for TDS

The hydrochemical data of different locations of Mahanga block is given in Table 1. The pH value indicates both acidic to alkaline nature of groundwater with a value of 6.56 to 8.25 (6.56 to 7.68 in tube wells and 8.15 to 8.25 in dug wells) indicating that shallow aquifer water are more alkaline than deeper aquifer. The conductivity value varies widely from 200 to 2010 µS/cm with an average of 665 µS/cm indicating saline water influence in some cases. The total dissolved solid concentration varies from 128 mg/l to 1246 mg/l and the isoconcentration map for TDS indicates higher concentrations in the central part (Figure 4). The total alkalinity (TA) of the water samples varies from 60 to 265 mg/l where as total hardness varies widely from 65 to 550 mg/l. Out of the total groundwater samples collected, 40% of the samples are "soft to moderately hard" whereas 60% of the samples are "hard to very hard" and are unsuitable for domestic and drinking purpose. The calcium concentrations can be classified as moderately high which varies from 12 to 200 mg/l where as Mg varies significantly from 1.2 to 42.1 mg/l. The sodium concentration of the groundwater samples in the area varies from 11 to 290 mg/l. The HCO_3 concentration of groundwater varies from 24 to 220 mg/l with an average of 101 mg/l and is the major anion facies of the groundwater followed by Cl which varies significantly from 7.1 to 600 mg/l. The isoconcentration maps for Ca and Cl are given in Figure 5 and Figure 6 respectively. The SO_4 concentrations vary from 0.7 to 70.9 mg/l.

Table 1. Hydrogeochemical data of Mahanaga block

Location	pH	EC	TDS	TA	TH	Ca	Mg	Na	K	SO_4	Cl	HCO_3	NO_3	F
Basudevpur (T)	7.18	921	589	250	260	35	42.1	170.1	2.4	68.3	55	110	12.8	0.56
Bhadreswar (T)	7.49	689	441	260	270	45	38.4	100.2	7.5	26.4	50	98	4.3	0.79
Bhaunria(T)	7.1	1310	838	260	490	130	40.2	120.8	4.3	33.3	135	110	24.6	0.88
Chahapada (T)	7.16	325	208	130	220	45	26.2	35.6	8.0	8.8	30	98	8.2	0.91
Haradia(T)	6.89	350	224	110	245	45	32.3	31.4	10.4	4.8	35	55	3.2	0.98
Kuanpal(T)	6.91	2010	1286	265	550	200	12.2	290.4	4.3	70.9	600	110	*49.3*	0.94
Kusupur(T)	6.93	1120	717	185	490	130	40.2	125.6	9.7	26.8	190	98	*45.6*	0.82
Madhupur (T)	7.45	386	247	155	100	25	9.1	65.5	2.4	3.8	25	55	3.8	*1.10*
Mahanga(T)	6.56	291	186	75	65	15	6.7	14.7	2.3	6.1	45	85	3.3	0.99
Olakana(T)	7.68	750	480	195	460	120	39.0	48.8	2.7	3.3	30	110	14.4	0.69
Achhutpur (D)	8.25	240	154	90	100	34	3.7	11	1.4	3.3	7.1	140	0.67	*1.02*
Balichandrapur(D)	8.24	430	275	70	90	12	14.6	61	4.1	19	99	24	19	0.32
Kuanpal(D)	8.18	720	461	180	255	60	25.6	48	5.5	29	92	220	30	0.47
Kusunpur(D)	8.19	230	147	65	85	32	1.2	14	3.1	0.7	18	104	1.2	0.27
Mahanga(D)	8.15	200	128	60	80	22	6.1	11	2	2.4	11	104	1.1	0.26

N.B. – Values are in mg/l except pH and EC, EC is in µS/cm.

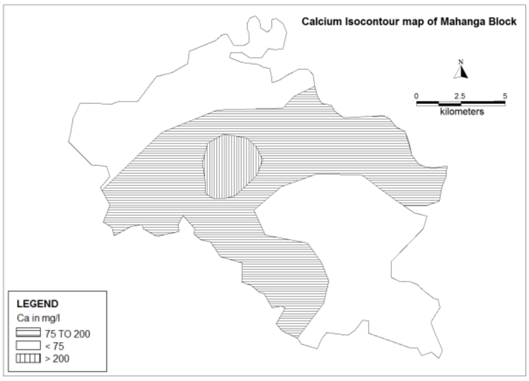

Figure 5. Isoconcentration map for Calcium

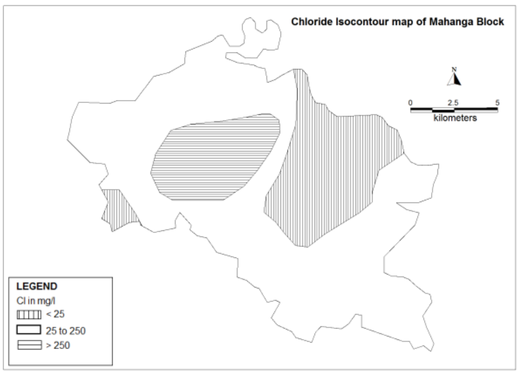

Figure 6. Isoconcentration map for Chloride

6. Hydrogeochemical Evaluation

The quality of groundwater shows the effect of lithological control since the plots are dominantly in the "rock dominance" field of the diagram (Figure 7 & Figure 8) proposed by Gibbs (1990). Piper classification (Figure 9) shows dominance of "alkali metals" over the "alkaline earth metals" and represents a Ca-HCO_3 facies as a dominant facies all over the area. The groundwater classification for drinking purpose as per specification of BIS (1991) (Table 2) indicate that, 26% of total samples are found above the desirable limit for total dissolved solids, total alkalinity, total hardness and Ca but not above the maximum permissible limit. According to Winslow and Kister (1956), the groundwater can be classified as non-saline (TDS =<1000 mg/l) to slightly saline (TDS =1000 – 3000 mg/l). The total hardness value indicates their classification range from "soft to very hard' (Twort et al, 1974) with 40% of the samples within "soft to moderately hard" category and 60% of the samples from "hard to very hard" but not beyond the maximum permissible limit (600 mg/l) of BIS (1991). With respect to cations, Ca is higher in most of the samples and 26% of the sample found to have values above 75 mg/l which is the highest desirable limit. The Mg concentration is second abundant after Ca with 40% of the samples have values above the highest desirable limit of 30 mg/l. Fluoride and nitrate values vary from 0.2 to 1.1 mg/l and

0.7 to 49.3 mg/l respectively. At Kuanpal and Kusupur, nitrate values found above 45 mg/l, which may be due to contamination from agricultural field lying nearby. Except two locations, the fluoride concentration is within the range of highest desirable limit.

Table 2. Comparison of the hydrogeochemistry of the area with that of BIS(1991) specifications

Quality Parameter	Pre-monsoon season			BIS (1991)		
	Min.	Max.	Avg.	Highest Desirable Limit	Maximum Permissible Limit	No. of Samples morethan the Desirable limit(out of 15)
pH	6.56	8.25	7.49	6.5 - 8.5	No Relaxation	Nil
EC (μS/cm)	200	2010	665	-	-	
TDS (mg/l)	128	1286	425	500	2000	4
Hardness (mg/l)	65	550	251	300	600	4
Alkalinity (mg/l)	60	265	157	200	600	4
Ca (mg/l)	12	200	63	75	200	4
Mg (mg/l)	1.2	42.1	23	30	100	6
Na (Mg/l)	11	290	77	-	-	
K (Mg/l)	1.4	10.4	5	-	-	
HCO_3 (Mg/l)	24	220	101	-	-	
Cl (mg/l)	7.1	600	95	250	1000	1
SO_4 (mg/l)	0.7	70.9	20	200	upto 400	Nil
F (mg/l)	0.2	1.1	0.73	1	1.5	2
NO_3 (mg/l)	0.7	49.3	14.8	45	100	2

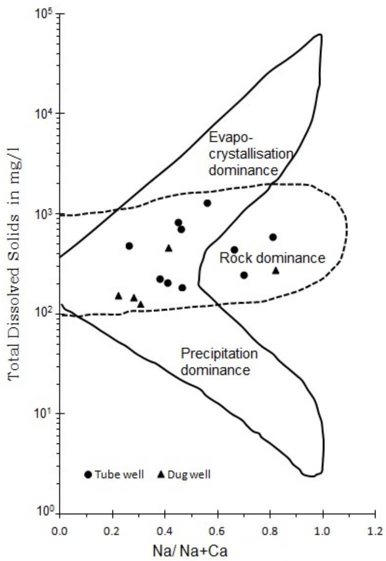

Figure 7. Plots in the Gibbs' diagram for cations

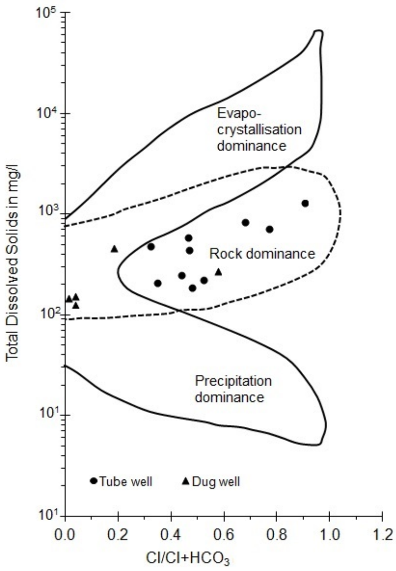

Figure 8. Plots in the Gibbs' diagram for anions

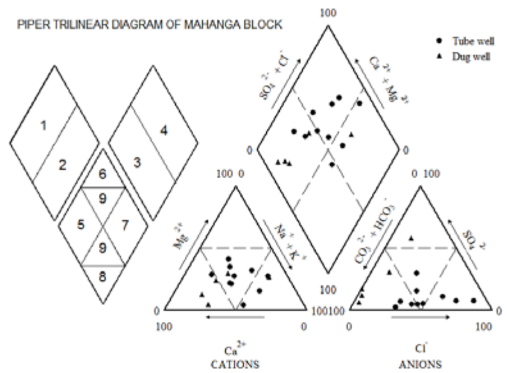

Figure 9. Plots in the Piper's diagram

To classify the groundwater for irrigation, various parameter such as potential soil salinity (PS), percent sodium (%Na), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), Mg ratio (MR) etc were calculated (Table 3) and interpreted. Calculated values of samples were plotted on USSL diagram, Wilcox diagram, Doneen diagram etc. for classification. On the basis of US Salinity Laboratory (Richards, 1954) diagram (Figure 10), 3 samples are classified as C1S1 (low sodium-low salinity), 8 samples as C2S1 (Low sodium-medium salinity) and 3 samples as C3S1 (Low sodium-high salinity) water for irrigation which are good for irrigation in alluvial area due to high porosity. Only one sample represent the C3S2 (Medium sodium-medium salinity) water which is moderately suitable for irrigation. With respect to Wilcox diagram (1955) (Figure 11), 26% of the total samples fall in the field of "permissible to doubtful", "doubtful to unsuitable" and "unsuitable" field but others are suitable for irrigation. In the Doneen diagram (1964), when total ion concentration is plotted against permeability index (Figure 12), 53% of the samples plotted fall in the field of "Class-II" i.e. the field of "moderately suitable water" for irrigation. The RSC values of the groundwater samples in the area classify them as "Good" for irrigation as they have less than 1.25. With respect to potential soil salinity (PS) value of groundwater, except two samples, all other samples are classified as "excellent to good" (<5 epm) but only one sample is classified as “good to injurious” category (5-10 epm) and one samples in “injurious to unsatisfactory” category (>10 epm). The index of magnesium hazard is a measure of magnesium ratio (MR), which is computed by following the formula as MR= {Mg/(Ca+ Mg)} X100 where all ionic concentration are expressed in meq/l. Magnesium Hazard occur when the fresh water acquire Mg ratio of more than 50% (Paliwal, 1972) resulting in low production of crops due to development of alkalinity in the soil. The excess amount of Mg due to ion exchange with Na in water enhances the alkalinity and affects the quality of soils, which is the cause of poor crop yields. The Mg ratio of the water samples varies from 5.9% to 66.8% with 4 samples having Mg ratio values of more than 50%, which may affect the production of crop yield in the study area. For industrial purpose, the corrosive ratio is taken to classify groundwater. The Corrosive ratio (C.R.) is defined by the formula (Rhyzner, 1944) as C.R.= {(Cl/35.5)+2(SO_4/96)} / {2(HCO_3+CO_3) / 100} where all ionic concentration are expressed in mg/l. On the basis of the CR, 53% of total samples are classified as safe (CR = <1) and 47% as unsafe (CR = >1).

Table 3. Parameters for groundwater quality assessment

Sl.No	SAR	%Na	P.S in epm	RSC in epm	P.I.	M.R.	Ca/Mg	Na/Cl	Cl/(HCO_3+CO_3)	BEI
1	4.59	58.89	2.26	-3.40	69.34	66.46	0.50	4.77	0.86	-3.81
2	2.65	45.72	1.69	-3.80	57.63	58.46	0.71	3.09	0.88	-2.23
3	2.37	35.38	4.15	-7.99	43.83	33.79	1.96	1.38	2.11	-0.41
4	1.04	28.47	0.94	-2.80	47.30	48.99	1.04	1.83	0.53	-1.07
5	0.87	24.94	1.04	-4.00	36.92	54.21	0.84	1.38	1.10	-0.65
6	5.39	53.71	17.66	-9.18	59.18	9.13	9.95	0.75	9.39	0.25
7	2.47	36.82	5.64	-8.19	44.10	33.79	1.96	1.02	3.34	-0.07
8	2.85	59.27	0.75	-1.10	78.33	37.62	1.66	4.04	0.78	-3.13
9	0.79	34.96	1.33	0.09	93.82	42.43	1.36	0.50	0.91	0.45
10	0.99	19.26	0.88	-7.40	30.62	34.90	1.87	2.51	0.47	-1.59
11	0.48	20.47	0.17	0.30	80.50	15.07	5.64	5.08	0.04	-4.46
12	2.80	60.48	1.57	-1.41	73.62	66.78	0.50	4.95	1.36	-4.15
13	1.31	30.41	1.78	-1.49	55.46	41.30	1.42	2.55	0.23	-1.72
14	0.66	28.85	0.21	0.01	83.02	5.91	15.92	31.84	0.01	-34.99
15	0.54	24.88	0.18	0.11	85.86	31.36	2.19	7.19	0.04	-6.96
Min	0.48	19.26	0.17	-9.18	30.62	5.91	0.50	0.50	0.01	-34.99
Max	5.39	60.48	17.66	0.30	93.82	66.78	15.92	31.84	9.39	0.45

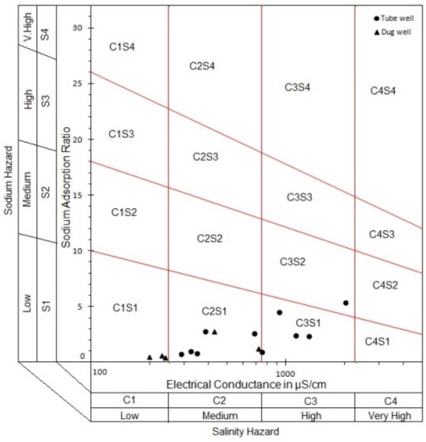

Figure 10. Plots in the U.S.Salinity diagram

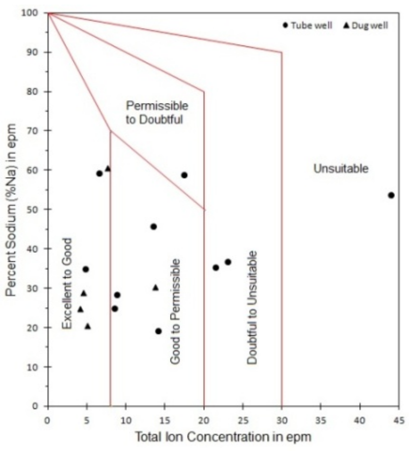

Figure 11. Plots in the Wilcox diagram

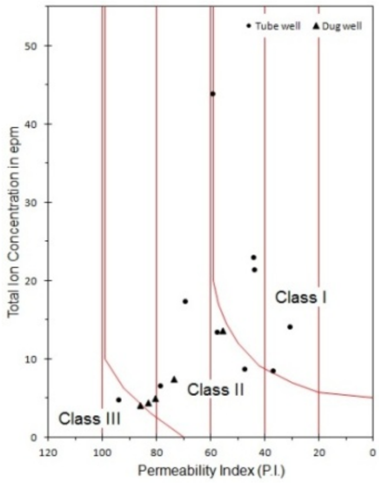

Figure 12. Plots in the Doneen diagram

Since the study area is a part of deltaic area and affected by marine transgression and regression during past history (Mahalik, 2000), some saline water patches lie in the area even after the flushing by fresh water. Certain chemical parameters such as Ca/Mg, Na/Cl, Cl/(HCO_3+CO_3) and base exchange index (BEI) were taken into consideration to assess the influence of saline water. A low value (0.18) of Ca/Mg ratio indicative of saline water intrusion (Hem, 1975; Mendel & Shiftan, 1981) but in the study area, the Ca/Mg ratio values vary in between 0.5 to 15.92 indicating no large scale saline water intrusion at the sample collected sites. In normal hydrogeological cycles, the Na/Cl ratio values should be morethan 1 for fresh water. The collected samples of the study area show the values varying within 0.50 to 31.84, so there is no saline water intrusion. Among the anions, Cl and (HCO_3+CO_3) indicate two different environments such as sea water and fresh water respectively. The ratio of Cl/(HCO_3+CO_3) values as given by Simpson (1946), classify the water of study area in to different types such as “fresh water” to “contaminated water” with a range of 0.01 to 9.39. Three samples fall in the range of normal freshwater (<0.05) type, 8 samples are in the slightly contaminated groundwater (0.05 – 1.30) type, 2 samples fall in the moderately contaminated groundwater (1.30 – 2.80) type and one samples each in the injuriously contaminated (2.80 – 6.60) and highly contaminated (6.60 – 15.50) groundwater type out of total 15 samples. So there is no indication of any saline intrusion except few local cause of contamination. Schoeller (1959) proposed base exchange index to interpret the effect of sea water intrusion. The BEI values of the collected water samples of the study area are mostly negative ranging within -34.99 to 0.45 indicating the release of alkali metals from the aquifer but few positive values indicate involvements of Na & K in ion exchange process. In the area of study, no large scale intrusion of saline water into the fresh water zone can be interpreted but the salinity in some cases could be due to local causes of contamination in small scales only. Presence of inherent salinity since the time of sedimentation and their entrapment within the sediments i.e. connate water sources could be the reason of local salinity of the groundwater in some cases.

7. Conclusions

The groundwater quality assessment of the Mahanga block of Cuttack district reveals that, in terms of drinking water quality, certain chemical constituents such as Ca, Mg, Cl, F, NO_3, TH, TA and TDS are higher than the desirable limit (BIS 1991). The higher concentration of Mg, Na, TDS makes the water unsuitable for irrigation purpose at some locations. The analysis of various cationic and anionic ratios such as Ca/Mg, Na/Cl, Cl/(HCO_3+CO_3) and BEI of groundwater samples indicate that there is no saline water intrusion in the aquifer except few local source of contamination due to entrapment of connate water within sediments.

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