J. Indian Chem. Soc.,
Vol. 97, May 2020, pp. 799-817

Increasing threat on groundwater reserves due to seawater intrusion in Contai belt of West Bengal

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Manuscript received online 27 January 2020, revised 24 February 2020, accepted 03 March 2020

India has a long coastline. Compared to the western coastline, the eastern coast line is severely affected by seawater intrusion. The Contai town is located in Purba Medinipur district of West Bengal on the eastern coastline of India. The soil of the region is mainly of fresh alluvials. There are few rivers flowing through the region, but this surface water is not sufficient to meet the domestic, industrial, agricultural demand. With the increasing population, urbanization, industrialization, the demand for water is increasing. To meet up such water demands, over extraction of groundwater is taking place due to which there is an inward movement of sea water into the region. The data obtained from the chemical analysis carried out by SWID at selected locations of the region stand as an evidence for the above statement.

Keywords: Sea water intrusion, pH value, chloride concentration, total dissolved solids (TDS), iron content, turbidity, artificial recharge, ground water contamination.

Introduction

India has a coastline of around 7530 km touching nine (9) states and four (4) Union Territories (UTs). Coastal length of mainland India is around 5300 km and coastal length of all islands (including Andaman and Nicobar, Kavaratti islands) is around 2000 km. It is washed by the Bay of Bengal and extends from the Ganga delta to Kanyakumari (North to South). It is a sandy coast with straight shorelines and mostly comprises of recent and tertiary alluvium deposits. It has many large river-deltas made by the large rivers originating in the Western Ghats and receives rainfall from both south-west and north-east monsoons. The western coastal plain is located between Kerala and Gujarat and extends from the Arabian Sea to the Western Ghats. Its total length is 1400 km, width ranges from 10 km to 80 km. The eastern coastal plains are a wide stretch of landmass of India, lying between the Eastern Ghats and the Bay of Bengal. It is wider and leveled than the western coastal plains and stretches from Tamil Nadu in the south to West Bengal in the north through Andhra Pradesh and Odisha. The lithological characteristic of eastern coast of India is such that it is more prone to saline water intrusion.

A field based study was done at Digha in Purba Medinipur district[1]. Data readings from augur holes were taken along three lines 25 km from Digha. Fresh water wedge (chloride concentration varying from 20 to 300 ppm) was found which are separated by saline water intrusion, one at top and one at bottom of the aquifer. Isochlor and chloride to bicarbonate ratio findings also supported the zone of varying thickness of sea water intrusion. Interface due to tidal and groundwater recharge movement also occurred. It had been calculated on Ghyben-Herzberg principle.

Work done on environmentally sensitive coastal area along the Adriatic coast of Emilia-Romagna[2] showed that water from unconfined aquifer on being examined proved that sea water intrusion was taking place. Detailed investigation on soil properties and chemical analysis of groundwater were carried out even in Purba Medinipur district. It was found that sea water invaded into the land area of the district and ground water quality was deteriorating[3].

The saline water intrusion in coastal aquifers is depended upon balance between fresh water and salt water from the sea[4]. It is also dependent upon geology, hydrogeology, pumping rates of wells. Quantification of the fresh water was done for which detailed analysis regarding tidal mixing, wind mixing and river flow had been carried out. For this reason detailed investigation was conducted in deltaic region of Bangladesh. According to this study the most affected area due to saline water intrusion was south western region of Bangladesh which was mainly caused by cyclone and storm surges, capillary action. It was recommended that the remedial measure like building up of dam, sluices, effective utilization of land uses etc. which could mitigate the saline water intrusion effect and increase the effective yield of crops.

The withdrawal of fresh water from the aquifer is the main reason of sea water intrusion[5]. It causes groundwater quality deterioration. Electrical resistivity sounding technique and hydro chemical studies were adopted to determine the interaction between saline water and fresh ground water[5]. The analysis was performed at Periyar River basin in central Kerala, India. By electrical resistivity method and water samples collected from thirty two shallow wells showed the direction of saline water intrusion in the study area.

The surface water is inadequate at Purba Medinipur district[6]. So use of groundwater is becoming more and more due to increased population, industrialization, urbanization. Due to over extraction of ground water, sea water intrusion is taking place in that district. To support this various field studies related to sub soil characteristics, ground water quality parameter assessment had been carried out. Piezometric surface of underground water at various seasons had also been developed. It had also been estimated the safe yield from vertical and qanat well in that locations. It had also been concluded from the journal that vertical riser coupled with quanta well were suitable for that district. A detailed analysis was done on how our livelihood was dependent upon fresh water obtained from aquifer[7]. Since the quality of fresh water was affected due to saline water intrusion especially in coastal aquifers of Nigeria. It was suggested various techniques to reduce the effect of saline water intrusion in fresh aquifers.

Mapping of subsurface extent of saline water intrusion into the Dahomey basin, Nigeria was done[8]. Geoelectric sounding methods were adopted to examine this. Hundred and eight vertical electrical soundings were done and nine induced polarization soundings data were collected using Schlumberger array techniques. By this method the depth of various aquifers in the study area was also estimated. Due to excessive overdraft of groundwater, sea water intrusion is taking place in Purba Medinipur district[9]. On the experimental studies, high values of ground water quality parameters were observed at various locations of the district. Remedial measures were proposed to mitigate the problem of sea water intrusion. Since sea water intrusion was taking place in Purba Medinipur district, and ground water is taking the shape of cone of depression[10].

An extensive research was carried out on Fum Al Wad aquifer which is located between Atlantic Ocean in the West and Laayoun in the East in Morocco[11]. Due to highly exploitation of water resources, sea water intrusion was taking place. Freshwater- salt water interface was governed by factors like precipitation, evapotranspiration etc. The modeling of the groundwater saltwater intrusion was done by SEAWAT 2000 software which was coupled with both MODFLOW 2000 and MT3DMS softwares. This work simulated variable density of groundwater flow and solute transport in three dimensions.

A detailed analysis was done on the level of saline water intrusion effect and its causes. The analysis was made based on water quality parameters like Cl^-, CO_3^{2-}, HCO_3^- and electrical conductivity (EC) values. Level of sea water intrusion was checked by chloride bicarbonate ratio method. Mapping of sea water intrusion was done by ArcGIS application program[12].

A detailed analysis on severity of sea water intrusion and fresh water in Eastern coast of India and its potential remediation had been discussed[13].

An analysis had been conducted to maintain groundwater quality parameter and finding out optimum water pumping rate numerically[14].

A detailed analysis on groundwater level at Purba Mednipur, West Bengal was carried out. Pumping rate of two different years were given as input in Visual Modflow software. Ground water level was validated. It had also been simulated for the study area from 2019 to 2023[15].

Fig. 1 shows the location map of study area and location of sampling points. The area under investigation is in coastal portion of Purba Medinipur. The geographical location of Purba Medinipur is that it is situated between 21°38′ N and 22°30′ N latitudes. Regarding longitudes Purba Medinipur is situated between 87°27′ E and 88°11′ E. Paschim Medinipur lies in northern and western border of it. The state of Odisha is southwest border of it. The Bay of Bengal lies in south. The Haldi River and South 24-Parganas lies to the east. Howrah district lie to the north east. Samples were taken from Contai belt within Purba Medinipur. In the map as shown in Fig. 1 the twenty two (22) sample locations are shown. The details of the locations along with their numeric digit are listed in Table 1.

Soil characteristics of study area

Purba Medinipur district has a wide range of fresh alluvial soils. It is consisted of three parts. One there is deltaic made of Entisols laid in Rupnarayan River and Hoogly River. Second one consists of coastal alluvial soils of Entisols group. Salt water has also intruded in the main land. Alkali soils are found in Digha to the east of Haldi River. The left part is consisted of older alluvium of Alfisols group in Western portion near Egra and in a tiny portion to the northwest along the river Kangsabati. So it is evident that Purba Medinipur has a wide variation of soil texture. About forty (40) percent of area is made of light soil; thirty (30) percent of area is made of medium soil, rest thirty (30) percent of area is made of heavy soils. Since presence of clay content is more in heavy textured soil it is found that about 60% to 70% of soils of Contai III block is made up of clayey soil. Contai I have less than 60% of clayey soil in its area. Similarly Contai II block has less than 30% clayey loam in its area. Moreover this higher percentage of clay loam present in Contai block is very much helpful for irrigation purpose,

Generally surface water is not plenty available for Purba Medinipur district for irrigation, drinking water supply, and industry purpose. Shallow aquifer is available in this district to augment the supply of water. But due to over use of ground water and soil characteristics of study area make salt water invasion into the aquifer and also in the land. It is taking the shape of cone of depression under the ground. This salt water intrusion makes irrigation field unfit for irrigation of crops, unfit for drinking water supply, unfit for domestic purposes and unsuitable for industry application.

Table 1. Chart showing the location of the sampling points

Digit shown in the map	Location	Block	Latitude	Longitude
1	Gotsauri	Contai-I	21°48′49.28″ N	87°46′59.87″ E
2	Fuleswar	Contai-I	21°48′20.84″ N	87°47′11.66″ E
3	Satikeshwar	Contai-I	21°47′02.94″ N	87°47′04.57″ E
4	Maisali	Contai-I	21°47′36.48″ N	87°40′18.07″ E
5	Parulia	Contai-I	21°49′29.62″ N	87°45′45.93″ E
6	Kantai	Contai-I	21°47′00.16″ N	87°40′49.09″ E
7	Satikeshwar	Contai-II	21°47′54.88″ N	87°47′05.87″ E
8	Kumirda	Contai-II	21°52′46.02″ N	87°43′28.90″ E
9	Marishda	Contai-II	21°50′59.59″ N	87°44′39.49″ E
10	Sabajput	Contai-I	21°43′45.15″ N	87°42′48.30″ E
11	Gobindapur	Contai-I	22°20′29.87″ N	87°52′32.72″ E
12	Talda	Contai-II	21°51′25.01″ N	87°42′30.87″ E
13	Kanaidighi	Contai-II	21°54′33.39″ N	87°47′01.07″ E
14	Ranichak	Contai-II	22°20′52.76″ N	87°52′59.53″ E
15	Dhamai	Contai-II	21°52′18.02″ N	87°43′14.87″ E
16	Kapasda	Contai-I	21°45′34.02″ N	87°41′06.68″ E
17	Majna	Contai-I	21°46′19.20″ N	87°40′31.30″ E
18	Karpura	Contai-II	21°51′45.39″ N	87°46′43.41″ E
19	Dholmari	Contai-I	21°49′32.61″ N	87°49′54.07″ E
20	Belda	Contai-I	21°49′04.02″ N	87°45′26.76″ E
21	Kulbaria	Contai-I	21°48′24.57″ N	87°39′49.87″ E
22	Ratnamala	Contai-II	21°50′01.68″ N	87°45′10.73″ E

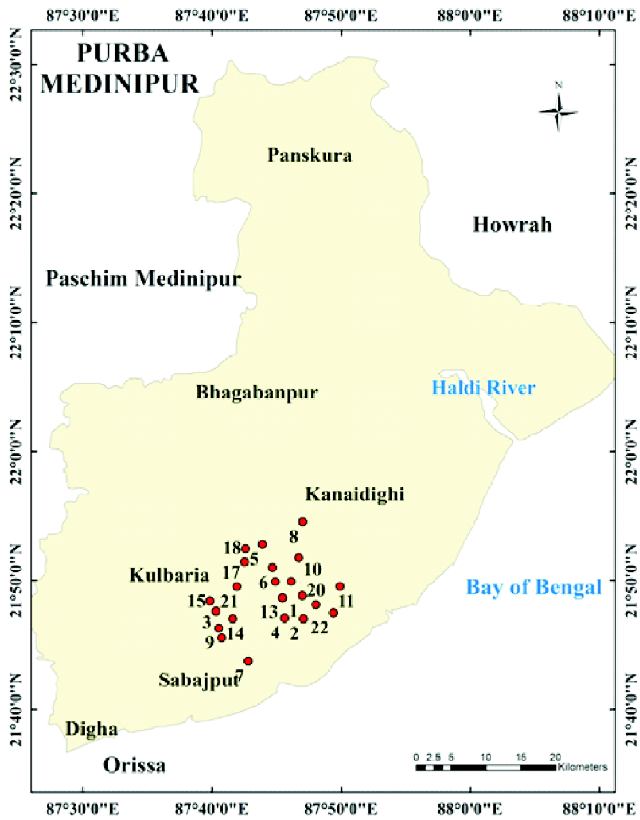

Fig. 1. Location map showing study area of Purba Medinipur.

Field investigation

Water samples from 22 deep tube wells from Contai belt were collected, the locations of which are shown in Fig. 1. Six years water sampling data were collected [years 2007, 2009, 2011 (not graphically shown here), 2013 (not graphically shown here) 2014 and 2016] to analyze and justify the statement that Contai is under threat of groundwater contamination due to sea water intrusion. These water samplings were collected from deep tube wells 20 m underground surface which were all under Public-Health-Engineering-Directorate (PHED), Government-of-West-Bengal (GoWB). Water samples were collected in a closed container. After that these samples were transferred to State-Water-Investigation-Directorate (SWID), GoWB for chemical investigations.

Year wise these chemical properties like pH, turbidity, specific conductivity, manganese, chloride, total hardness $CaCO_3$, iron, total dissolved solids (TDS) concentration at various locations are needed to be determined to determine whether sea water intrusion is taking place or not and other aspects.

The chemical properties of water sample at various location of Purba Medinipur district for the year 2016 are displayed in Table 2. We will analyze each chemical property at various locations one by one.

Since the ground water from aquifer is utilized for drinking, irrigation, industrial purpose so the chemical properties of water sample obtained at different locations of Contai belt needs to be compared with Indian Standard (IS) 10500:2012 which is drinking water specification. Since West Bengal is renowned for processed food industry and water is utilised there, so IS 4251.1967 which is for quality tolerance for water for processed food industry is also taken for reference for chemical analysis and Central Pollution Control Board (CPCB) guidelines for water quality management for irrigation is taken as a reference for chemical analysis too.

Analysis of pH in groundwater

Based on four year's data, Fig. 2 depicts contour map of pH values of various locations of Contai I, Contai II and Contai III blocks of Purba Medinipur district. pH is equal to negative logarithm of hydrogen ion concentration. pH determines corrositivity of water. pH has no direct impact to consumers, but it is one of the most important parameter of water quality.

From Fig. 2 we can observe that in the year 2007 pH in the study area ranges from 7.1 to 7.7. In the year 2007 pH value of ground water at Fuleswar is of 7.1. Fuleswar is located in the southern portion of study area. pH value at Sabajput is of 7.7. Sabajput is located south-east portion of study area. Compared to other data of pH of groundwater of the year 2007 pH value Sabajput is 7.6 and Parulia is of 7.76. Both Kantai and Parulia are located in the central portion of study area. But the pH values of all the places are gradually approached to the permissible limit of (IS) 10500:2012 of drinking water specification, IS 4251.1967 water quality requirement of food processing industry, CPCB manual water quality for irrigation.

In the year 2009 pH value of ground water is from 7.1 to 7.9. pH value of groundwater of Ranichak is 7.1 and pH value of groundwater of Kapasda is 7.9. Kapsada is located in the south west portion of study area and nearer to Bay of Bengal. Kapsada is located in the eastern portion of study area and comparatively far away from Bay of Bengal. In the year 2007 the values for Kapsada and Ranichak were 7.1 and 7.14, respectively. Although there were not much change in

Table 2. Chemical properties of water samples in 2016

Sl. No.	Location	pH	Turbidity in NTU	Specific conductivity $\mu\Omega^{-1}$/cm at 25°C	Manganese in ppm	Chloride (Cl^-) in ppm	Total hardness $CaCO_3$ ppm	Iron in ppm	TDS in ppm
1.	Gotsauri	7.0	Nil	2100	0.02	925	510	0.3	1344
2.	Fuleswar	7.0	Nil	2520	0.30	1000	520	0.5	619
3.	Satikeshwar	7.1	18.76	2350	0.20	999	600	1.2	1503
4.	Maisali	7.2	Nil	1825	0.02	819	580	0.2	1168
5.	Parulia	7.0	Nil	6000	0.50	2800	800	0.7	4320
6.	Kantai	7.0	3.54	3430	0.65	1234	630	0.9	2215
7.	Satikeshwar	7.3	19.65	11170	2.00	6513	1060	3.5	8790
8.	Kumirda	7.3	10.61	4060	2.30	2315	710	3.0	2300
9.	Marishda	7.3	8.63	4100	2.20	2008	690	3.1	2200
10.	Sabajput	7.4	Nil	7380	1.00	4031	2100	2.4	5621
11.	Gobindapur	7.2	Nil	2160	0.02	1099	600	0.3	1385
12.	Talda	7.2	60.5	1650	0.56	941	570	1.7	1057
13.	Kanaidighi	7.1	25.9	2440	0.43	1010	640	0.6	1559
14.	Ranichak	7.4	1.98	10460	0.85	9011	940	0.2	7364
16.	Kapasda	7.0	6.67	4370	0.98	2087	740	1.4	3130
17.	Majna	7.4	Nil	3630	1.23	1454	660	0.5	2260
18.	Karpura	7.5	Nil	4400	0.30	2396	710	0.7	2931
19.	Dholmari	7.0	7.76	9929	1.20	4922	1270	3.6	5620
20.	Belda	7.0	Nil	6100	0.50	2800	800	0.7	4260
21.	Kulbaria	7.3	Nil	6030	0.30	3122	910	0.9	4820
22.	Ratnamala	7.3	10.20	8003	0.67	4068	650	0.8	4500

pH value in groundwater in Kapsada but in Ranichak it was increased manifold. From Fig. 2 it is seen that pH value of most of the places had been increased.

In the year 2011, pH is ranged from 6.5 to 7.7. From the Fig. 2 we get in the year 2011 pH of Gotsauri and Dholmari which are low in groundwater compared to year 2007 and 2009. This reduction of groundwater quality parameter pH was taken place due to geomorphologic reason. In the year 2011 pH in Kapsada was 7.7 in groundwater. So it has been seen that pH value in groundwater in Kapsada has been increased year by year. On comparison the pH value for the year 2011 and year 2007 and 2009 it is seen that pH value in most of the places has been increased.

In the year 2013 pH value ranges from 7.1 to7.9. pH value in groundwater in Gotsauri and Ratnamala were ranged as 7.1. Since Gotsauri is located south east portion and Ratanmala is located central portion of study area, so there were not much effect had fallen due to sea water intrusion regarding pH value. pH in groundwater in Sabajput is 7.9. So these places are highly affected over the years. Compared to other previous years it has been observed that pH value of groundwater of most of the places has been increased.

In the year 2013 the pH value of groundwater was ranged from 7.1 to 7.9. pH of Gotsauri and Ratnamala were very low in groundwater. So these places were unaffected due to sea water intrusion. pH of Kapsada is 7.9. So this place like other places of Contai is showing upward trend year wise. These places are highly affected by sea water intrusion contamination of fresh water with sea water are shown in aquifer of these places.

In the year 2014 the pH value in ground water were the ranged from 7.0 to 7.9. In Gotsauri pH was in groundwater is 7.0. So Gotsauri is showing a constant value of pH over the year and unaffected by sea water ingression. pH in Kaspada was in groundwater as 7.9 in the year 2014. So this place was affected by sea water intrusion year wise.

In the year 2016 pH value of Contai was ranged from 7.0 to 7.5. pH value Gotsauri, Fuleswar, Parulia, Kantai, Kapasda,

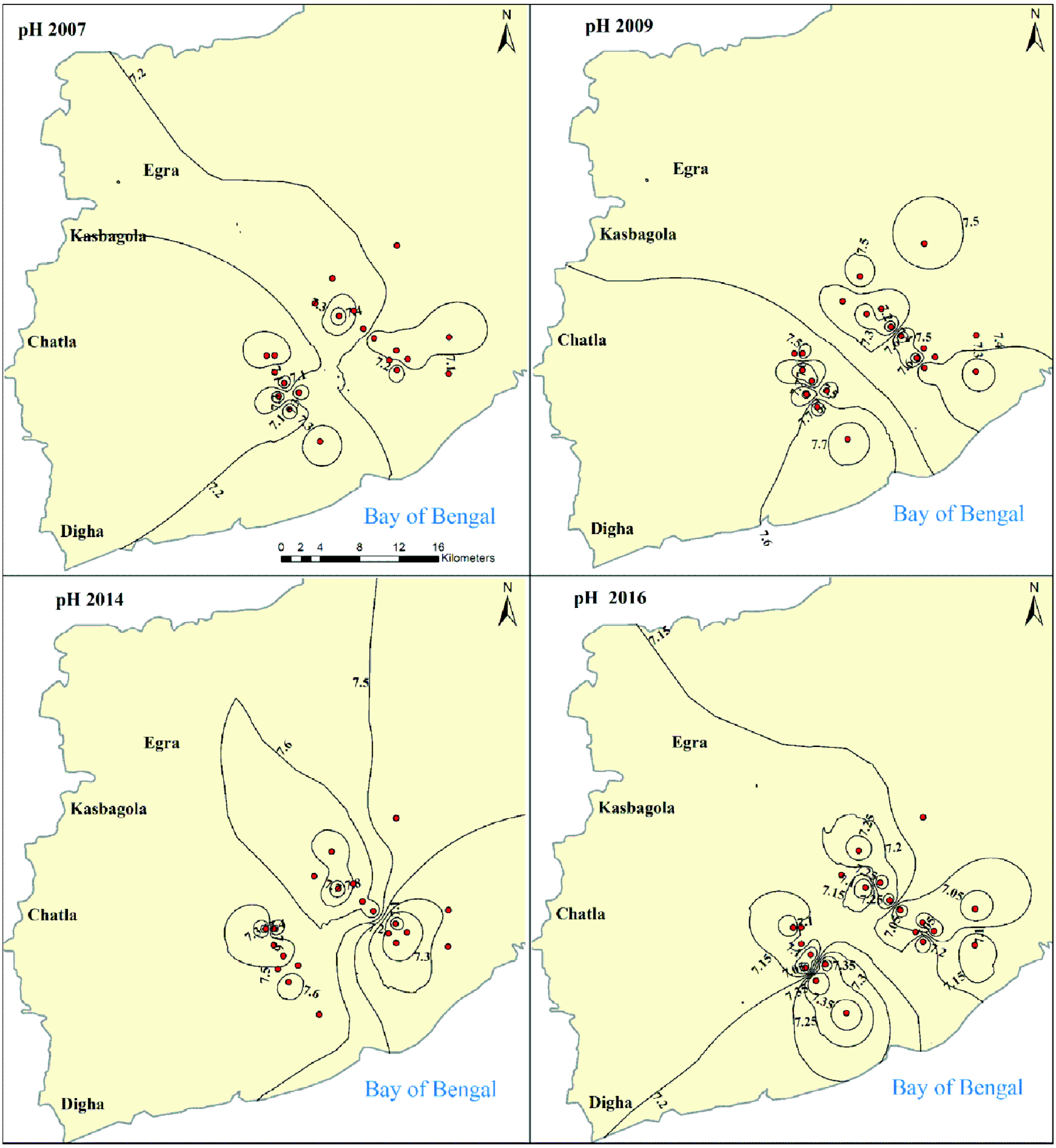

Fig. 2. Contour map of pH values of twenty two sample location points of Contai belt.

Dholmari, Belda had been showed low range. pH of Karpura was in groundwater as 7.5. Lower value of pH in groundwater in the year 2016 may be taken place due to geomorphologic value.

Inferences from analysis of pH in groundwater

From the above discussion based on six years data, it is confirmed that Contai is affected by sea water which is confirmed by pH value in groundwater which shows an upward trend for most of the years. It is also shown that pH value in groundwater is approaching permissible limit of various references. According to IS 10500:2012 which is used for drinking water specification has shown that acceptable limit of drinking water is 6.5–8.5. It has been seen that from the year 2007 to 2016, in those six years data of pH value are within permissible limit according to IS 10500:2012 standards. But most concerned fact is that it is increasing year by year in Contai belt which can be an indication of sea water intrusion. So in near future it may happen that pH value of locations of Contai belt exceed the acceptable limit of pH value of drinking water as per IS 10500:20012. According to CPCB guideline for water quality management for irrigation water pH value of water must be 6.0–8.5. So same analysis, as it had done for pH by IS 10500:2012, can be stated here. IS 4251.1967 which is used for quality tolerances for Water For ·Processed Food Industry 6.5–9.2. So same analysis as done with previous two references can be drawn here.

Analysis of turbidity in groundwater

Based on four year's data, contour map of turbidity values at different locations of Contai belt is plotted in Fig. 3. Turbidity is caused by chemical and biological particles. It is not desirable from aesthetic point of view. Turbidity above 4 NTU is visible and not acceptable.

In the year 2007 range of turbidity in NTU was from nil to 3.1. It has been seen that Marishda which is far away from Bay of Bengal showed nil turbidity whereas turbidity at Maisali which is at south portion of Contai is seen to be around 3.1 NTU.

In the year 2009 the range of turbidity showed that it was from nil to 7.9 NTU of turbidity. Turbidity at Satikeshwar, Gobindapur, Ranichak, Marishda are seen to be absent. Turbidity at Kapasda was 7.9 NTU. But in the year 2007 this place had a turbidity value of 7.8 NTU.In most of the places turbidity is seen upward trend from the year 2007 to year 2009. For example turbidity at Kantai in 2007 was 2.12 NTU whereas in 2009 it was 2.3 NTU.

In the year 2011 the range of turbidity in groundwater samples was nil to 8.0. No turbidity has been seen in Satikeshwar. Turbidity at Kapasda was 8.0 NTU. In 2009 the value of turbidity of Kapasda was 7.9 NTU. Turbidity in most of the places in Contai is seen to be having an upward trend. For example turbidity at Maisali has been increased from 3.2 NTU in 2009 to 3.3 NTU in 2011. So it showed deterioration of groundwater samples year by year from turbidity point of view.

In the year 2013 the turbidity value of water samples ranged from 0.7 to 3.4. Turbidity of Satikeshwar and Ratnamala are of 0.7 NTU. Value of Maisali was 3.4 NTU. So turbidity value in most of the locations has been increased in the year 2013 compared to that of the year 2011.

In the year 2014 range of turbidity value in Contai was ranged between 0.8 and 7.1. Turbidity of Satikeshwar is of 0.8 NTU in 2014. Turbidity of Kapasda is 7.1 NTU in groundwater. In 2013 turbidity of Satikeshwar and Kapsada were 0.7 NTU and 6.9 NTU respectively. So value of turbidity over Contai was increasing year by year. For an example turbidity of Fuleswar was of 1.5 NTU in the year 2013 which had been increased to 2.5 NTU in the year 2014.

In the year 2016 the value of turbidity in groundwater was ranged between nil and 60.5 NTU. Turbidity of Gotsauri, Maisali, Sabajput, Gobindapur has shown nil value. The reduction of turbidity in these places might have occurred due to change in path line of sea water. Turbidity in Talda was of 60.5 NTU in its groundwater in the year 2016 which had been increased from 3.2 NTU of turbidity in the year 2014.

In the year 2016 the value of turbidity in groundwater ranged from nil to 60.5. Gotsauri, Maisali, Parulia and few other places has nil value of turbidity. Talda had turbidity value of 60.5 NTU in 2016 which had been increased from 3.2 NTU in 2014.

Inferences from analysis of turbidity in groundwater

From the above discussion based on six years data, it is clear that turbidity value of most of the locations in Contai has been increased over the years. So this stands as an evidence of sea water ingression from Bay of Bengal to aquifer of Contai. It isn't seasonal variation of groundwater quality parameters. According to IS 10500:2012 for drinking water purpose, the acceptable limit of turbidity should be less than 1 NTU. From the year 2007 it is seen that it is increasing year by year. From the year 2007 to 2014 it had not been shown safe turbidity in groundwater according to drinking water specification but it was increasing over time. In the year 2016 the value of turbidity of Talda had exceeded the permissible value of turbidity with its highest value. So as sea water invades in the aquifer it became unfit for drinking water purpose. If that phenomenon continues then in near

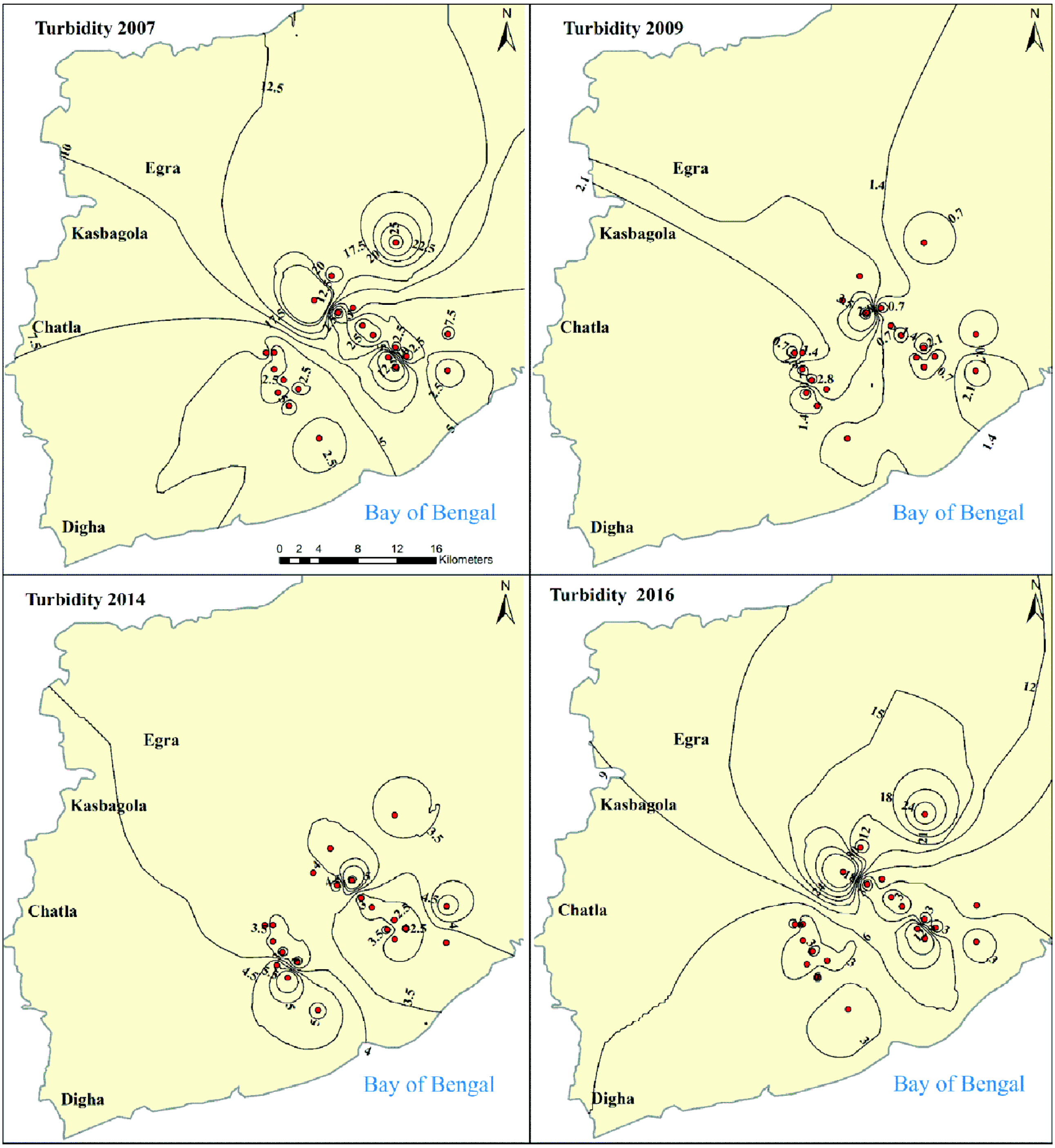

Fig. 3. Contour map of turbidity values in NTU at different locations of Contai belt.

future whole Contai belt groundwater will become unfit for drinking water purpose from turbidity point of view.

Analysis of specific conductivity in groundwater

Based on four year's data, specific conductivity of water means total amount of dissolved salts present in water. From Fig. 4, in the year 2007 the value of specific conductivity in groundwater of Contai is ranged from 956 micromhos/cm ($\mu\Omega^{-1}$/cm) to 6120 $\mu\Omega^{-1}$/cm. In Talda groundwater specific

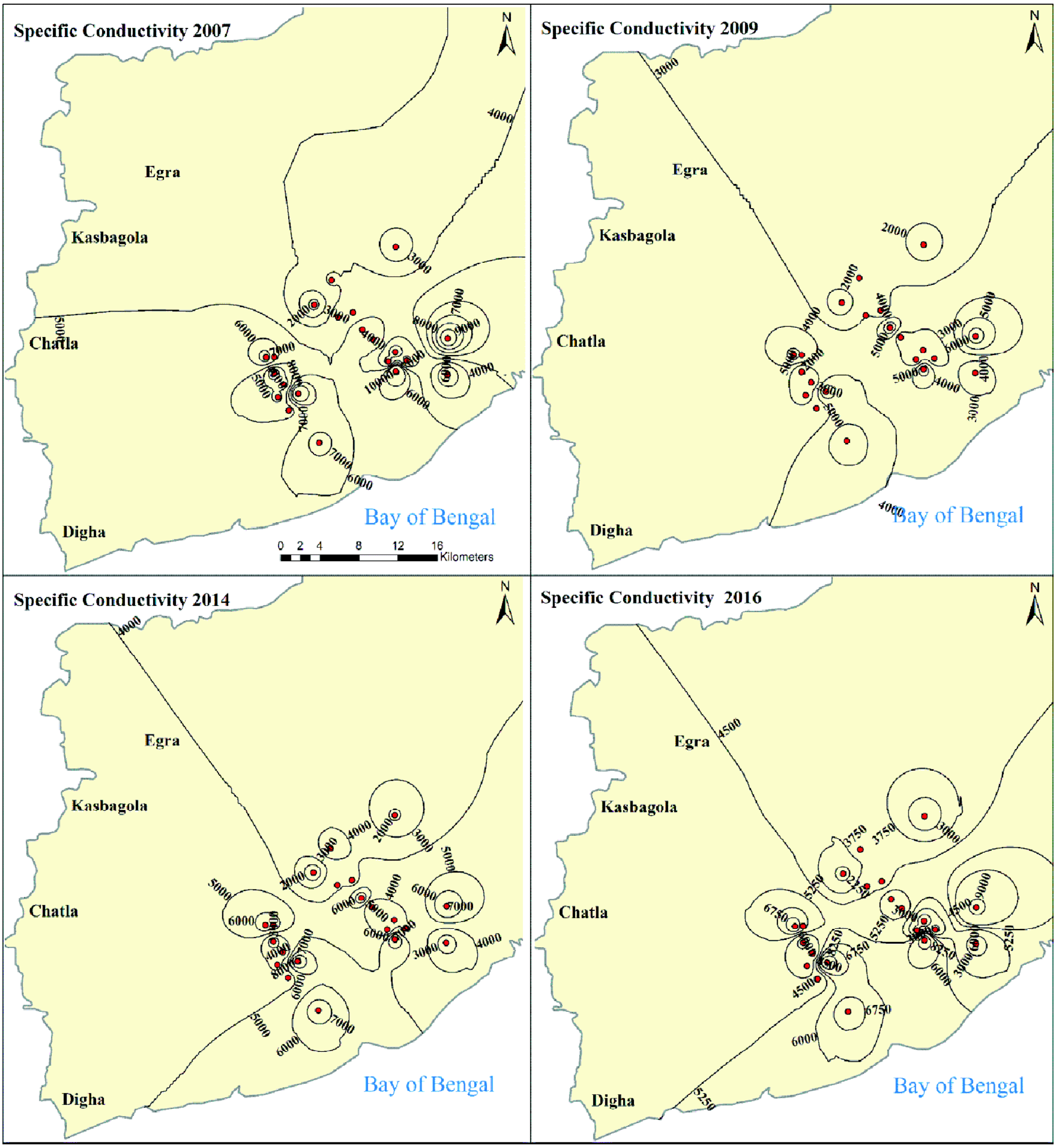

Fig. 4. Contour map of specific conductivity in $\mu\Omega^{-1}$/cm of different locations of Contai belt.

conductivity is 956 $\mu\Omega^{-1}$/cm whereas in Dholmari groundwater it was 6120 $\mu\Omega^{-1}$/cm. In other places of Contai belt also specific conductivity is quite high.

In 2009 specific conductivity value of Contai belt ranges between 1000 $\mu\Omega^{-1}$/cm and 6500 $\mu\Omega^{-1}$/cm. Specific conductivity of Talda was of 1000 $\mu\Omega^{-1}$/cm in 2009 whereas in 2007 it was 956 $\mu\Omega^{-1}$/cm. Similarly specific conductivity at Dholmari is 6500 $\mu\Omega^{-1}$/cm in 2009, but in 2007 it had specific conductivity value as 6120 $\mu\Omega^{-1}$/cm. In all the other places it had been seen high value of specific conductivity value in 2009 was high compared to that in 2007.

In 2011 the specific conductivity value ranged between 1050 $\mu\Omega^{-1}$/cm to 6600 $\mu\Omega^{-1}$/cm. Talda and Dholmari locations have the lowest and highest value respectively. But from earlier discussions it has been seen that specific conductivity value of both Talda and Dholmari have increased since 2009. Even other places showed higher value of specific conductivity value in 2011 compared to 2009.

In 2013 the value of specific conductivity was between 1100 $\mu\Omega^{-1}$/cm and 8000 $\mu\Omega^{-1}$/cm. Talda and Sabajput have the lowest and highest value respectively. In 2011 specific conductivity Talda has 1050 $\mu\Omega^{-1}$/cm and Sabajput has 6500 $\mu\Omega^{-1}$/cm. So it had been observed that all the places of Contai are having higher value of specific conductivity compared to previous years.

In 2014 specific conductivity Talda was of 1250 $\mu\Omega^{-1}$/cm which was the lowest value and specific conductivity of Ranichak had of 8500 $\mu\Omega^{-1}$/cm. But in 2013 specific conductivity of Talda was of 1050 $\mu\Omega^{-1}$/cm and specific conductivity of Ranichak had 8000 $\mu\Omega^{-1}$/cm. So it is showing an upward trend year wise.

In 2016 specific conductivity value of Contai was from 1650 $\mu\Omega^{-1}$/cm to 11170 $\mu\Omega^{-1}$/cm as seen from Fig. 4. Talda has the least value and Satikeshwar has the highest value respectively. In 2014 Talda has specific conductivity value 1050 $\mu\Omega^{-1}$/cm and Satikeshwar had 7500 $\mu\Omega^{-1}$/cm. All other places of Contai belt also show rising trend of specific conductivity in its groundwater year wise.

Inferences from analysis of specific conductivity in groundwater

From the data collected over a period of six years it is seen that year by year all the places of the study area have shown gradual increasing value of specific conductivity. It is clear from the above discussions that sea water intrusion is taking place in Contai belt and all the locations chosen for collecting samples are affected heavily. According to IS 10500:2012 for drinking water purpose, the acceptable limit of specific conductivity is 200–800 $\mu\Omega^{-1}$/cm. From the year 2007 to 2016 it has been seen that specific conductivity value in groundwater of Contai belt exceeded the permissible limit of drinking water. So groundwater level of study area already became unfit for drinking water purpose from the specific conductivity. According to IS 4251.1967 the specific conductivity value of water to be used for food industry must be of low value. But since all the locations in the study area has high, so those can't be utilized for industrial purpose. According to CPCB guideline for water quality management for irrigation water specific conductivity for irrigation water must be 25 $\mu\Omega^{-1}$/cm to maximum 2250 $\mu\Omega^{-1}$/cm. From this reference it can be inferred in the similar way that had been done in case of groundwater specification. So groundwater was not fit for agriculture purpose as well since 2007.

Analysis of manganese in groundwater

From Fig. 5, it is observed that in 2007 the range of value of manganese in ppm in Contai belt groundwater was nil to1.90 ppm based on four year's data. Manganese in ppm in Kantai and Satikeshwar are the lowest and highest value of in groundwater respectively.

In 2009 the value of manganese in ppm in Contai belt groundwater was a ranged from nil to 2.0. Manganese in Kantai was nil and Satikeshwar was highest in the year 2009. So it is seen that manganese in groundwater Satikeshwar was of higher value of in 2009 compared to that of in the year 2007. Other locations also show rise of manganese value in its groundwater. For example value of manganese in groundwater in Maisali increased from 0.531 ppm to 0.681 ppm. In 2011 the range of manganese in groundwater was 0.03 ppm to 2.0 ppm. Gobindapur and Satikeshwar have the lowest and highest value of manganese in groundwater. All the locations of Contai were having higher value of manganese in 2011 compared to 2009. For example manganese in Ranichak in the year 2011 has value as 0.88 ppm whereas in 2009 it had 0.85 ppm, which shows an increasing trend.

In 2013 the range of manganese in groundwater is 0.07 ppm to 2.125 ppm. Manganese in groundwater is lowest at Marishda and Kulbaria. Highest range of manganese is in Satikeshwar. These three locations show higher value of manganese in groundwater compared to that of 2011.

In 2014 value of manganese in groundwater was from 0.06 ppm to 1.67 ppm as seen from Fig. 5. Gobindapur has the lowest value of manganese whereas Dholmari shows the high value of manganese. In the year 2013 these places had manganese value of 0.04 ppm and 1.4 ppm. So it has been shown that the value of manganese in groundwater in every location was increasing year by year.

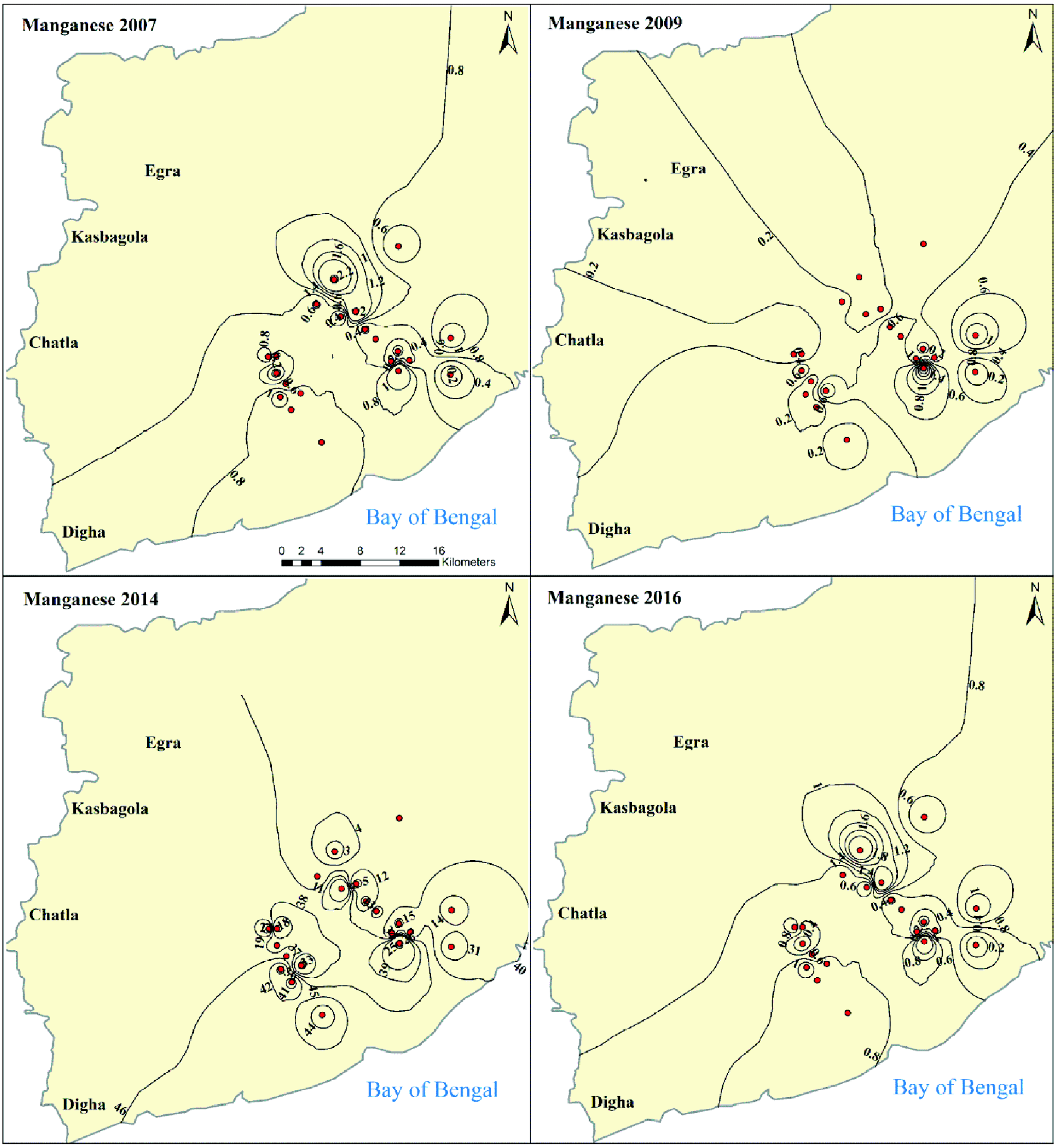

Fig. 5. Contour map of manganese in ppm different locations of Contai belt.

In 2016 value of manganese in groundwater ranged from 0.02 ppm to 2.3 ppm. Gotsauri, Maisali, Gobindapur has the lowest value of manganese in groundwater. Kumirda had highest value of manganese in groundwater in that year. In 2014 Kumirda had manganese value in groundwater as 0.09 ppm. So it had been increased manifold yearly.

Inferences from analysis of manganese in groundwater

From the above discussions it had been found that manganese value in ppm of groundwater of every locations of Contai belt has been increased tremendously from the year 2007 to 2016. So it stands as clear evidence that Contai belt is suffering from sea water intrusion. According to IS 10500:2012 for drinking water purpose, the acceptable limit of manganese is 0.1 ppm and permissible limit is 0.3 ppm. From the year 2007 it had been investigated that the value of manganese in ground water exceeded the permissible limit. As in the year 2016 the situation of manganese in groundwater became worst. So from 2016 to current year it is unsafe for industrial purpose.

Analysis of chloride in groundwater

Chloride is the most important water quality parameter that determines sea water intrusion. Based on four year's data from Fig. 6, it is observed that in the year 2007 the range of chloride in study area is 150 ppm at Kantai location to 5713 ppm at Satikeshwar locations.

In 2009 the range of chloride in groundwater in study area was 18 ppm of Kapasda location to 6513.07 ppm of Satikeshwar. In 2007 chloride in Kapasda, Satikeshwar are 16 ppm and 5713 ppm respectively as mentioned above. So it is increased yearly.

In 2011 range of chloride in study area was 75 ppm at Kapasda location and 6550 ppm of Satikeshwar. From previous analysis it has been found that all the places of Contai has lost its quality from sea water intrusion. For an example chloride value in groundwater in Sabajput has been increased from 270 ppm in 2009 to 280 ppm in 2011.

In 2013 the range of chloride in study area was 80 ppm of Kapasda to 6750 ppm at Satikeshwar. From previous analysis it has been seen that all the locations of study area has shown increasing value of chloride in the year 2013 compared to that of 2011.

In 2014 the range of chloride in groundwater was from 340 ppm at Kumirda to 7500 ppm at Satikeshwar. So it has been seen that chloride was increasing from year 2013 to 2014. It is a serious sign of sea water intrusion into the aquifer of study area.

In 2016 the value of chloride in groundwater was ranged from 925.24 ppm of Gotsauri to 6513.07 ppm of Satikeshwar. In 2014 value of chloride in groundwater in Gotsauri and Satikeshwar are 600 ppm and 7500 ppm respectively.

Inferences from analysis of chloride in groundwater

It has been observed that chloride value in groundwater at all the locations has been increased tremendously from the year 2007 to 2016. So it indicates sea water intrusion into the study area. According to IS 10500:2012 for drinking water purpose, acceptable limit of chloride is 250 ppm and permissible limit is 1000 ppm. From year 2007 it has been seen that chloride value of most of the places has exceeded permissible limit of drinking water specification. So water is not drinkable in Contai belt from chloride point of view. Moreover it confirms sea water intrusion in study area. According to IS 4251.1967 maximum value of chloride in water for food industry is 250 ppm. Since the value of chloride has exceeded the maximum value for food industry since 2007 and it continues to enhance year by year that is seen from the contour map of chloride 2016. So it may refer that groundwater from Contai belt are unfit for industrial purpose.

The obtained result of chloride concentration in ppm at different locations of Purba Medinipur is shown in Fig. 6 as a contour map. From the Fig. 6 and Table 1 it is observed that the places near Bay of Bengal like Satikeshwar (Contai III) has high value of chloride about 6500 ppm. Also like other places Kumirda (2314 ppm), Parulia (2800 ppm), Ratnamala (4067 ppm), Kulbaria (3122 ppm), Belda (2800 ppm) possess high value of chloride in its ground water. So northern portion and eastern portion's which are close to Bay of Bengal are severely affected. Sea water intrusion is taking place from this portions to northern portion of study area which has comparatively low chloride concentration in ground water like Gotsauri (925 ppm), Fuleswar (1000 ppm), Satikeshwar of Contai II (998 ppm), Kantai (1233 ppm).

From the Fig. 6 and Table 1 it has been observed that chloride value in ground water of Gotsauri, Satikeshwar (Contai II), Maisali, Talda are beyond acceptable limit but just below permissible limit. So ground water from these places only can be used for drinking water purpose but only after its treatment. Rest of the places in the Contai belt contains ground water which is unfit for drinking purpose.

According to IS 4251.1967 maximum value of chloride in water for food industry is 250 ppm. Since chloride values in ground water of twenty two sample locations of Contai belt is well above this standard value so ground water from Contai belt is not suitable for industrial purpose of food.

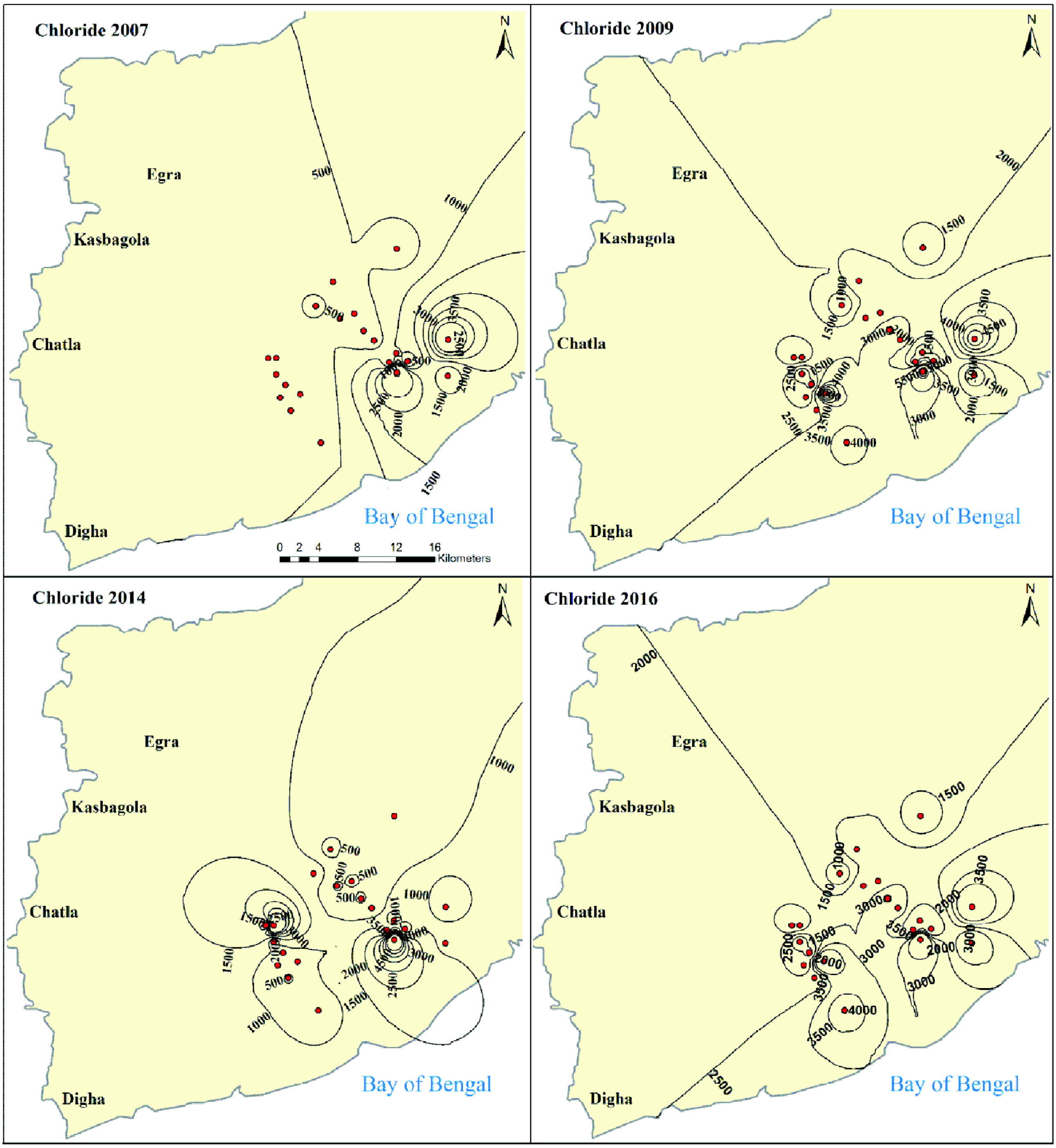

Fig. 6. Contour map of chloride in ppm at different locations of Contai belt.

Analysis of total hardness as $CaCO_3$ in groundwater

Samples from twenty two locations of Contai belt are tested for total hardness $CaCO_3$ point of view. The contour map of total hardness is plotted in Fig. 7 using four years data.

From Fig. 7 it has been observed that in 2007 the value of total hardness in groundwater in study area ranged from 321 ppm of Ranichak to 987 ppm of Satikeshwar.

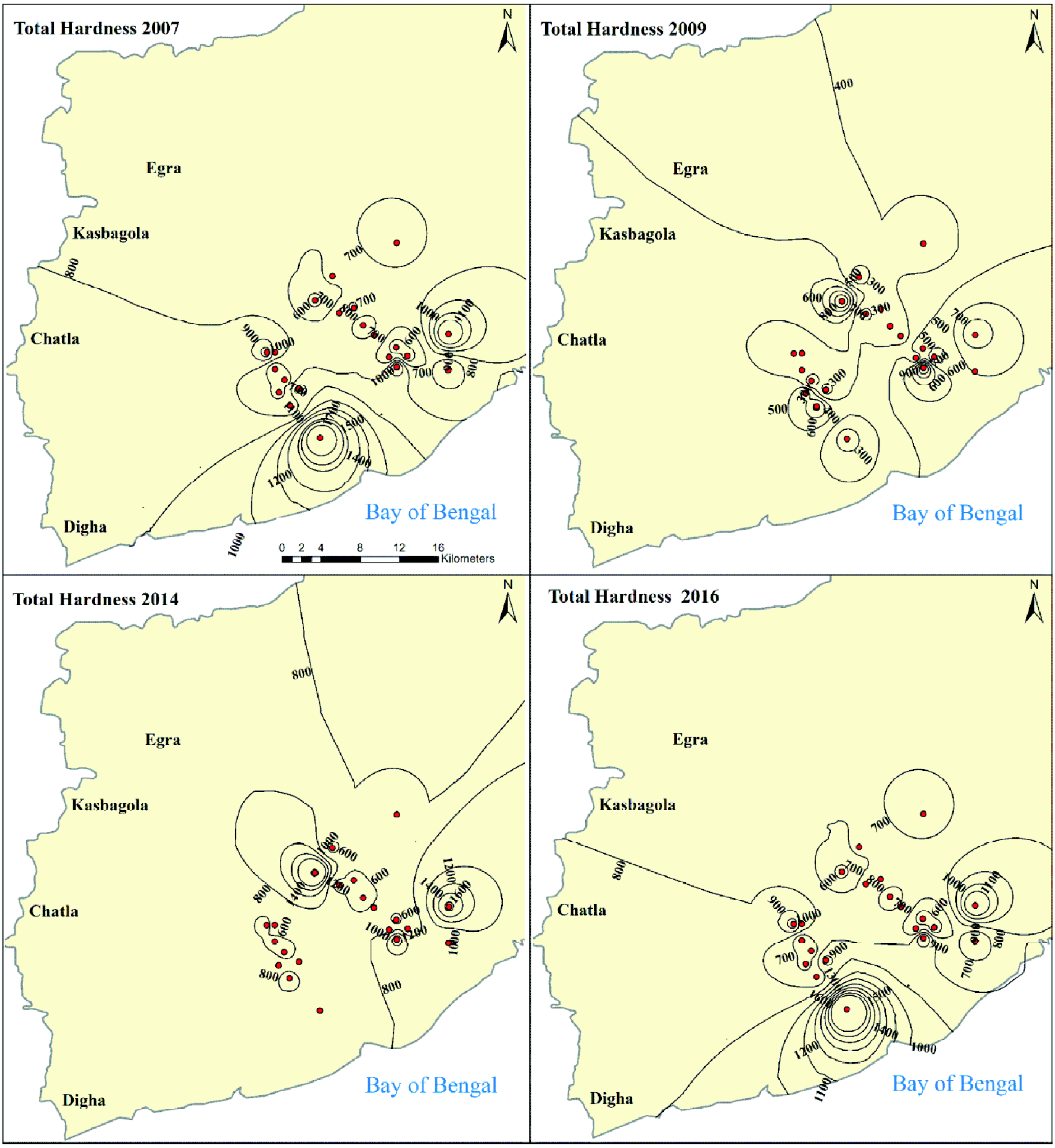

Fig. 7. Contour map of total hardness $CaCO_3$ ppm of Contai belt.

In 2009 the value of total hardness was ranged from 200 ppm at Kantai to 1060 Satikeshwar. So it has been seen that value of total hardness in Satikeshwar is increasing yearly. In 2009 value of total hardness in groundwater of Ranichak and that of Kantai in 2007 were 250 ppm and 187 ppm respectively. So it has been seen that the groundwater of Contai is getting contaminated by sea water intrusion yearly.

In 2011 range of total hardness in groundwater of study area is ranged from 250 ppm of Gotsauri and Kumirda to 1060 ppm of Satikeshwar. In 2009 both these places have less value of total hardness as seen in the Fig. 7.

In 2013 value of total hardness in groundwater of Contai belt is ranged from 265 ppm at Sabajput to1100 ppm at Talda and Satikeshwar respectively. In 2011 total hardness value of Sabajput, Talda and Satikeshwar were 260 ppm, 1000 ppm and 1060 ppm respectively. So the total hardness values in groundwater in all locations have been increased.

In 2014 total hardness in groundwater of Contai ranges from 475 ppm of Kantai to 2100 ppm of Talda. From the Fig. 7 it has been observed all the locations has been shown increasing trend of total hardness value in groundwater.

In 2016 total hardness value of groundwater is ranged from 510 ppm of Gotsauri to 2100 ppm of Sabajput. In 2014 Sabajput has total hardness value as 665 ppm.

Inferences from analysis of total hardness in groundwater

From the qualitative point of view according to IS 10500:2012 for drinking water purpose total hardness ($CaCO_3$) value of 200 ppm is accepted and value of 600 ppm is permissible. From the year 2007 it has been seen that total hardness value of groundwater exceeded the permissible limit. As the year went on it s value enhanced. So groundwater is unfit for drinking from total hardness point of view. According to IS 4251.1967 maximum value of total hardness in water for food industry is 600 ppm. Groundwater from Contai belt is unfit for industrial purpose from total hardness point of view.

Analysis of iron in groundwater

From Fig. 8 it has been observed that in 2007 range of iron in groundwater of study area is 0.11 ppm of Marishda to 3.76 ppm of Dholmari.

On the contrary in the year 2009 groundwater of study area is ranged from 0.12 ppm at Marishda to 3.6 ppm at Dholmari. So it has been seen that both places like other places of Contai are affected by sea water intrusion over the years.

In 2011 the value of iron is ranged from 0.13 ppm at Marishda to 3.7 ppm at Dholmari. So the increasing trend of iron in groundwater in Contai is continued.

In 2013 range of iron in groundwater in Contai belt is 0.06 ppm at Marishda to 3.8 ppm at Dholmari. So similar trend of iron content in groundwater of study area is observed like previous analysis.

In 2014 iron content in groundwater of Contai belt is ranged from 0.24 ppm at Marishda to 3.12 ppm at Dholmari. From the previous data it was seen that both this places like other places of Contai show higher value year wise.

In 2016 iron in groundwater in Contai is ranged from 0.2 ppm at Maisali and Ranichak to 3.6 ppm at Dholmari. The values of iron in groundwater of Maisali, Ranichak and Dholmari in 2014 are 0.15 ppm, 0.18 ppm and 3.12 ppm respectively. So it is showing increasing trend.

Inferences from analysis of iron in groundwater

From the above analysis it was seen that iron content in groundwater in Contai belt is increasing yearly. So it is a clear evident that Contai belt is highly affected by sea water intrusion.

From the qualitative point of view according to IS 10500:2012 for drinking water purpose if iron in water is 0.3 ppm then it is accepted. From the year 2007 it has been seen that most of the places of Contai have been exceeded the permissible limit. As year progresses the value of iron is enhanced. So groundwater from Contai is unfit for drinking water purpose from iron point of view. According to IS 4251.1967 maximum value of iron in water for food industry is 0.3. So analysis of ground water from different places of study area is same as it has been done for drinking water supply before.

Analysis of TDS in groundwater

Based on four year data from the contour map of TDS of Contai belt shown in Fig. 9 it is clear that in 2016 range of value of TDS in study area was 1057 ppm at Talda to 8790 ppm at Satikeshwar. It is seen that value of TDS in groundwater in Contai belt was enhanced enormously in the year 2016 from year 2014.

From the qualitative point of view according to IS 10500:2012 the upper limit of TDS for drinking water was 500 ppm. So ground water from all the places is unfit for drinking water purpose. So it had been shown that from the initial year 2007 the value of TDS in groundwater in most of the places of Contai belt had exceeded the maximum value for drinking water specification. As year progressed the value of TDS enhanced. So it has been inferred that groundwater

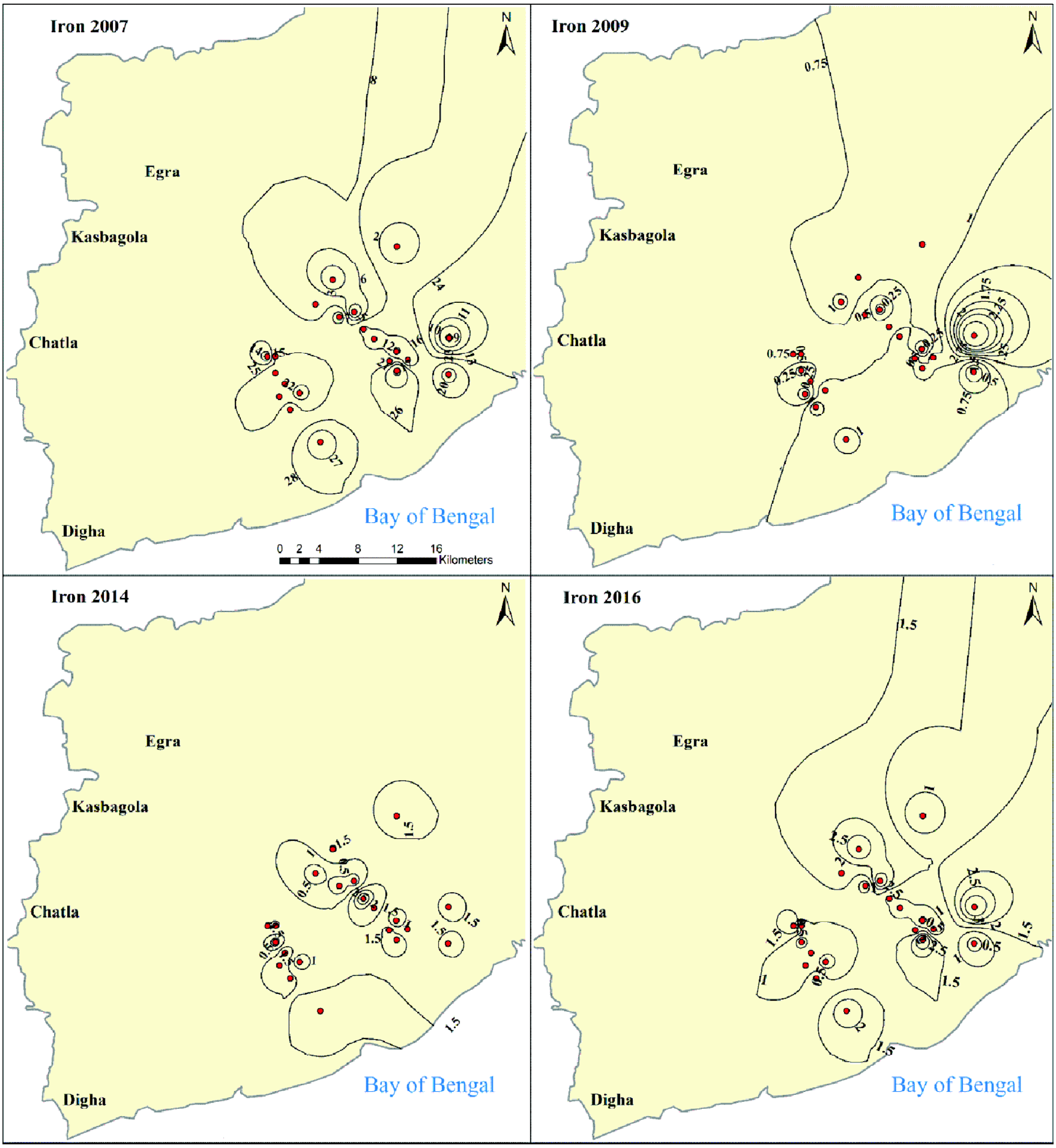

Fig. 8. Contour map of iron in ppm of Contai belt.

became unfit for drinking water purpose. According to IS 4251.1967 the maximum value of TDS in water for food industry is 1000 ppm. Similarly since 2007 to 2016 it has been seen that most of the places in Contai belt had exceeded maximum value of industrial purpose. So groundwater from Contai belt is unfit for industrial purpose.

From the contour map of TDS of Contai belt shown in Fig. 7 it is clear that all the locations of study area have high

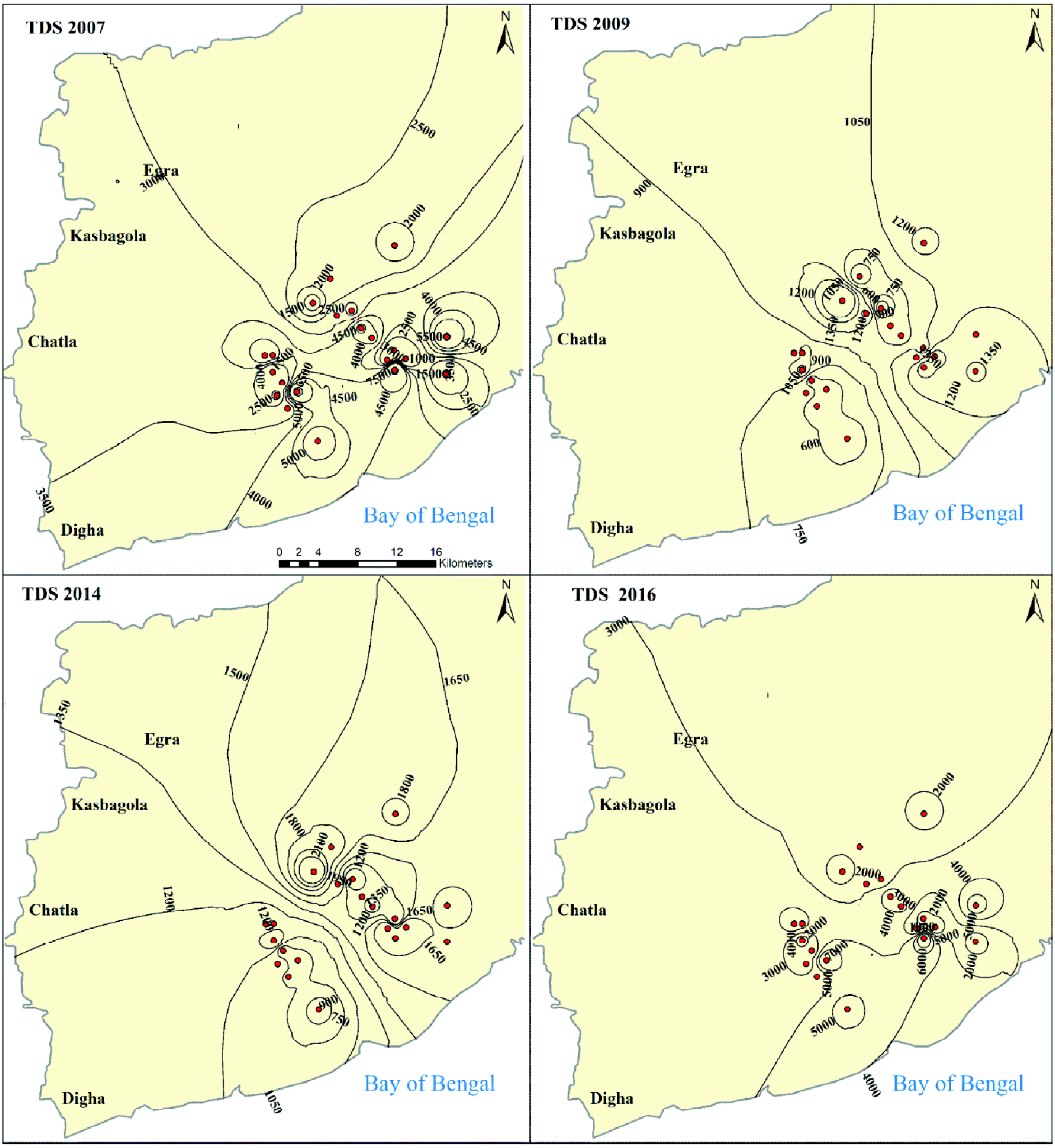

Fig. 9. Contour map of TDS in ppm of Contai belt.

value of TDS. South portion of study area which is near Bay of Bengal like Satikeshwar has most value of TDS in groundwater i.e. 8790 ppm. In the eastern portion the places like Ratnamala (4500 ppm), Belda (4260 ppm) also possess high value of TDS in groundwater. In the western portion of study area the places like Marishda (2200 ppm), Kulbaria (4820 ppm), Ranichak (7364 ppm) also have very high value of TDS. In the northern portion of study area the place like

Kumirda (2300 ppm) has high value of TDS. So it is evident that sea water intrusion increases the TDS value in aquifer in whole study area.

From the qualitative point of view according to IS 10500:2012 the upper limit of TDS for drinking water is 500 ppm. So groundwater from all the places is unfit for drinking water purpose.

According to IS 4251.1967 the maximum value of TDS in water for food industry is 1000 ppm. Only the location Fuleswar has TDS value below maximum value i.e. 619 ppm. So groundwater from Fuleswar can be used for food industry. Groundwater from rest twenty one (21) places is not acceptable for food industry.

Overall inferences from analysis in groundwater

From the detailed discussion above it is seen that value of water quality parameters like pH, turbidity, specific conductivity, manganese, chloride, total hardness, iron, TDS had been increasing year by year. Six different year data were collected. It has been seen that value of this eight water quality parameters had been increased with increasing time. If proper measures are not taken then fresh water in aquifer of Contai belt will become too redundant for use. It has been seen that south place of study area like Satikeshwar, south western portion of Contai belt like Fuleswar and Gobindapur are worst affected by sea water intrusion over the years. Compared to these places Kumirda, Parulia, Kulbaria which are located northern portion of the study area are less affected. Similarly Satikeshwar, Kapasda, Marishda which are weastern portion of Contai belt are less affected than southern portion of study area.

So from the above analysis it can be inferred that sea water intrusion is affecting mainly the southern and eastern portion of Contai belt. Then through the lithology and groundwater aquifers it is moving into the west portion of study area. Finally from south, east, and west portion it is moving into the north portion of Contai belt and affecting whole area of Contai belt. This has been done over the years.

Path line of sea water intrusion

From the chemical analysis of groundwater of twenty two locations of Purba Medinipur it is evident that sea water intrusion is taking place in the aquifer of study area. So the path line of sea water intrusion into the study area can be predicted. These probable path lines are well illustrated in Fig. 10.

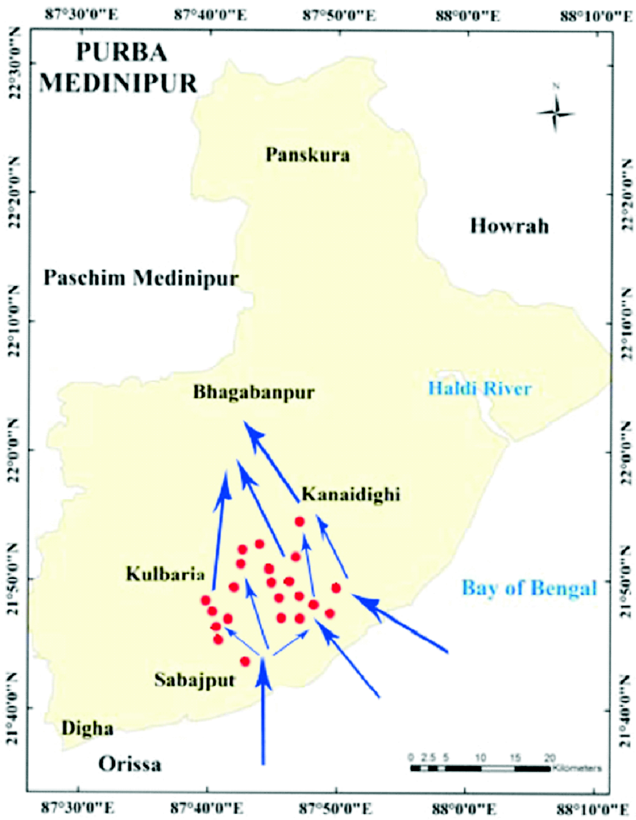

Fig. 10. Probable path lines of sea water intrusion at study area.

Sea water from Bay of Bengal is entering the aquifer of mainland in like Satikeshwar (Contai-III), Marishda, Ratnamala, Gobindapur etc. which are near to the sea. Then it is moving towards northern portion of study area like Kantai, Majna, and Parulia and also towards eastern portion of study area like Sabajput, Belda. Finally the sea water is entering the northern portion of study area like Kumirda. In the path of salt water movement it renders aquifer water unfit for drinking water supply and other purposes.

Remedial measures

As a remedial measure the following processes may be adopted.

If groundwater level in the study area is maintained at higher level than sea water level then sea water intrusion will not be possible as water moves from higher level head to lower head. It may also be possible to provide a high ridge near sea water level so that sea water may not be over-topped the ridge and mixed with fresh water of study area.

During extraction of water pumping through trough can be provided so that contaminant can be excluded.

It is high time to harvest rain water so that much stress on groundwater will not fall. As a result sea water intrusion in Contai belt will not be taken place.

Conclusions

In the coastal area of Purba Medinipur the soil generally found is fresh alluvial. Rupnarayanpur River, Rashulpur River and Hoogly River are located nearby to the Purba Medinipur. The population of Purba Medinipur is around fifty lakh as on year 2019. Contai is a block in Purba Medinipur. Since the population is increasing day by day and due to industrialization the surface water is becoming insufficient to augment the supply. So people are becoming dependant on groundwater more. But in summer season groundwater lowers down which accelerates further due to groundwater extraction. So sea water encroachment is taking place all over the Purba Medinipur.

To support this statement chemical analysis were carried out at different locations in Contai block. From the aquifer ground water samples have been taken. Different parameters of groundwater like pH, turbidity, specific conductivity, manganese, chloride, total hardness, iron, total dissolved solids have been determined. For the data analysis purpose the quality parameters of ground water are compared with IS 10500:2012, IS 4251.1967 and CPCB guidelines for water quality management for irrigation to understand whether groundwater from the twenty two sample locations are fit for drinking, industrial and irrigation purpose or not. It has been observed that groundwater quality is worst in most of the places. It has been found that all the parameters which are practically suitable for drinking water, irrigation water, industry water purpose have exceeded the permissible value except pH value. So it makes the water unfit for all purposes. Some remedial measures have also been recommended so that sea water does not mix up with fresh water aquifer.

Acknowledgement

The authors acknowledge with thanks to the Assistant Engineer, Contai Sub-Division, PHED, GoWB for permitting to collect water samples from the deep tube-wells at different locations of the study area.

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