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Groundwater Quality assessment using Water Quality Index (WQI) in parts of Varanasi District, Uttar Pradesh, India

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ABSTRACT

The water quality index (WQI) is an important tool to determine the drinking water quality in urban, rural and industrial area. WQI is defined as an index reflecting the composite influence of different water quality parameters which is considered and taken for calculation of water quality index. In the present study, sixteen groundwater samples were collected from the southern portion of the Varanasi district, Uttar Pradesh, India, during the pre monsoon period of May, 2015. The twenty two water quality parameters have been considered for the calculation of water quality index viz. pH, electrical conductivity (EC), total hardness (TH), total dissolved solid (TDS), alkalinity, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrates ($NO^{3''}$), bicarbonate (HCO_3^-), chlorides (Cl^-), sulphates (SO_4^-), fluorides (F^-), chromium (Cr), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), nickel (Ni), lead (Pb) and cadmium (Cd). The Bureau of Indian Standard (BIS, 2012) has been considered to assess the suitability of groundwater for drinking purposes and for the calculation of WQI. Correlation study between various physicochemical properties also reveals significant negative relationships. The current study shows that ~20% area is falling under the non suitable for drinking water category and rest is falling under good, moderate, poor, very poor as per the WQI classification. The present study is helpful in proper planning and management of available water resource for drinking purpose.

INTRODUCTION

Groundwater is an important source of water supply throughout the world. It occurs almost everywhere beneath the earth surface not in a single widespread aquifer but in multiple of local aquifer systems and compartments that have similar characters. Groundwater is a finite resource and it is a rare benefit in many parts of the world. In the countries where the water is a limited resource, the competition is rampant among agriculture, industry and domestic use.

Groundwater resources are affected in principle by three major activities. First is excessive use of fertilizers and pesticides in agricultural areas. The second is untreated/partially treated wastewater to the environment and the third is excessive pumping and improper management of aquifers. According to WHO, about 80% of all the diseases in human beings are caused by contaminated water.

In India, most of the population is dependent on groundwater for drinking purpose. As per the latest estimate of central pollution control board, about 29,000 million litre/day of wastewater generated from class-I cities and class-II towns out of which about 45% is generated from 35 metro-cities alone (Mangukiya et al., 2012).

In drinking water quality assessment, the decision-making based on water quality data is a crucial issue because number of parameters compromises its quality. There has been considerable advancement particularly based on the principle of WQI using slightly modified concepts (Smith, 1990; Dojlido et al., 1994; Stambuk - Giljanvoic, 1999; Pesce and Wunderlin, 2000; Nagel et al., 2001; Sargaonkar and Deshpande, 2003; Kannel et al., 2007; Nasirian, 2007; Singh et al., 2008). The basic differences among these indices are the way their sub-index development and aggregation function. These indices are intended to reflect the overall condition of water in different environmental conditions. In this context an innovative approach has emerged in the methodology of drinking water quality index through the present study. The aim of the present study is to adopt the reliable drinking water quality Indexing system for groundwater of the study area.

The objective of the study is to determine the class of all sixteen samples using the weighted arithmetic index method as per Brown et. al., 1972. In this method, the twenty two important parameters such as pH, electrical conductivity (EC), total hardness (TH), total dissolved solid (TDS), alkalinity, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrates (NO_3^-), bicarbonate (HCO_3^-), chlorides (Cl^-), sulphates (SO_4^-), fluorides (F^-), chromium (Cr), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), nickel (Ni), lead (Pb) and cadmium (Cd) were taken for the assessment.

STUDY AREA

The study area falls in the state of Uttar Pradesh, Varanasi district which is covered by alluvial sediments of river basins, coastal and deltaic tracts constitute the unconsolidated formations. These are most significant ground water reservoirs for large scale and extensive development (CGWB, 2014). The study area falls along the Indo - Gangetic plain and is surrounded by the Kashi Vidya Peeth nlock in east, Sevapuri block in west, Harahua nlock in north and Mirzapur district in south. The block is also bounded by small rivers like Varuna on the north and Assi on the south. It is lying between 24°34' N to 26°12' N latitude and 82°05' E to 83°58' E longitude in the south-eastern part with an area of about 207.69 km^2. Study area has low relief features with an average elevation of 80.71 amsl.

MATERIAL AND METHODOLOGY

A total of 16 numbers groundwater samples were collected from various locations of the study area as per the standard protocol prescribed by APHA (1995). The groundwater sample location points were marked by using global positioning system (GPS). Groundwater sample location points are shown in Fig. 1. In this study, the above

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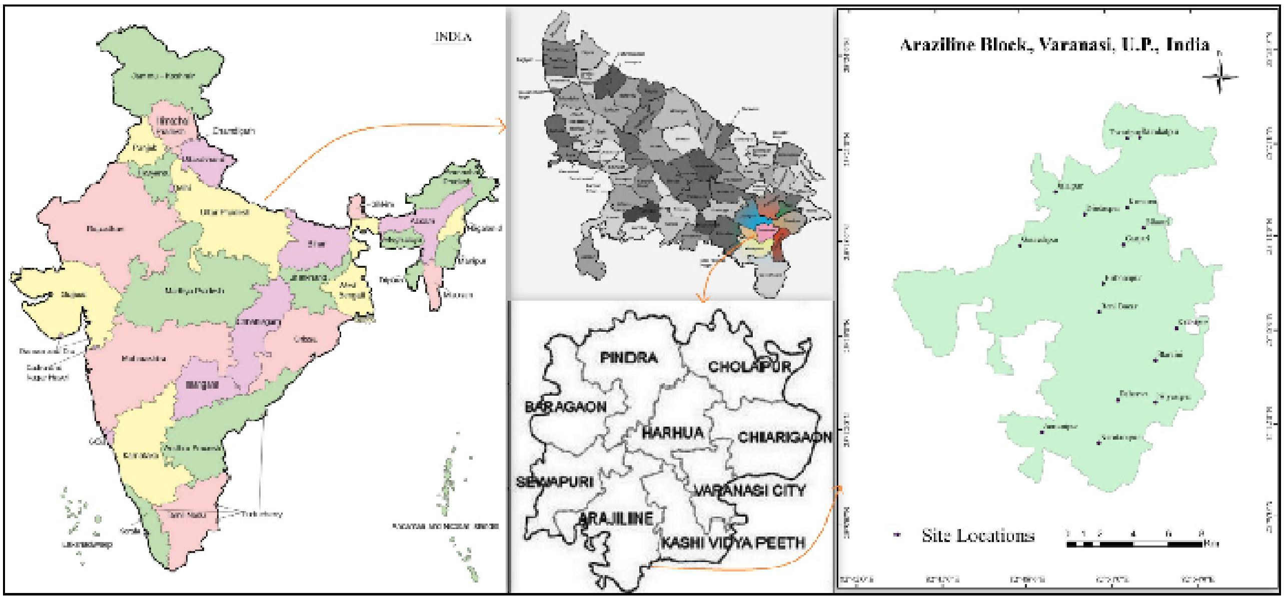

Fig.1. Study Area Map showing well locations

mentioned twenty two groundwater quality parameters were analyzed using standard method prescribed by APHA (1995). The statistical analysis of the analyzed groundwater quality is given in Table 1; Correlation matrix between groundwater quality parameters is also carried out and is given in Table 2.

Groundwater Quality

The groundwater quality mapping has also been carried out using GIS for above mentioned 22 parameters and depicted in Fig.2.

pH: Water in a pure state has a neutral pH which shows a concentration of hydrogen ion in water. The pH has to be in the range of 6.5–8.5 for the drinking purpose (BIS, 2009). In the current study the pH ranges between 7.62 (minimum) to 8.29 (maximum) which shows that it is within the permissible limit (6.5 to 8.5).

EC: Electrical conductivity (EC) is a measurement of the dissolved material in an aqueous solution; higher the dissolved material in a water sample, higher is the EC. The desirable limit of EC for drinking purpose is 300 µS/cm. In the present study the electrical conductivity varies from 1450 to 450 µS/cm.

Table 1. Statistical analysis of analysed physico - chemical groundwater quality parameter

Parameter	Maximum	Minimum	Mean	Standard Deviation
pH	08.29	07.62	08.05	00.1758
EC	1450	450	677.50	295.6243
Hardness	384	104	170.75	66.7191
TDS	723	139	285.1875	163.9574
Alkalinity	428	88	172.75	83.7761
Sodium	94.08	10.83	56.94563	23.0470
Potassium	09.12	01.31	03.554375	01.7087
Calcium	76	22	35.09938	11.9647
Magnesium	74.84	19.93	32.626875	13.1318
Nitrate	18.15	01.69	08.236875	04.7042
Bicarbonate	522.16	107.36	210.755	102.2069
Chloride	183.44	59.98	91.27938	33.0003
Sulfate	36.70	00.00	09.2125	10.9749
Fluoride	01.65	00.29	00.95688	00.3940
Chromium	00.016	00.00	00.00319	00.0057
Zinc	00.31	00.00	00.1675	00.1062
Copper	00.0055	00.00	00.00292	00.00123
Manganese	00.0167	00.01	00.01283	00.00153
Iron	00.0157	00.0028	00.00579	00.00405
Nickel	00.0201	00.0014	00.0031	00.0046
Lead	00.0138	00.004	00.00826	00.00343
Cadmium	00.0346	00.0005	00.00916	00.00868

Hardness: Total hardness is an important parameter of water for its use in domestic sector. It arises due to the presence of calcium and magnesium. In general, hard waters originate in areas where the top soil is thick and limestone formations are present (Arumugam 2010). In the current study area hardness ranges from 104 to 384 mg/l which is within the permissible limits.

TDS: It mainly comprises inorganic salts and small amounts of organic matter that are dissolved in water. The principal constituents are usually calcium, magnesium, sodium and potassium and the anions carbonate, bicarbonate, chloride and sulphate. According to the BIS, the ideal TDS for drinking water is below 500 mg/l and the max permissible limit is 2000 mg/l. In the current study area it varies from 723 to 139 mg/l.

Alkalinity: Alkalinity is due to the presence of carbonate, bicarbonate and hydroxide ions. The desirable limit of total alkalinity in drinking water is 200 mg/l. Beyond this limit, taste of water become unpleasant, whereas in absence of alternate water source, alkalinity upto 600 mg/l is permissible. In the present study area the alkalinity ranges between 88 to 428 mg/l which lies within the limits.

Sodium: All groundwater contains some sodium because most rocks and soils contain sodium compounds from which sodium is easily dissolved. The permissible limit of sodium is 200 mg/l and in the study area it varies from 10.83 to 94.08 mg/l.

Potassium: Potassium is common in many rocks. Many of these rocks are relatively soluble and potassium concentrations in ground water increase with time. In the present study area it varies from 1.31 to 9.12 mg/l and is within the permissible limit (12 mg/l).

Calcium: Calcium is present as divalent cations. In the current study area the calcium concentration ranges from 14 to 82 mg/l which is under permissible limit (200 mg/l).

Magnesium: The higher concentration of magnesium causes hardness of water. In the study area the concentration ranges from 25 to 38 mg/l which is under permissible limit (100 mg/l).

Nitrate: Nitrate concentration causes health hazards beyond the permissible limit (45 mg/l) as per BIS, 2012 (Krishna Kumar et al., 2011, Kumar et al. 2014). Nitrate concentration in the study area ranges from 0.6 to 10.4 mg/l which is under desirable limit. The major causative source of nitrate is anthropogenic.

Bicarbonate: It comes due to action of carbon dioxide in water on carbonate rocks such as limestone and dolomite, bicarbonate

Table 2. Correlation matrix between various Groundwater quality parameters

	pH	EC	TH	TDS	Alkal	Na	K	Ca	Mg	NO_3	HCO_3	Cl	SO_4	F	Cr	Zn	Cu	Mn	Fe	Ni	Pb	Cd
pH	1																					
EC	-0.22	1																				
TH	0.00	0.87	1																			
TDS	-0.17	0.98	0.84	1																		
Alkalinity	-0.09	0.97	0.89	0.98	1																	
Na	0.26	0.26	0.15	0.37	0.30	1																
K	-0.41	0.59	0.39	0.58	0.47	0.38	1															
Ca	0.28	0.65	0.91	0.64	0.73	0.17	0.06	1														
Mg	0.00	0.86	1.00	0.84	0.89	0.14	0.39	0.91	1													
NO_3	-0.25	0.02	0.08	-0.05	-0.09	-0.18	0.40	-0.03	0.08	1												
HCO_3	-0.09	0.97	0.89	0.98	1.00	0.30	0.47	0.73	0.89	-0.09	1											
Cl	0.32	0.44	0.49	0.51	0.60	0.25	-0.14	0.55	0.50	-0.43	0.60	1										
SO_4	-0.24	0.97	0.78	0.97	0.95	0.30	0.57	0.54	0.77	-0.01	0.95	0.42	1									
F	0.21	-0.45	-0.43	-0.47	-0.47	0.08	-0.19	-0.26	-0.43	-0.17	-0.47	-0.31	-0.50	1								
Cr	0.15	-0.28	-0.19	-0.30	-0.31	-0.39	-0.43	-0.13	-0.19	-0.11	-0.31	0.10	-0.26	-0.07	1							
Zn	0.47	-0.21	-0.01	-0.17	-0.10	0.35	0.02	0.14	0.00	-0.10	-0.10	0.15	-0.29	0.49	-0.45	1						
Cu	0.13	0.26	0.46	0.32	0.41	0.03	0.02	0.47	0.48	-0.06	0.41	0.66	0.25	-0.23	0.01	0.39	1					
Mn	0.13	-0.08	-0.12	-0.03	-0.09	0.20	0.29	-0.09	-0.12	0.17	-0.09	-0.31	-0.15	0.41	-0.49	0.39	-0.18	1				
Fe	-0.11	0.14	-0.17	0.16	0.13	0.19	0.04	-0.29	-0.18	-0.13	0.13	-0.05	0.32	-0.27	-0.04	-0.53	-0.41	-0.31	1			
Ni	-0.09	-0.25	-0.23	-0.28	-0.32	-0.41	-0.31	-0.19	-0.24	-0.10	-0.32	-0.04	-0.29	0.06	0.46	-0.25	-0.06	-0.05	-0.28	1		
Pb	0.26	0.07	0.13	0.12	0.13	-0.03	0.20	0.07	0.14	0.00	0.13	0.03	0.10	-0.06	0.13	0.10	0.30	0.23	-0.01	-0.46	1	
Cd	-0.26	0.26	0.12	0.29	0.31	-0.04	-0.06	0.04	0.12	0.20	0.31	0.20	0.39	-0.61	-0.01	-0.56	0.08	-0.40	0.62	-0.35	0.05	1

(HCO^{3-}) produces an alkaline environment. In the present study area it ranges from 107.36 to 522.16 mg/l within the permissible limit of 600 mg/l.

Chloride: The higher concentration of chlorine in water makes it hazardous to human health (Anitha et al. 2011; Sadat-Noori et al. 2014). In the present study the concentration ranges from 65.98 to 115.25 mg/l which is under desirable limit (250 mg/l).

Sulfate: Sulfates (SO_4^{2-}) are dissolved from rocks containing gypsum, iron sulfides, and other sulfur compounds. In the study area it ranges from the 0 to 36.7 mg/l which is under desirable limit of 200 mg/l.

Fluoride: The main source of Fluoride in water is geogenic. High concentration (>3.0 mg/l) of fluoride may lead to skeletal fluorosis (N. Janardhana Raju, 2009). In the study area the fluoride concentration ranges from 0.28 to 2.01 mg/l.

Chromium: Major sources of Cr-contamination is electroplating processes and the disposal of Cr containing wastes. In the current study it ranges from 0 to 0.016 mg/l under the permissible limit (0.05 mg/l).

Zinc: Drinking water seldom contains zinc above 0.1 mg/l. In the present study area it ranges from 0.0 to 0.31 mg/l; under the permissible limit (5 mg/l).

Copper: Copper normally occurs in drinking water from Cu pipes, as well as from additives designed to control algal growth. In the study area it ranges from 0 to 0.0055 mg/l which is under permissible limit (0.05 mg/l).

Manganese: It comes from some rocks and soils. In the current study area manganese contents ranges from 0.01 to 0.0167 mg/l under the permissible limit (0.1 mg/l).

Iron: Iron (Fe) is dissolved from all rocks and soils. Water having a low pH tends to be corrosive and may dissolve iron in objectionable quantities from pipe, pumps, and other equipment. In the current area the iron ranges from 0.0028 to 0.0157 mg/l lies within the permissible limit (0.3 mg/l).

Nickel: The primary source of nickel in drinking water is leaching from metals in contact with drinking water, such as pipes and fittings. In the present study area it ranges from 0.0014 to 0.0201 mg/l slightly crosses the permissible limit (0.02 mg/l).

Lead: It enters environment from industry, mining, plumbing, gasoline, coal and as a additive. It ranges from 0.004 to 0.0138 mg/l which is slightly above the permissible limit (0.01 mg/l).

Cadmium: In the current study area it ranges from 0.0005 to 0.0346 mg/l which crosses the permissible limit (0.003 mg/l).

Water Quality Index (WQI): In the current study eight important parameters were chosen to calculate the water quality index. The WQI has been calculated using the standards of drinking water quality recommended by the World Health Organisation (WHO), Bureau of Indian Standard (BIS) and Indian Council for Medical Research (ICMR). The weighted arithmetic index method (Brown et. al., 1972) has been used for the calculation of WQI of the water.

Calculation of Quality Rating/ Sub Index (q_n): Quality rating is calculated by the following equation:

$$q_n = (V_n - Vio)/ (S_n - Vio)* 100$$

(Let there be n water quality parameters and quality rating or sub index (q_n) corresponding to n^{th} parameter is a number in the polluted water with respect to its standard permissible value). q_n = quality rating for the n^{th} water quality parameter. V_n = estimated value of the n^{th} parameter at a given sampling station. S_n = standard permissible value of the n^{th} parameter. V_{io} = ideal value of n^{th} parameter in pure water. (i.e. 0 for all other parameter except the parameter pH {7}).

Calculation of Unit Weight (W_n): Unit weight was calculated by a value inversely proportional to the recommended standard value S_n of the corresponding parameter.

$$W_n = K/ S_n$$

W_n = unit weight for the n^{th} parameter. S_n = standard value for n^{th} parameters. K = Constant for proportionality.

The overall water quality index is calculated by aggregating the quality rating with the unit weight linearly.

$$WQI = Sq_n \text{ X } W_n/ SW_n$$

RESULTS AND DISCUSSION

Twenty two groundwater quality parameters viz. pH, electrical conductivity (EC), total hardness (TH), total dissolved solid (TDS), alkalinity, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrates (NO^{3-}), bicarbonate (HCO^{3-}), chlorides (Cl^-), sulphates (SO^{4-}), fluorides (F^-), chromium (Cr), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), nickel (Ni), lead (Pb) and cadmium (Cd) were analyzed to evaluate the WQI of groundwater for 16 different location under study area and assess the suitability of groundwater for drinking purpose under different class (Table 4 and 5).

The correlation matrix for the different 22 water quality parameters

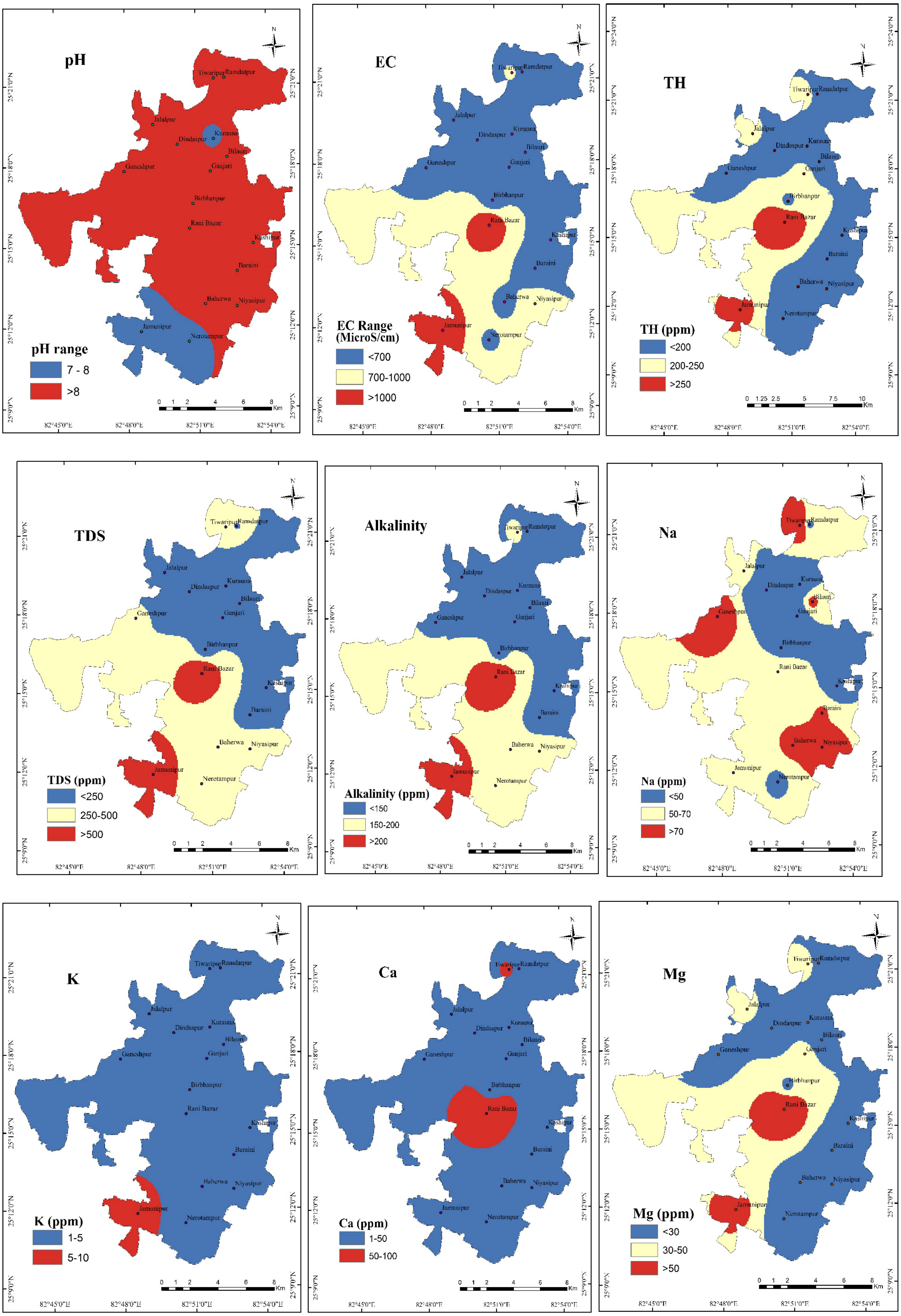

Fig. 2. Spatial distribution map of pH, EC, Hardness, TDS, Alkalinity, Na, K, Ca, Mg

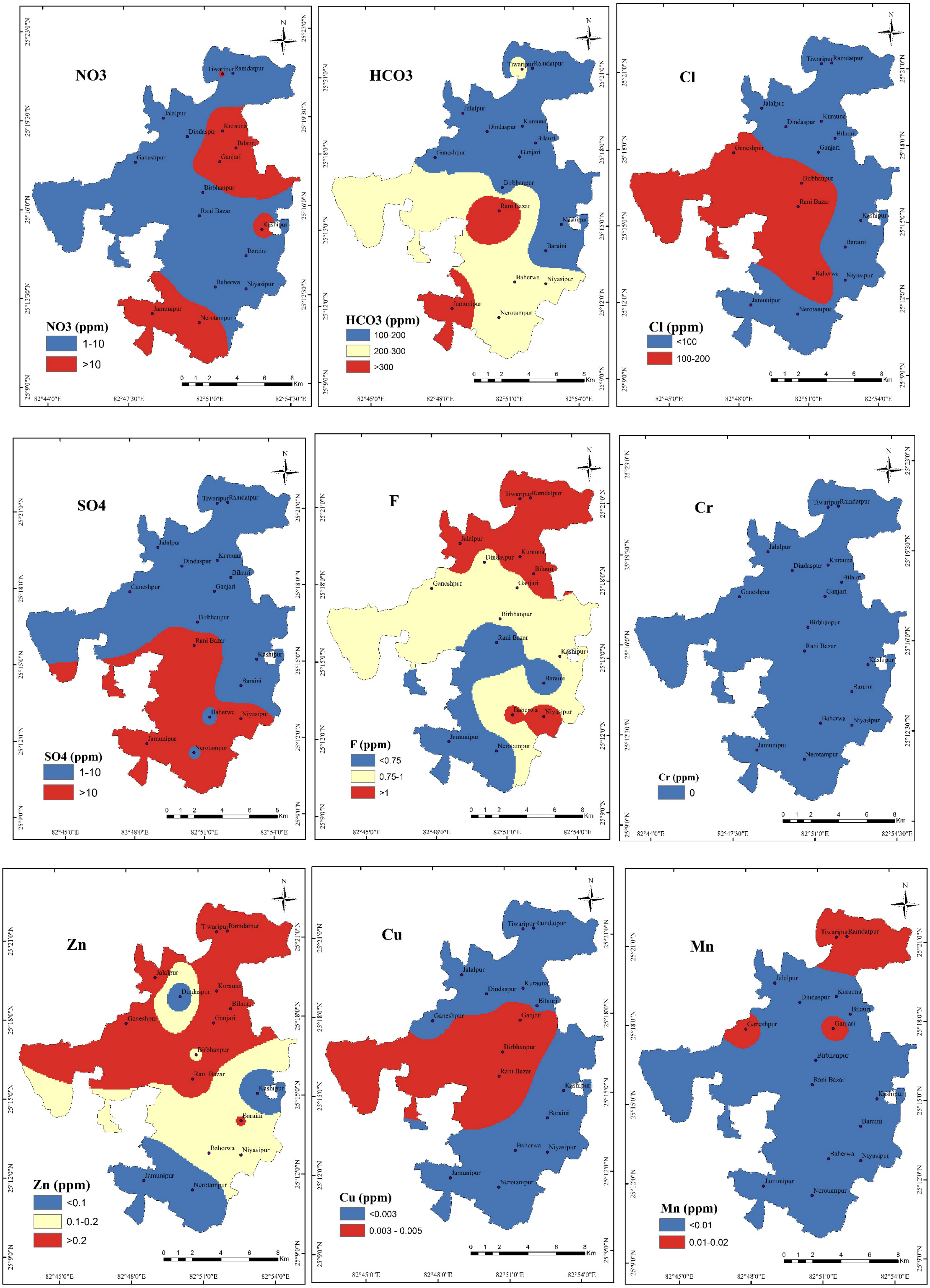

Fig. 2 Contd.. Spatial distribution map of Nitrate, Bicarbonate, Cl, Sulphate, F, Cr, Zn, Cu, Mn.

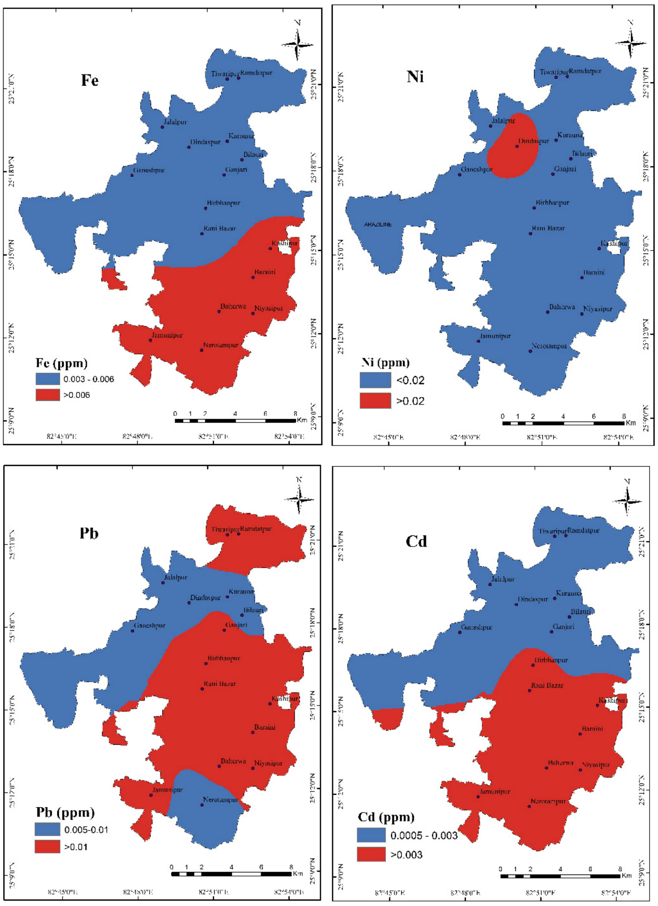

Fig. 2 Contd... Spatial distribution map of Fe, Ni, Pb and Cd.

has been analysed. Out of 22 parameters 8 heavy metals were analysed and correlation matrix for all the heavy metals were also calculated (Table 2).

The most of the parameters are negatively correlated with each other. But, electrical conductivity shows >0.50 correlation with Total Hardness, TDS, Alkalinity, Bicarbonate and Sulphate .These parameters show the higher influence on groundwater quality than other major radicals and physical parameters.

A perusal of correlation matrix for 8 heavy metals, shows that Fe is positively correlated with HCO_3 and sulphate SO_4 while Ni is significantly positively correlated with Cr. Pb has positive correlation with Cr, Cu and Mn which shows that Pb is very sensitive and significant heavy metal to be carefully observed in future for groundwater quality in the study area. Secondly, Cd is also positively correlated with Fe, SO_4 and NO_3. This depicts that higher concentration of Fe may trigger the concentration of Cd.

The areal distribution pattern for all twenty two parameters contour map have been prepared and shown in Fig. 2. These maps show that the SW part of the study area is affected by the higher concentration of TH, EC, TDS, Alkalinity, K, Mg and HCO_3 and also characterised by higher groundwater level fluctuation (5 to 9 m). It is due to significant availability of fluxing zone. The maximum part of the study area is characterised by higher pH value and shows more alkaline groundwater except limited to southern extreme of study area.

The northern part of the study area is influenced by the higher concentration of Ni, Mn, F, and Zn (Fig.2) where the groundwater level varies from 10 to 22 mbgl in post and pre-monsoon period respectively. It shows that rainfall recharge has sympathetic relationship with less mobile heavy metal and major radicals concentration in groundwater.

The southern part of the study area (Fig.2) is influenced by the higher concentration of Cd & Fe in groundwater while the central

Table 3. Weight (wi) and Relative weight (Wi) of each parameter

Parameter	BIS Standard	Weightage (wi)	Relative weight (Wi)
pH	6.5-8.5	1	0.03125
EC	300	1	0.03125
Hardness	200-600	1	0.03125
TDS	500-2000	1	0.03125
Alkalinity	200-600	1	0.03125
Sodium	50-200	2	0.0625
Potassium	10-12	1	0.03125
Calcium	75-200	1	0.03125
Magnesium	30-100	1	0.03125
Nitrate	45	2	0.0625
Bicarbonate	300-600	1	0.03125
Chloride	250-1000	1	0.03125
Sulfate	200-400	1	0.03125
Fluoride	1-1.5	2	0.0625
Chromium	0.05	1	0.03125
Zinc	5	1	0.03125
Copper	0.05	2	0.0625
Manganese	0.1	2	0.0625
Iron	0.3	3	0.09375
Nickel	0.02	2	0.0625
Lead	0.01	2	0.0625
Cadmium	0.003	2	0.0625
		Swi = 32	SWi = 1

portion is influenced by the Cu & Ca concentration where the groundwater level varies from 5 to 10 mbgl in post and pre monsoon period respectively.It shows that solubility of these heavy metals and Ca is more pronounced under shallow groundwater level (5-10 mbgl).

On the basis of all twenty two water quality parameters a WQI contour map have been drawn (Fig.3). This clearly shows that groundwater quality in northern part (approx.35%) is suitable for drinking purpose (Table 5). The type of groundwater vis-a-vis WQI has been tabulated (see Table 4). Study reveals that over all southern

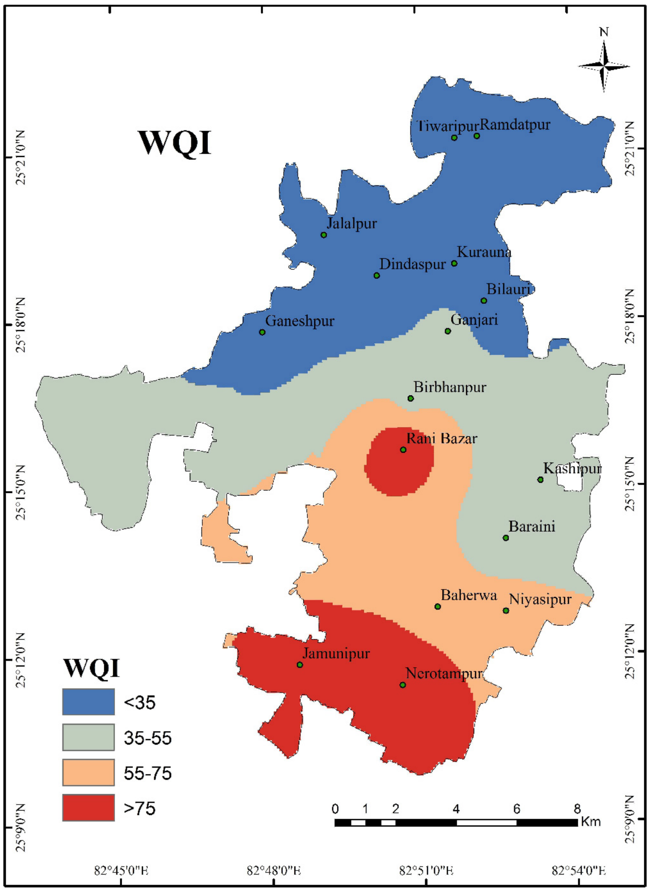

Fig. 3. Water Quality Index map of study area

Table 4. Classification of Groundwater quality according to WQI range

WQI Range	Type of water
<35	Excellent
35-45	Good
45-55	Moderate
55-65	Poor
65-75	Very poor
>75	Not suitable for drinking water

Table 5. Water quality index value for groundwater samples in study area

S. No.	Groundwater Samples	Type of GW abstraction Structures	WQI value	Classification
1.	Tiwaripur	Tubewell	62.03550625	Poor
2.	Ramdatpur	Handpump	57.08944732	Poor
3.	Jalalpur	Well	52.85367156	Moderate
4.	Kurauna	Handpump	44.22990355	Good
5.	Dindaspur	Handpump	41.64484516	Good
6.	Bilauri	Handpump	54.1182875	Moderate
7.	Ganeshpur	Well	57.86622906	Poor
8.	Ganjari	Tubewell	70.41651875	Very Poor
9.	Birbhanpur	Handpump	75.65166818	Not suitable for drinking
10.	Rani Bazar	Well	107.5154584	Not suitable for drinking
11.	Kashipur	Handpump	71.27131094	Very Poor
12.	Baraini	Handpump	64.77716576	Poor
13.	Niyasipur	Handpump	83.22350531	Not suitable for drinking
14.	Baherwa	Well	84.02582084	Not suitable for drinking
15.	Jamunipur	Well	97.07864188	Not suitable for drinking
16.	Nerotampur	Handpump	113.6949991	Not suitable for drinking

part of the study area is affected by the water quality problems and not suitable for drinking purposes. It covers almost 20 % of the total study area. Rest approximately 45% area is under moderate to poor for drinking pourpose (Table 5).

It is found that groundwater in most of the part of Araziline block is not suitable for drinking purposes due to high electrical conductivity and marginally high value of TDS, lead and cadmium as prescribed by permissible limit of BIS (2012). To evaluate groundwater suitability for drinking purposes water quality index of the study area was calculated using different groundwater quality parameters during pre monsoon of May 2015 and tabulated as under.

CONCLUSION

In present study, the reliable drinking WQI system has been adapted using 22 relevant parameters in study area for groundwater to minimize the uncertainty and imprecision in the decision-making. The rating of water quality shows that the ground water in 20% of the study area is not suitable for drinking purpose and pollution load is comparatively high during rainy and summer seasons.

It is also inferred that southern part of the study area is more prone to contamination than northern part (Fig.3). The WQI is having sympathetic relationship with shallow groundwater level in southern part of the study area.

The study suggests that priority should be given to water quality monitoring and its management to protect the groundwater resource from contamination as well as provide technology to make the groundwater fit for domestic and drinking particularly in southern part of the study area at Jamunipur, Rani Bazar and Narottampur. The groundwater quality in northern part of the study area (Fig.3) is quite safe and protected from the contamination as on date.

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