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ASSESSMENT OF THE DRINKING WATER QUALITY IN THE SHALLOW AQUIFERS OF A CANNAL COMMAND AREA IN NORTH INDIA

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ABSTRACT

Ground water was extensively collected from shallow aquifers of the study area and analysed for physico-chemical parameters and specific ions to assess the drinking water quality. The water samples were alkaline in reaction (pH 8.1 - 9.8) and high in electrical conductivity (0.3 - 4.3 dS m^{-1}). Sulphate was the dominant ion (109.68 - 3570.7 mg L^{-1} ; mean 794 mg L^{-1}) followed by bicarbonate (12.2 - 3233 mg L^{-1} ; mean 341.4 mg L^{-1}), nitrate (0.3 - 557.8 mg L^{-1} ; mean 92.3 mg L^{-1}), carbonate (18 - 162 mg L^{-1} ; mean 51.14 mg L^{-1}), chloride (7.1 - 685.15 mg L^{-1}; 51.41 mg L^{-1}) and fluoride (0.4 to 21.1 mg L^{-1}; mean 8.61 mg L^{-1}); whereas among the cations, sodium was dominant (251 - 1652 mg L^{-1}; mean 612.2 mg L^{-1}), followed by magnesium (12 - 220.8 mg L^{-1}; mean 48.37 mg L^{-1}), calcium (4 - 34 mg L^{-1}; mean 13.1 mg L^{-1}) and potassium (1.1 - 450.4 mg L^{-1} ; mean 20.1 mg L^{-1}). A total of 10%, 79% and 11% of the samples were found to possess good, poor and completely unsuitable water quality, respectively, warranting immediate attention.

KEY WORDS
Water quality index
Specific ion toxicity
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INTRODUCTION

Availability good quality surface water is decreasing due to contamination by effluents from different industries, discharge of drainage systems in natural water reservoirs, different human activities, washing from salt pans etc. (Tamberkar *et al.,* 2007). Human beings thus depend on ground water resources for drinking to a large extent. It is estimated that approximately one third of the world's population use groundwater for drinking (Nickson *et. al.,* 2005). Deterioration of ground water quality had become a matter of concern in India in recent years (Subba Rao, N. 1983, Saha *et. al.,* 2008, Udayalaxmi *et. al.,* 2010, Subba Rao, N. *et. al.,* 2013) and is a major cause of epidemic and chronic diseases in human beings (Tamberkar and Charan, 2004). Access to safe drinking water is an internationally accepted human right (WHO, 2004) and one of the ten targets of the Millennium Development Goals (UN, 2006) is to halve the proportion of people without sustainable access of safe drinking water by 2015. The issue of sustainability and maintenance of quality of drinking water supplied is, therefore, an area of concern for most developing countries.

The Sharda Sahayak Pariyojana (SSP) is a 260 km long feeder channel of the SSP originating from the river Sharda with an aim of creating irrigating culturable command area of 16.77 lakh hectares in central and eastern Uttar Pradesh. It was commissioned in 1926, started in 1968, and was completed in 2000. Seepage from irrigation canals can be an important source for recharging shallow groundwater aquifers and can affect groundwater quality. The chemical quality of groundwater determines its suitability for specific use (eg. drinking) and hence it is imperative to examine the chemistry of ground water quality in canal command areas for sustainable development. As the chemical quality of groundwater is controlled by many interrelated processes, the understanding of such processes is needed before one can act towards the achieving of water quality control and improvement. There are no previous reports of groundwater quality assessment in the Sharda Sahayak Pariyojana canal command area in Uttar Pradesh. The present investigation was therefore undertaken to understand the processes governing water quality in the shallow aquifers of the recently completed Sharda Sahayak Pariyojana cannal command area in Pratapgarh district of Uttar Pradesh, India and determine its suitability for drinking purposes.

MATERIALS AND METHODS

The study covers three blocks namely Kalakanker, Babaganj and Sangramgarh in the Kunda tehsil of Pratapgarh district in Uttar Pradesh. The area lies between 25º44 and 25º55 N latitudes and 81º22 E and 81º34 E longitudes and enjoys a tropical climate with mild winter and long summer days. It receives rainfall from the southwest monsoon lasting from June to September with a mean annual rainfall of 1180 cm, 85-90 percent of which is received during June to September and the potential evapo- transpiration (PET) is about 1400 mm. The temperature of the area varies from 4º C to 45ºC. The temperature begins to rise from the middle of February and reached its maximum by the end of May or middle of June. The mean relative humidity is 62 percent, which increases up to 85 percent from July to September and goes down to 20 percent from the end of April to first week of June.

Sampling and analytical methods

Water samples were collected in a systematic way from tube wells; hand pumps and open dug wells during the summer of 2012 covering the entire study area (Table 1 and 2). Hand pumps and tube wells were continuously pumped for 10 minutes prior to sampling to ensure that ground water sampled was representative of the aquifer. Samples were stored in previously rinsed plastic bottle and were brought to the laboratory for detailed chemical analysis. The physiochemical analysis of water samples was carried out for various quality parameters such as pH, electrical conductivity (EC), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-) by adopting standard analytical procedures (APHA, 2005; Trivedi and Goel, 1984; Vogel, 1964) and fluoride (F^-) using the ion selective electrode (Sabal *et. al.,* 2008). Water quality index (WQI) was calculated using eleven parameters as recommended by Ravikumar *et al.* (2013). Briefly, chemical parameters were assigned weights (w_i) between 2 (Ca^{2+}, Mg^{2+}, K^+ and HCO_3^-) and 5 (NO_3^-, F^-, Cl^-) based on their perceived effects on primary health and their relative importance in the overall water quality. The relative weight (W_i) of each parameter was calculate as a ratio using the formula $W_i = (w_i/\Sigma w_i)$. A quality rating scale (q_i) for each parameter was then calculated by dividing the concentration of each studied parameter in each water sample by its respective standard according to BIS (2003) and the results were multiplied by 100. The sub indices of water quality was then calculated by multiplying the quality rating scale (q_i) and relative weight (W_i) for each parameter. The overall water quality index for a particular water sample was arrived at by summing all the water quality sub indices (*i.e.* $\Sigma W_{i\,*}\, q_i$).

RESULTS AND DISCUSSION

The drinking water quality of the samples were analysed and the experimental results compared with the standard limits recommended by WHO (2004) and Indian Standards (BIS, 2003). Considerable deviations from the desirable limits were observed in water quality in the present study.

pH

The pH of the ground water samples in the study area was alkaline and ranged between 8.4 to 9.6 with a mean value of 9.1. pH of ground water sample in the Kalakankar, Sangramgarh and Babaganj development blocks were similar in value and ranged between 8.5 to 9.5, 8.1 to 9.8 and 8.5 to 9.6 respectively (Tables 3, 4 and 5). Water is classified as desirable for drinking if the pH ranges between 6.5 and 8.5 (BIS, 2003; WHO, 2004). Drinking water outside the prescribed limits is known to damage the mucous membrane present in eyes, nose, mouth, abdomen, anus, etc. As per the limit, only 9% of the water samples were in the desirable limit of safe drinking water and 91% of the water samples were not safe for drinking. Among the three development blocks, 94% of the water samples of Kalakankar and Babaganj blocks and 84% of the water samples in the Sangramgarh block were outside the desirable limit for drinking (Table 6). The pH of groundwater is controlled by carbon dioxide, carbonate and bicarbonate equilibrium. Dissolved carbon dioxide (CO_2), which forms carbonic acid in water, imparts an important control on the pH of natural waters (Hem, 2013), whereas pH of ground water can be lowered by organic acids from decaying vegetation, or by dissolution of sulphide minerals (Davis and De Wiest, 1970). The alkaline nature of most of the samples in this study might be due to high mineral rich rocks like gabbro and basalt making up the aquifers. Alkalinity of surface water has been previously reported by Y. Avasn. Maruthi *et al.* (2010) and Deshmukh and Urkude (2014).

Electrical Conductivity

The Electrical Conductivity of the ground water samples in the study area ranged between 0.3 to 4.3 dS m^{-1} with a mean value 0.86 dS m^{-1}. EC values of ground water in the Kalakankar, Sangramgarh and Babaganj development blocks were similar and ranged between 0.3 to 2.7, 0.4 to 1.7 and 0.4 to 4.3 dS m^{-1} respectively (Tables 3, 4 and 5).

Cations

Calcium

The calcium concentration of the ground water samples in the study area ranged between 4 to 34 mg L^{-1} with a mean value 13.1 mg L^{-1}. Calcium concentration in ground water of the Kalakankar, Sangramgarh and Babaganj development blocks were similar and ranged between 4 to 34, 6 to 34 and 4 to 26 mg L^{-1} with mean value 13.3, 13.68 and 12.44 mg L^{-1} respectively (Tables 3, 4 and 5). The desirable limit of calcium content in drinking water according is 75 mg L^{-1} (BIS, 2003; and WHO, 2004). According to BIS all water samples were below the desirable limit for drinking purpose. Calcium is an important element for proper bone growth and low calcium levels in drinking water can impair bone development.

Magnesium

Magnesium content of ground water samples in the study area ranged between 12 to 220.8 mg L^{-1} with a mean value 48.37 mg L^{-1}. Among the blocks, the mean magnesium content in Kalakankar, Sangramgarh and Babaganj 42.85, 40.66 and 50.6 mg L^{-1} respectively (Tables 3, 4 and 5). The desirable limit of Mg in drinking water is 30 mg L^{-1} (BIS, 2003; WHO, 2004). Accordingly, 76% of the water samples were above the desirable limit for drinking purposes (Table 6). Kalakankar, had 27% water sample within the desirable limit, whereas, Sangramgarh and Babaganj had 32 and 11% water sample within the desirable limit only (Table 6). Mg^{2+} is an essential ion needed for functioning of cells in enzyme activation, but at higher concentrations, it acts as a laxative agent (Garg *et. al.,* 2009). The higher concentration of Mg^{2+} compared to that of Ca^{2+} found in the present study is probably due to the effect of ferromagnesium minerals, ion exchange (between Na^+ and Ca^{2+}) and precipitation of Ca as $CaCO_3$ (Hem, 2013; Subba Rao, 2002).

Table 1: Locations of sampling points in Kalakankar block in Pratapgarh district, Uttar Pradesh, India.

Sl No.	Location	Water Source	Depth (ft)	Sl No.	Location	Water Source	Depth (ft)
1	Adalabad south	W	10	20	Madhgawa pur	HP	35
2	Adalabad	HP	35	21	Natohi	HP	40
3	Sindurai pur khas	HP	35	22	Aalapur kham	HP	55
4	Mamasai	HP	35	23	Chhachhamau	HP	25
5	Abdul vahid gang	HP	30	24	Kandhai	HP	30
6	Kakariha	HP	32	25	Avadheshpuram	HP	35
7	Milkia	W	30	26	Garauli	HP	45
8	Rajawapur	HP	30	27	Bijuli pur	HP	45
9	Kakariha east	HP	60	28	Trilochanpur	W	10
10	Chandapur	HP	30	29	Antukhas	W	10
11	Dewara lawan	HP	30	30	Atuliya pure	IHP	60
12	Dulahitapur	W	15	31	Panigau	HP	30
13	Kashipur	HP	40	32	Panigau	HP	30
14	Kasba siria	HP	25	33	Lalabajar south	HP	30
15	Karanou	W	11	34	Jajupur manar	HP	30
16	Keravdeeh	HP	35	35	Asthawa narth	HP	30
17	Keravdeeh khas	HP	20	36	Asthawa south	HP	30
18	Kekhapurva khas	W	15	37	Meerapur	W	15
19	Madhawapur narth	HP	35				

W = Well; HP = Hand Pump; IHP = India Hand Pump (Samples water at a greater depth)

Table 2: Locations of sampling points in Sangramgarh and Babaganj blocks in Pratapgarh district, Uttar Pradesh, India

Sl No	Location	Water Source	Depth (ft)	Sl No	Location	Water Source	Depth (ft)
38	Balla	HP	30	57	Ramapur bhuval	HP	40
39	Mashwan	W	40	58	Garaua	HP	25
40	Dhanuvan	W	15	59	Khas ram pur	HP	30
41	Meerapur	W	15	60	Kanjia kasba	HP	30
42	Meerapur	HP	40	61	Kamapatti lakhia	HP	30
43	Kusemar	W	10	62	Khanvari	W	10
44	Mangarh	HP	40	63	Sangram garh	HP	40
45	Matarzapur	HP	30	64	Ashogi	HP	45
46	Kajipur kusemar	W	10	65	Hisampur	W	25
47	Mangarh	W	15	66	Raguvarpur	W	35
48	Samsuddeen pur	W	12	67	Kalu ka purva	HP	25
49	Laroo	HP	30	68	Vijai Mau	HP	30
50	Dadaura khas	HP	30	69	Ashogi	HP	35
51	Daduira	W	20	70	Aushan ganj	HP	30
52	Miya ka purva	W	23	71	Dhangarh	HP	35
53	Aghori ka bazar	HP	30	72	Babupur	HP	40
54	Agohi south	HP	30	73	Goubra	HP	35
55	Mahamdpur	W	10	74	Mashwan	W	40
56	Dhanuvan	W	15				

W = Well; HP = Hand Pump; IHP = India Hand Pump (Samples water at a greater depth)

Sodium

The sodium content of the ground water samples in the study area ranged between 251 to 1652 mg L^{-1} with a mean value 612.2 mg L^{-1}. According to (BIS, 2003; WHO, 2004) ground water containing up to 200 mg L^{-1} of sodium is unsuitable for drinking. The average sodium content of ground water samples in the Kalakankar, Sangramgarh and Babaganj development blocks were 514.51, 564.63 and 756.93 mg L^{-1} respectively, which is considered to be very high (Table 6). The entire water samples collected in the study were unsafe for drinking and pose a serious health effect.

Potassium

Potassium is an important ion in drinking water as it maintains the fluid balance in the body. However, according to WHO (2004), potassium content above 10 mg L^{-1} in drinking water is considered to be unsafe for drinking. Potassium content of the ground water samples in the study area ranged between 1.1 to 450.4 mg $L^{-1}$with a mean value 20.1 mg L^{-1}. The average potassium content of ground water samples in the Kalakankar, Sangramgarh and Babaganj development blocks were 8.64, 36.74 and 14.73 mg L^{-1} respectively (Tables 3, 4 and 5). Only 8% of the water samples were above the safe limit for drinking (Table 6). Potassium in groundwater is generally less due to its higher solubility (Das *et al.,* 2010). Higher concentrations are occasionally found where the rock contains potassium e.g. certain granites and sandstones.

Anions

Carbonate and Bicarbonate

The carbonate content of the ground water samples in the study area ranged between 18 to 162 mg L^{-1} with a mean value 51.14 mg L^{-1} and was similar in all the three block studies ranging between 18 to 102 mg L^{-1} in Kalakankar, 24 to 162 in

Table 3: Characteristics of ground water of the Kalakankar block,Uttar Pradesh, India.

Sl No.	pH	EC dS m^{-1}	Ca^{2+} mg L^{-1}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	F	WQI
1	9.2	0.4	16.0	31.2	387.5	5.4	66.0	134.2	7.1	537.9	108.0	2.7	141
2	9.1	0.3	4.0	34.8	289.3	4.9	24.0	140.3	10.6	183.1	141.2	1.9	120
3	8.9	0.6	6.0	43.2	645.9	6.1	42.0	219.6	28.4	217.4	133.6	2.4	161
4	9.4	0.6	6.0	15.5	651.6	3.4	42.0	237.9	7.1	114.2	119.2	2.0	142
5	9.3	0.6	6.0	49.2	483.9	7.0	54.0	225.7	17.8	286.1	121.6	4.4	167
6	9.2	0.4	8.0	132.0	429.2	4.9	30.0	158.6	17.8	892.7	50.0	2.9	163
7	8.5	2.7	30.0	20.4	1378	126.2	54.0	341.6	351.5	812.6	15.5	0.2	285
8	9.2	0.4	6.0	33.6	362.7	7.1	30.0	213.5	7.1	515.8	13.0	2.6	110
9	9.3	0.4	6.0	24.0	492.4	5.9	24.0	213.5	10.7	1120.8	75.1	3.0	169
10	9.1	0.3	12.0	21.6	303.5	3.2	60.0	335.5	10.7	1212.0	73.4	1.1	139
11	9.5	0.7	16.0	21.6	684.5	5.0	54.0	634.4	17.8	1660.8	92.2	3.6	233
12	8.9	0.9	14.0	36.0	370.1	5.6	42.0	286.7	131.4	422.4	147.6	2.5	159
13	9.0	0.4	14.0	28.8	622.1	5.5	18.0	158.6	24.9	525.6	62.0	0.5	126
14	9.2	0.7	16.0	31.2	251.7	5.6	36.0	195.2	28.4	296.2	50.0	3.8	115
15	9.2	0.8	12.0	75.6	639.7	5.5	102.0	24.4	24.9	230.1	111.0	6.6	195
16	9.1	0.4	20.0	43.6	326.9	5.3	72.0	85.4	24.9	954.2	45.6	2.6	135
17	8.8	0.3	18.0	20.4	285.4	1.4	72.0	12.2	10.7	362.0	233.2	1.4	144
18	9.1	1.4	20.0	116.4	597.4	6.9	48.0	189.1	209.5	767.8	196.0	2.8	232
19	9.3	0.5	20.0	31.2	359.0	5.6	42.0	292.8	24.9	175.5	127.6	3.6	145
20	9.1	0.4	10.0	39.6	338.5	4.6	60.0	128.1	10.7	811.2	24.8	2.6	122
21	9.2	0.5	14.0	34.8	391.7	4.0	36.0	219.6	17.8	405.6	0.3	3.5	113
22	9.0	0.5	18.0	22.8	334.6	3.7	54.0	189.1	10.7	141.8	10.7	3.4	95
23	8.5	0.6	16.0	52.8	403.6	7.2	42.0	274.5	17.8	899.5	55.6	3.9	163
24	9.3	0.6	24.0	12.0	642.5	5.3	42.0	213.5	28.4	264.0	21.6	3.0	128
25	9.5	0.6	20.0	34.8	550.2	4.6	66.0	164.7	10.7	394.9	20.0	3.7	133
26	9.2	0.7	10.0	38.4	594.0	6.3	48.0	280.6	24.9	331.2	72.8	4.6	165
27	9.2	1.3	8.0	57.6	920.2	8.1	78.0	439.2	85.2	438.7	145.8	3.5	224
28	9.3	0.8	4.0	39.6	703.9	4.8	54.0	317.2	28.4	361.9	71.2	3.4	164
29	9.5	1.1	20.0	21.6	932.2	5.1	60.0	427.0	35.5	2446.1	96.6	3.3	283
30	8.6	0.6	24.0	43.2	402.5	6.2	48.0	225.7	39.1	274.2	36.6	2.2	112
31	9.0	0.6	14.0	42.0	486.4	5.9	54.0	268.4	10.7	1634.4	44.4	4.8	203
32	9.0	0.6	8.0	44.4	460.3	6.3	36.0	280.6	17.8	274.2	75.0	7.6	180
33	8.7	0.8	16.0	70.8	459.1	6.7	18.0	427.0	46.2	669.1	50.6	4.0	167
34	8.6	0.6	8.0	66.0	369.9	6.3	48.0	317.2	17.8	307.1	60.2	5.1	150
35	9.0	0.5	10.0	44.4	331.6	5.0	54.0	183.0	10.7	252.0	73.0	5.9	147
36	8.7	0.9	8.0	63.6	634.2	3.9	42.0	329.4	39.1	724.1	95.2	5.3	204
37	9.2	0.6	6.0	46.8	520.5	5.0	60.0	274.5	17.7	175.5	104.4	3.2	148
Mean	9.1	0.7	13.2	42.9	514.5	8.6	49.0	244.8	38.8	597.1	80.4	3.3	161
Max	9.5	2.7	30.0	132.0	1378.0	126.2	102.0	634.4	351.5	2446.1	233.2	7.6	525
Min	8.5	0.3	4.0	12.0	251.0	1.4	18.0	12.2	7.1	114.0	0.3	0.5	45

Babaganj and 24 to 96 mg L^{-1} in Babaganj. The bicarbonate content of the ground water samples ranged between 12.2 to 3233 mg L^{-1} with a mean value 341.4 mg L^{-1} and varied from 12.2 to 634.4 mg L^{-1} in Kalakankar, 134.2 to 506 mg L^{-1} in Sangramgarh and 158.6 to 3233 mg L^{-1} in Babaganj blocks respectively (Tables 3, 4 and 5). Bicarbonate is a major element in the human body which is necessary for digestion. When ingested with mineral water, it helps buffer lactic acid generated during exercise and also reduces acidity of dietary components, and has a prevention effect on dental cavities. However it should not exceed 300 mg L^{-1} in potable water (WHO, 2004), as it may lead to kidney stones in the presence of higher concentration of Ca^{++}, especially in dry climatic regions (Subba Rao *et al.,* 2012). As per the drinking water guidelines, 24%, 21 % and 56% of the ground water samples of Kalakankar, Sangramgarh and Sangramgarh were not suitable for drinking (Table 6).

Chloride

Chloride is considered as an important inorganic ions, which determines the quality of drinking water to a larger extent. The origin of Cl^- is mainly from the non-lithological sources and can be contributed from the surface sources through domestic wastewaters, septic tanks, irrigation-return flows chemical fertilizers and organic wastes (Todd, 1980; Hem, 2013). The chloride content of the ground water samples in the study area ranged between 7.1 to 685.15 mg L^{-1}. The range in chloride content was 7.1 to 351.5 mg L^{-1} in Kalakankar, 7.1 to 85.2 mg L^{-1} in Sangramgarh and 10.65 to 685.15 mg L^{-1} in Babaganj with mean values of 38.8, 31.01 and 98.81 mg L^{-1} respectively (Tables 3, 4 and 5). The concentration of Cl^- in the groundwater of the study area is perhaps caused by the influences of irrigation return flows and chemical fertilizers. Water is classified as desirable if the chloride content is within 200 mg L^{-1} (WHO, 2004) and the permissible limit of chloride is 250 mg L^{-1} (BIS, 2003). As per the BIS guidelines, among the three development blocks, 100% of water samples in the Sangramgarh block and 97% and 89% of the samples in Kalakankar and Babaganj blocks was unsuitable for drinking (Table 6). Chloride plays an important role in balancing the

Table 4: Characteristics of ground water of the Sangramgarh block, Uttar Pradesh, India.

Sl No	pH	EC dS m^{-1}	Ca^{2+} mg L^{-1}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	F	WQI
38	9.2	0.8	14	24	730.2	5.5	30	183	46.2	416.8	557.8	1.1	297
39	8.9	0.4	18	18	413.5	5	24	170.8	24.9	109.7	155	1.2	125
40	9.8	1.1	10	20.4	969.5	5.3	36	457.5	17.8	1426.0	104.8	21.1	414
41	9.2	0.9	12	30	663	5.7	42	219.6	85.2	1184.6	130.6	0.4	186
42	9.1	0.6	16	55.2	424.7	6.8	54	268.4	24.9	377.7	90.8	3.8	153
43	8.5	0.7	14	52.8	428.6	7.6	30	195.2	35.5	141.6	15.3	1.5	96
44	9.2	1.7	16	44.4	1253	450	108	481.9	81.7	1864.7	198.6	0.7	556
45	9.2	0.5	6	16.8	465.9	2.2	24	231.8	24.9	954.2	86	3	161
46	9.3	0.5	8	57.6	395.1	7.3	42	250.1	10.8	366.2	46	3.4	131
47	9.6	1.3	10	48	1007	8.5	162	506.3	28.4	2414.9	184.8	6.7	357
48	9.1	0.5	8	46.8	384	7.3	36	262.3	17.8	927.1	163.2	4	196
49	9.2	0.5	16	48	356.4	7.8	42	219.6	24.9	812.6	18.7	3.3	136
50	9	0.4	14	52.8	345.5	5.9	24	134.2	10.7	3570.7	46	0.8	235
51	8.6	1.1	34	43.2	851.2	140	54	341.6	63.9	354.8	188	2.9	292
52	8.7	0.5	8	54	405	7.3	42	256.2	17.8	892.7	173	4	200
53	8.7	0.6	20	40.8	404.5	5.9	24	164.7	10.7	595.1	49	4.7	149
54	8.5	0.6	14	38.2	527.7	6.8	48	268.4	7.1	377.7	68	9.3	202
55	8.87	0.4	10	26.4	293.6	5.6	24	134.2	17.8	354.8	15.4	1.5	84
56	8.1	0.6	12	55.2	409.5	7.1	42	256.2	39.1	286.1	95.3	2.7	138
Mean	9.0	0.7	13.7	40.7	564.6	36.7	46.7	263.3	31.0	917.3	125.6	4.0	216
Max	9.8	1.7	34	57.6	1253	450.4	162	506.3	85.2	3570.7	557.8	21.1	944
Min	8.1	0.4	6	18	293	2.2	24	134.2	7.1	109.7	15.3	0.4	57

Table 5: Characteristics of ground water of the Babaganj block, Uttar Pradesh, India

Sl No	pH	EC dS m^{-1}	Ca^{2+} mg L^{-1}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	NO_3^{-}	F	WQI
57	8.7	0.6	10.0	49.2	372.0	5.9	30.0	268.4	28.4	148.8	152.0	2.2	141
58	8.7	0.4	26.0	20.4	360.5	5.2	30.0	158.6	24.9	331.2	106.0	1.7	120
59	9.4	0.9	6.0	20.4	863.8	5.1	54.0	366.0	46.2	354.8	72.0	1.8	162
60	8.9	4.3	22.0	220.8	1652.0	4.4	84.0	256.2	685.2	1283.4	111.6	4.9	393
61	8.7	2.0	12.0	92.4	1068.0	8.5	66.0	311.1	276.9	3528.0	73.2	1.3	342
62	9.0	1.3	20.0	38.4	1024.0	9.2	96.0	518.5	63.9	328.8	85.2	12.3	292
63	8.5	0.6	10.0	31.2	598.1	1.1	66.0	286.7	10.7	427.2	58.8	12.0	229
64	8.9	1.1	16.0	52.8	846.7	4.4	66.0	488.0	39.1	877.4	49.0	11.6	279
65	9.0	1.3	8.0	42.0	994.2	1.8	72.0	646.6	74.6	734.9	56.8	16.1	334
66	9.2	0.8	14.0	32.4	801.1	9.0	66.0	506.3	10.7	460.7	4.1	5.4	180
67	9.4	1.6	4.0	94.8	913.1	4.7	78.0	396.5	220.1	2259.6	61.6	6.0	311
68	9.5	1.2	6.0	76.8	810.4	17.0	48.0	402.6	103.0	1283.4	106.6	1.9	232
69	9.3	0.7	6.0	46.8	595.4	5.8	36.0	3233.0	35.5	877.4	23.7	3.5	248
70	9.6	1.1	10.0	63.6	838.0	8.4	90.0	457.5	28.4	141.8	112.4	4.2	199
71	9.4	0.6	12.0	44.4	527.0	4.1	60.0	292.8	17.8	175.5	88.6	5.5	166
72	9.0	0.6	10.0	52.8	402.2	6.2	42.0	256.2	10.7	120.7	36.1	4.6	128
73	9.2	1.9	12.0	66.0	682.2	161.5	24.0	244.0	92.3	2040.0	36.2	2.0	309
74	8.8	0.5	20.0	63.6	276.0	2.9	30.0	201.3	10.7	296.2	44.6	4.1	122
Mean	9.1	1.2	12.4	61.6	756.9	14.7	57.7	516.1	98.8	870.5	71.0	5.6	232
Max	9.6	4.3	26.0	220.8	1652.0	161.5	96.0	3233.0	685.2	3528.0	152.0	16.1	694
Min	8.5	0.4	4.0	20.4	276.0	1.1	24.0	158.6	10.7	141.8	4.1	1.3	63

level of electrolytes in blood plasma, but higher concentration can develop hypertension, risk of stroke, left ventricular hypertrophy, osteoporosis, rental stones, and asthma (McCarthy, 2004). The dissolution of halite (NaCl) is sometimes cited as a source of both sodium and chloride in ground water. Variation in the EC and chloride values suggests that some part of the area has a non-homogeneously mixed groundwater system.

Sulphate

The sulphate concentration of the ground water samples in the study area ranged between 109.68 to 3570.7 mg L^{-1} with a mean value of 794 mg L^{-1}. The average sulphate concentration in groundwater of Kalakankar, Sangramgarh and Babaganj were 597.1, 917.3 and 870.5 mg L^{-1} respectively (Tables 3, 4 and 5). Water is classified as desirable if the sulphate content is within 150 mg L^{-1} (BIS 2003), and 200 mg L^{-1} (WHO, 2004). As per the WHO norms, 85% of the water samples were unsuitable for drinking (Table 6). Among the three development blocks 88, 89 and 78% of the samples in Kalakankar, Sangramgarh and Babaganj blocks were above the permissible limit for drinking purpose (Table 6). High

Table 6. Criteria for groundwater quality of drinking in the, Pratapgarh district of UP, India.

Parameter	BIS (2003)	WHO (2004)	Sample exceeding the desirable limit in different development blocks as per BIS / WHO guidelines (%)			
			Kalakankar	Sangramgarh	Babaganj	Overall
pH	6.5–8.5	6.5–8.5	94	84	94	91
Ca^{2+} (mg L^{-1})	75	75	0	0	0	0
Mg^{2} (mg L^{-1})	30	30	72	68	89	76
Na^{+} (mg L^{-1})	200	200	100	100	100	100
K^{+} (mg L^{-1})	-	10	0	12	12	8
HCO_2^{-} (mg L^{-1})	-	300	24	21	56	34
$Cl^{'}$ (mg L^{-1})	250	200	3	0	11	5
SO_4^{2-} (mg L^{-1})	150	200	88	89	78	85
NO_3^{-} (mg L^{-1})	45	45	75	84	78	79
$F^{'}$ (mg L^{-1})	0.6-1.2	1.5	92	74	100	89

Table 7: Distribution (%) of water samples in different water quality index categories

WQI	Category	Per-centage of water samples			
		Kalakankar	Sangramgarh	Babaganj	Overall
< 50	Excellent	0.0	0.0	0.0	0.0
50-100	Good	2.8	10.5	16.7	10.0
100-200	Poor	78.4	52.6	44.4	58.5
200-300	Very poor	18.9	21.1	22.2	20.7
> 300	Unsuitable	0.0	15.8	16.7	10.8

Table 8: Correlation coefficients among different water quality parameters

	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	No_3^{-}	F
pH	1											
EC	0.01	1										
Ca^{2+}	-0.32**	0.24*	1									
Mg^{2+}	-0.1	0.61**	-0.02	1								
Na^{+}	0.19	0.86**	0.14	0.34**	1							
K^{+}	-0.03	0.33**	0.22	-0.01	0.38**	1						
CO_3^{2-}	0.25*	0.39**	0.06	0.19	0.54**	0.23*	1					
HCO_3^{-}	0.16	0.11	-0.15	0	0.21	0.05	0.07	1				
Cl^{-}	-0.13	0.92**	0.26*	0.68**	0.68**	0.14	0.22	0.02	1			
SO_4^{2-}	0.19	0.37**	-0.03	0.23*	0.37**	0.22	0.22	0.11	0.3	1		
NO_3^{-}	0.08	0.07	0.01	-0.01	0.16	0.14	0.13	-0.1	0.06	-0.02	1	
F	-0.01	-0.04	0.01	-0.02	-0.03	-0.03	0.03	-0.01	-0.1	0.14	-0.08	1

concentrations of sulphate in drinking water is associated with several disorders like diarrhea, catharsis, dehydration and gastrointestinal irritation (Garg *et al.,* 2009).

Nitrate

Nitrate is one of the most common contaminants identified in groundwater. The nitrate ion is not adsorbed on the clay or organic matter. It is highly mobile and under wet conditions is easily leached out of the rooting zone through soil and permeable subsoil. Under natural conditions, the concentration of NO_3^- does not exceed 10 mg L^{-1} in water (Cushing *et al.,* 1973; Ritzi *et al.,* 1993). A higher nitrate concentration reflects manmade pollution (Hem, 2013) due to application of fertilizers targeted for higher crop yields. Nitrate content in the ground water samples of the study area ranged between 0.3 to 557.8 mg L^{-1} with a mean value 92.3 mg L^{-1}. The range of values in the ground water of Kalakankar, Sangramgarh and Babaganj development blocks were between 0.3 to 233.2, 15.3 to 557.8 and 4.1 to 152 mg L^{-1} with mean values of 80.40, 125.6 and 71.03 mg L^{-1} respectively (Tables 3, 4 and 5). Water is considered to be unsafe for drinking if the nitrate content is more than 45 mg L^{-1} (WHO, 2004; BIS, 2004). As per the classification, only 21% of the water samples were within the permissible limits for drinking water. Among the three developmental blocks 75, 78 and 84% of the water samples collected from Kalakankar, Babaganj and Sangramgarh was unsafe for drinking (Table 6). Nitrate in drinking water is often associated with methemoglobinemia (Subba Rao *et al.,* 2012) and spontaneous abortions in women (Grant *et al.,* 1996).

Fluoride

The fluoride content of the ground water samples in the study area ranged between 0.4 to 21.1 mg L^{-1} with a mean value 8.61 mg L^{-1}. Sabal *et al.* (2008) reported lower fluoride content of ground water of Amber tehsil of Jaipur district of Rajasthan. The three developmental blocks also has similar fluoride content. Fluoride content in drinking water is physiologically beneficial, if it is in the safe limit, as it promotes dental health (Subba Rao, 2003). The desirable limit of fluoride in ground water is 0.6 to 1.2 mg L^{-1} (BIS, 2004). Fluoride content below 0.60 mg L^{-1} is known to cause dental decay, whereas a concentration more than 1.20 mg L^{-1} in drinking water result in dental fluorosis. As per the classification, only 4% of the water samples had a fluoride content below 0.6 mg L^{-1}, 7% of the water samples were between 0.6 to 1.2 mg L^{-1} and 89% of the water samples were above the permissible limit (1.2 mg L^{-1}) for drinking purposes (Table 6). Among the three development blocks, Sangramgarh block had 74% of water samples above the permissible limit and Kalakankar and Babaganj had 92% and 100% samples above the permissible limit for drinking (Table 6). According to the WHO (WHO, 2004) 84% of the water sample were unsafe for drinking purpose. Higher intake of F^- may change the metabolic activities of soft tissues (thyroid, reproductive organs, brain, liver, and kidney) (Raja Reddy, 1979). High fluoride content could be due to fractured hard rock zone with pegmatite veins composed of minerals like topaz, fluorite, fluor-apatite, villuamite, cryolite and fluoride replaceable hydroxyl ions in ferro-magnesium silicates. Apatite, biotite, clay and chemical fertilizers are also responsible for increased fluoride content in the groundwater (Subba Rao, 2009).

Water Quality Index

The water quality index was calculated and presented in Tables 3, 4 and 5 and summarised in Table 7. The water quality index of the Kalakankar block ranged between 45 and 525 with a mean value of 161. The corresponding water quality indices for Sangramgarh and Babagang blocks ranged between 57-944 (mean 216) and 63-694 (mean 232) respectively. Accordingly only 2.8, 10.5 and 16.7 % of the water samples in the Kalakankar, Sangramgarh and Babaganj blocks had good groundwater quality. Overall, only 10% of the ground water samples of the study area was categorised to be good and 58.9, 20.7 and 10.8 % of the samples were categorised as poor, very poor and completely unsuitable for drinking purposes.

Correlation studies

Correlation studies between water quality parameters have a great significance, for example, the relative high positive correlation between some chemical parameter of drinking water may indicate a common origin or progressive enrichment of both parameters. Among the parameters studies, pH was negatively correlated to Ca^{2+} (r= -0.32**) indicating that acidity increases with decrease in calcium content (Table 8). A significant positively correlation was observed between EC and Mg^{++} (r = 0.61**), Na^+ (r = 0.86**), K^+ (r = 0.33**), CO_3^{2-} (r = 0.39**), SO_4^{2-}(r = 0.37**) and Cl^- (r = 0.92**), suggesting that increasing salts as contributed by Mg^{2+}, SO_4^{2-}, Na^+, Cl^-, K^+ and CO_3^- ions, which may be caused by mineral dissolution, mineral solubility, ion exchange, evaporation, anthropogenic activities, and marine sources, are responsible for high EC. Mg^{2+} shows significant positively correlated with Na^+ (r= 0.34**) and it is believed that magnesium behaves like sodium ion in increasing alkalinity. Na^+ showed significant positive correlation with K^+ (r = 0.38**), CO_3^- (r = 0.54**), Cl^- (r = 0.68**) and SO_4^{2-} (r = 0.37**) suggesting the presence of sodium carbonate, halite and sodium sulphate minerals. However the fluoride and nitrate content did not bear any correlation between any of the parameters studied.

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