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Chemical Quality Evaluation of Groundwater for Human Domestic Consumption in Saharanpur and Adjoining Area, Uttar Pradesh, India.

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Abstract. Chemical analysis of water samples have played a remarkable role in delineation of groundwater quality for varied applications. In India, Saharanpur located in Uttar Pradesh, is one of important industrial cities, which is facing problem of good quality water supply during summer. The chemical quality evaluation of groundwater in Saharanpur city and adjoining area for human domestic consumption has been discussed in detail. The representative groundwater samples were collected from the shallow dug and bore wells existing in vicinity of Saharanpur. It has been observed that except for a few, all the samples are colourless, whereas all the samples are odourless and tasteless. The pH values reveal a range of 6.80 to 8.00 apart from those samples having pH less than 7.0 are acidic and unsuitable for drinking. Electric conductivity varies from 263 to 1259 micro mho/cm and most of samples are in range of 263 to 986 micro mho/cm, except Pilakhani samples having a value of 1259 micro mho/cm. Total Dissolved Solids are within standard limits indicating rather favourable groundwater quality. Based on the interpretation of chemical parameters and comparison of determined parameters with the standard prescribed limits recommended by Indian Council of Medical Research, Bureau of Indian Standards and (WHO) World Health Organization, groundwater suitability for the human domestic consumption has been evaluated. The chemical parameters suggest that groundwater is of Ca-Mg-CO_3-HCO_3 type and favourable for human domestic applications, except the concentration of Ca, Mg, and SO_4 at some localities (more than the standard recommended limits) requires proper treatment of purification before water supply.

Introduction

Groundwater is one of the dynamic, replenishable and most remarkable earth resources. The groundwater effectiveness is more than surface water due to its natural availability at the point of use (Dhawan, 1989). It plays a significant role in overall sustainable development of life throughout the world, and acts as a only possible substitute of surface water demand of populace. Chemical analysis of water samples plays an important role in evaluation of groundwater quality for domestic, food production, industry, energy and sport sectors.

Currently, the increasing emphasis is on degradation of groundwater quality due to geologic, anthropogenic and human activities. It has been recommended that groundwater of better-quality could be obtained by tube well installation on hill slopes rather than valley bottoms, although it is recognized that ground water yields may be compromised by this approach (Jacks *et al.*, 1993). The water for drinking purpose should be colourless, odourless, tasteless and free from turbidity (Karanth, 2003). The present status of groundwater quality for domestic applications based on chemical analytical data has been elaborated in Saharanpur city and adjoining area.

Study Area

The study is conducted in the vicinity of Saharanpur city and adjoining area, in western Uttar Pradesh, and is limited within latitude 29° 50′ to 30° 05′N and longitude 77° 30′ to 77° 40′E (Survey of India Toposheet nos. 53 G/9 and 53 F/12 ; Fig. 1). It is located on Meerut-Ambala railway track and easily accessible both by rail and road all through the year. The area is characterized by a rather flat topography. Paondhoi and Dhamola rivers provide main surface drainage. The climate is mainly tropical and favourable for luxuriant growth of vegetation and forest development. The temperature is recorded within range of 6.6°C to 45°C with an average of 23.3°C. Rainfall data reveal variation from 497.70 to 1566.10 mm with an annual average of 1058.82 mm (Singh and Dev, 2009). Humidity ranges from 29% to 85%, and wind plays an effective role in the climate.

Hydrogeology of the Area

Hydrogeological examination involves well monitoring in vicinity of Saharanpur study area and indicates that groundwater occurs under both the unconfined and confined conditions and is being extracted through manual and pumping operations. Groundwater conditions in

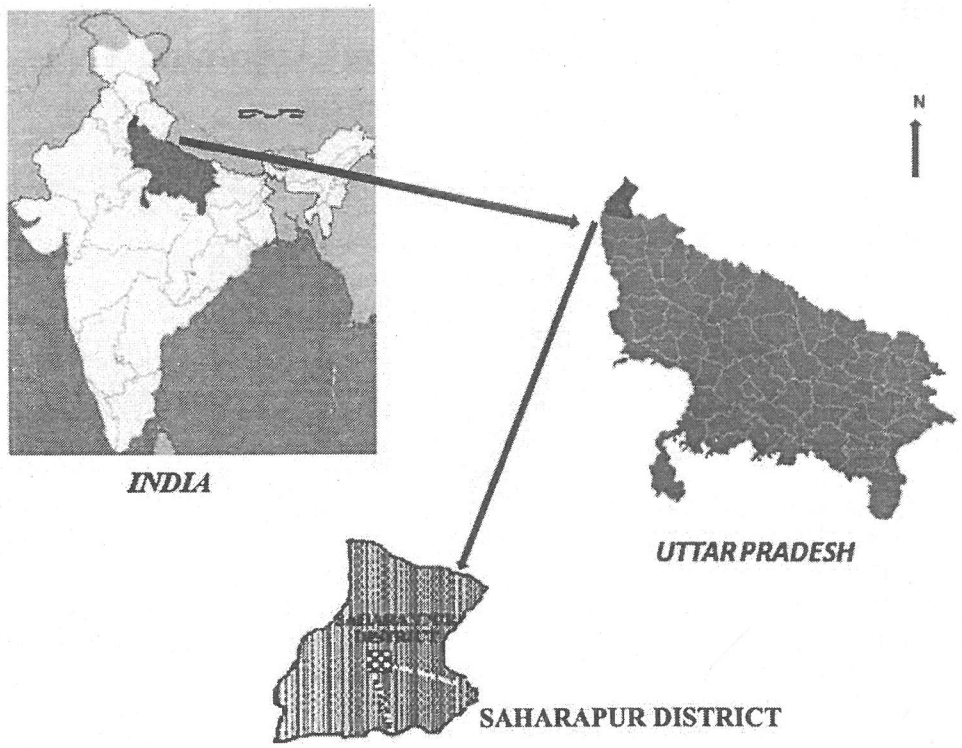


Fig 1. Location map of study area, Saharanpur City, Uttar Pradesh. India.

alluvial terrains are considerably influenced by varying lithology of subsurface formations The rainfall is main recharge source of groundwater body besides infiltration from rivers; canals and return flow from irrigation, and inflow from the neighbouring areas. The groundwater structures mainly shallow and deep tube wells and a few dug wells contribute to water supply.

Shallow wells are in abundance in the study area. The depth of the wells ranges from 29 to 37 mb.g.l. The diameter of shallow wells is 0.15 m. The depth of water levels ranges from 6.10 to 8.60 mb.g.l. (Table 1). The depth of wells varies from 47.71 to 178.00 mb.g.l. A limited number of dug wells are constructed up to the deep ground water zone. The depth of water levels ranges from 4.50 to 18.35 mb.g.l. Most of the wells are lined by bricks and cement. The mode of water lifting from wells is mainly by motors of different powers. (Table 2). The hydraulic gradient is about 0.5 to 1.3 m / km range in southern part of Saharanpur city with the direction from NE to SW and north to south. The existence of a three-tier aquifer system in Saharanpur area has been observed. The first aquifer (sand thickness is about 88 m with 64% of sand) system lies down to 147 mb.g.l.

Table 1. Showing measurements of water level in the shallow wells of study area.

S. no.	Location of wells	Diameter of well (m)	Depth of well (m)	Water level measurement			Discharge in LPM
				Post - monsoon (m.b.g.l.)	Pre - monsoon (m.b.g.l.)	Fluctuation (m)%	
1	Sarsawa	0.15	35	7.45	8.40	0.95 (3.51)	18
2	Sarsawa Govindpur	0.15	35	8.30	9.00	0.70 (2.59)	18
3	Malhipur	0.15	36	6.60	7.80	1.20 (4.44)	18
4	Mission Compound	0.15	35	8.60	9.90	1.30 (4.81)	18
5	Haquit Nagar	0.15	36	7.90	9.20	1.30 (4.81)	17
6	Pilkhani	0.15	33	6.80	8.80	2.0 (7.40)	18
7	Haquit Nagar	0.15	34	7.10	8.90	1.80 (6.66)	18
8	Nagal	0.15	37	8.50	10.50	2.0 (7.40)	18
9	Awas Vikas	0.15	30	8.20	9.80	1.60 (5.92)	18
10	Haquit Nagar	0.15	36	6.10	7.30	1.20 (4.44)	18
11	Paper Mill	0.15	36	6.30	7.90	1.60 (5.92)	18
12	Tapri	0.15	34	7.00	8.50	1.50 (5.55)	17

Table 2. Showing measurements of water level in the tube wells of study area.

S. no.	Location of wells	Depth (m)	Mode of lifting purpose	Lind/ Unlined	Static water level(m) post monsoon	Static Water level during summer(m) pre monsoon	Fluctuation (m) %
1	Sarsawa	110.00	A	L	11.00	12.20	1.20 (3.63)
2	Nagal	143.15	A	L	13.50	14.10	0.60 (1.81)
3	Tapri	110.00	A	L	6.00	7.90	1.90 (5.75)
4	Nawada(1)	145.20	A/D	L	6.00	7.10	1.10 (3.33)
5	Nawada(2)	93.60	A	L	6.00	7.85	1.85 (5.60)
6	Chunheti	119.60	D	L	7.20	7.70	0.50 (1.51)
7	Puwarka	147.91	A	L	13.50	14.10	0.60 (1.81)
8	Remond Depot	116.80	A	L	6.40	7.60	0.20 (0.60)
9	Paper Mill	110.40	D	L	4.00	5.56	1.56 (4.72)
10	Pinjora	89.90	A/D	L	3.15	4.90	1.75 (5.30)
11	Malhipur	91.67	A	L	7.90	8.65	0.75 (2.27)
12	Umahi	90.31	A/D	L	6.30	8.10	1.80 (5.45)

The second aquifer (granular material is found upto 64 m thickness with 54% sand) starts from 167 to about 267 mb.g.l. and third aquifer (sand range up to 63%) is at depth below 290 mb.g.l. The specific capacity of shallow aquifer system ranges from 338 to 2500 m^2/day. The field permeability ranges from 15.44 to 17.09 m /day and yield capacity is 1610 to 2210 l. p. m. In Saharanpur city, the water table has been reducing at a rate of 0.047 metre / year (Central Ground Water Board, 2000).

Previous Studies and Methodology

The survey of literature reveals that hydrogeochemical studies on groundwater of Saharanpur district have been conducted by several workers including (Seth, 1993; Rao *etal.*, 2004; Saini *etal.*, 2006; Singh, 2008) and others.

Groundwater samples have been collected from fifty wells existing in the Saharanpur study area (Fig. 2) for

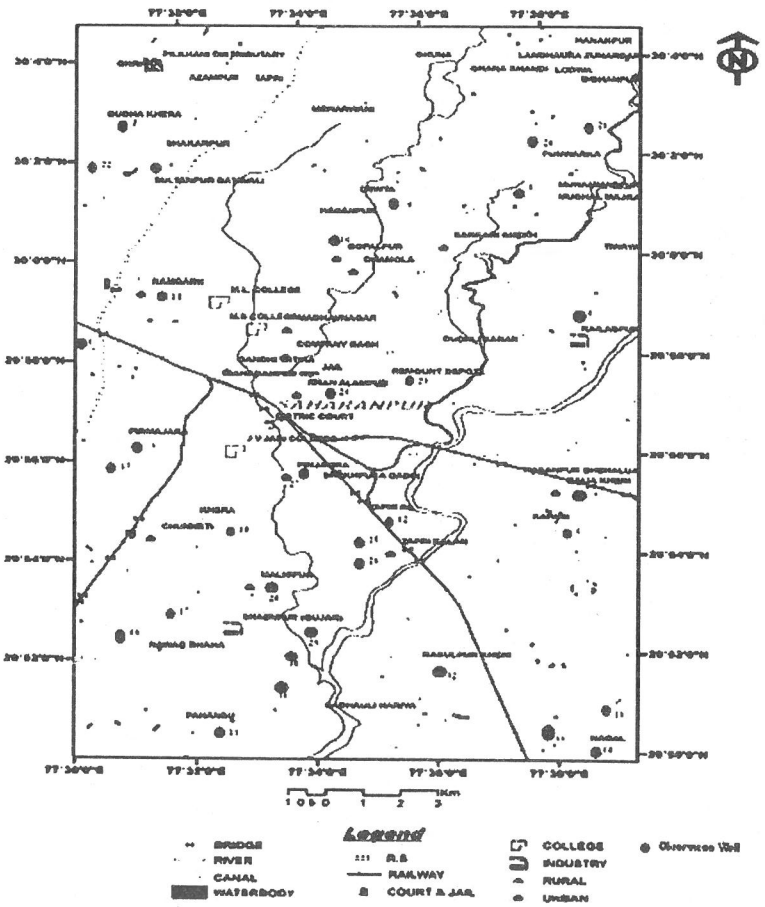


Fig 2. Location of well sample sites in Saharanpur study area, Uttar Pradesh. India.

delineation of groundwater quality. Chemical parameters of groundwater samples have been analyzed in tube well and hand pump well samples. The determinations of cations plus anions are recorded by following standard methods of data representation. These methods of chemical analysis have been proposed by several workers including Rainwater and Thatcher (1960), Brown *etal.*, (1970), Vogel (1975), and American Public Health Association (1998). The procedure suggested by Richards (1954) for verification of chemical analysis has been adopted for checking the determined values.

The determined physical and chemical parameters are displayed (Table 3 and 4). The ionic concentrations have

Table 3. Physical parameters of tube-well and shallow well water samples of Saharanpur study area, Uttar Pradesh. India.

S.No.	Name of a Place	Colour (hazen)	Odour	Taste	pH	Temperature (C)	Conductivity (µS per cm at 25°C)	T.D.S. (mg/l)
1	J.V.Jain College Road	10.00	O.L.	T.L.	7.40	21.00	513.00	506.00
2	Remound Depo	20.00	O.L.	T.L.	7.80	22.00	478.00	470.00
3	Fatehpur	60.00	O.L.	T.L.	7.70	21.00	300.00	284.00
4	Nagal(Dispensary)	150.00	O.L.	T.L.	7.80	22.00	337.00	329.00
5	Nawada Bhajru	20.00	O.L.	T.L.	7.10	22.00	360.00	332.00
6	Roshangarh	20.00	O.L.	T.L.	7.50	21.00	330.00	324.00
7	Nawada	20.00	O.L.	T.L.	7.30	20.00	290.00	283.00
8	Pinjora	10.00	O.L.	T.L.	7.10	23.00	505.00	486.00
9	Jamalpur	10.00	O.L.	T.L.	7.70	20.00	349.00	341.00
10	Rasulpur	10.00	O.L.	T.L.	7.00	21.00	324.00	320.00
11	Paper Mill	40.00	O.L.	T.L.	7.10	22.00	438.00	429.00
12	Neharu Market	60.00	O.L.	T.L.	7.60	22.00	318.00	309.00
13	Sahidganj	20.00	O.L.	T.L.	7.40	20.00	500.00	486.00
14	Haquit Nagar	200.00	O.L.	T.L.	7.10	23.00	977.00	969.00
15	Hasanpur Bhalsua	20.00	O.L.	T.L.	7.70	20.00	263.00	258.00
16	Pilakhani (1)	80.00	O.L.	T.L.	6.90	21.00	652.00	643.00
17	Pilakhani (2)	60.00	O.L.	T.L.	6.80	21.00	942.00	930.00
18	Sarsawa Govindpur	300.00	O.L.	T.L.	6.80	20.00	606.00	598.00
19	Sarsawa	20.00	O.L.	T.L.	7.30	22.00	571.00	564.00
20	Umahi	60.00	O.L.	T.L.	7.60	22.00	528.00	519.00
21	Missian Compound	10.00	O.L.	T.L.	7.63	23.00	507.00	498.00
22	Avas Vikas	20.00	O.L.	T.L.	7.64	21.00	626.00	619.00
23	Officer Colony	20.00	O.L.	T.L.	7.42	21.00	850.00	834.00
24	Vikas Bhawan	10.00	O.L.	T.L.	7.62	22.00	463.00	443.00
25	Malhipur	10.00	O.L.	T.L.	7.48	22.00	488.00	462.00
26	Nazar Pura	20.00	O.L.	T.L.	7.50	21.00	944.00	900.00
27	Avas Vikas	10.00	O.L.	T.L.	7.60	21.00	558.00	556.00
28	Haquit Nagar	10.00	O.L.	T.L.	7.40	21.00	716.00	699.00
29	Railway Colony	20.00	O.L.	T.L.	7.70	20.00	512.00	509.00
30	Labour Colony	10.00	O.L.	T.L.	7.00	21.00	986.00	984.00
31	Tapri R.S.	20.00	O.L.	T.L.	7.00	22.00	424.00	470.00
32	Tapri Khurd	20.00	O.L.	T.L.	7.50	21.00	635.00	626.00
33	Nawada	10.00	O.L.	T.L.	7.60	20.00	347.00	339.00
34	Chunheti	20.00	O.L.	T.L.	7.60	21.00	742.00	731.00
35	Landhaura (gujar)	10.00	O.L.	T.L.	7.00	22.00	532.00	521.00
36	Sarsawa	40.00	O.L.	T.L.	7.30	20.00	780.00	774.00
37	Sarsawa (A.F.S.)	10.00	O.L.	T.L.	7.30	21.00	650.00	649.00
38	Pilakhani	500.00	O.L.	T.L.	7.70	21.00	1259.00	1245.00
39	Sarsawa Govindpur	10.00	O.L.	T.L.	7.20	22.00	812.00	800.00
40	Pilkahani	40.00	O.L.	T.L.	7.20	21.00	324.00	315.00
41	Nagal Dispensary)	20.00	O.L.	T.L.	7.50	21.00	386.00	380.00
42	Bhat Kheri	40.00	O.L.	T.L.	7.40	21.00	408.00	395.00
43	Nagal	40.00	O.L.	T.L.	8.00	20.00	454.00	446.00
44	Shekhpura Qadim	20.00	O.L.	T.L.	7.20	21.00	635.00	542.00
45	Chak Haraiti	20.00	O.L.	T.L.	7.50	21.00	523.00	384.00
46	Paper Mill	10.00	O.L.	T.L.	7.74	20.00	450.00	439.00
47	Rasulpur	20.00	O.L.	T.L.	7.64	21.00	410.00	382.00
48	Malhipur	10.00	O.L.	T.L.	7.70	21.00	422.00	413.00
49	Manav Mandir	10.00	O.L.	T.L.	7.20	22.00	340.00	319.00
50	Avas Vikas	10.00	O.L.	T.L.	7.50	21.00	354.00	324.00

Abbreviations: O L = Odour less, T L = Tasteless, pH = Hydrogen ion Concentration, T.D.S. = Total Dissolved Solids

been plotted on the Trilinear diagram of Piper (1944 and 1953), and Back and Hanshaw (1965), Sadashivaiah *etal.*, (2008) diagram.

Physical Parameters

The determined values of different physical parameters

Table 4. Determination of percentage PPM / EPM of ground water samples of Saharanpur and adjoining areas, Uttar Pradesh, India.

S. No.	Location Name/ Owner Name	Ca ppm/*epm*	Mg ppm/*epm*	Na+ K ppm/*epm*	SO_4 ppm/*epm*	Cl ppm/*epm*	CO_3+HCO_3 ppm/*epm*
1	J.V.Jain College Road / Hera Lal	271	53.00	7.5	59	95.00	267
		13.52	*4.35*	*0.31*	*1.23*	*2.68*	*4.38*
2	Remound Depo	131	290	13.7	27	72.00	243
		6.53	*23.85*	*9.59*	*0.56*	*2.03*	*3.98*
3	Fatehpur / Makhi Ram	191	123	27	107	28.00	226
		9.53	*10.11*	*1.14*	*2.23*	*0.79*	*3.70*
4	Nagal (Dispensary)	162	172	43.9	66	31.00	230
		8.08	*14.14*	*1.89*	*1.37*	*0.87*	*3.77*
5	Nawada Bhajru	108	96.00	17.4	8	27.00	235
		5.38	*7.89*	*0.74*	*9.17*	*o.76*	*4.`5*
6	Roshangarh	112	52.89	20.7	56	44.00	200
		5.58	*4.27*	*0.87*	*1.17*	*1.24*	*3.28*
7	Nawada / Sunny Dhaiya	118	38	27.8	47	21.00	180
		5.88	*3.12*	*1.19*	*0.98*	*0.59*	*2.95*
8	Pinjora	292	104	9.3	23	148.00	269
		14.57	*8.55*	*0.4*	*0.48*	*4.18*	*4.41*
9	Jamalpur	232	50	18.8	2	18.00	218
		11.57	*3.11*	*0.79*	*0.04*	*0.51*	*3.57*
10	Rasulpur	220	52	8.6	55	17.00	197
		10.97	*4.27*	*0.53*	*1.15*	*0.48*	*3.23*
11	Paper Mill	258	102	7.3	63	75.00	240
		12.87	*8.39*	*0.28*	*1.31*	*2.12*	*3.93*
12	Nehru Market	162	80	28.2	5	30.00	230
		8.08	*6.58*	*1.2*	*0.10*	*0.85*	*3.77*
13	Sahidganj / Vikey Makhija	256	106	29.5	33	78.00	262
		12.77	*8.71*	*1.27*	*0.69*	*2.20*	*4.29*
14	Haquit Nagar / Sonu Gulati	520	70	19.6	9	134.00	310
		25.94	*5.75*	*0.79*	*0.19*	*3.78*	*5.08*
15	Hasanpur Bhalsua / Vivek Rana	104	42	14.2	16	52.00	149
		5.18	*3.45*	*9.56*	*9.33*	*1.47*	*2.44*
16	Pilakhani (1)	282	260	22.9	47	86.00	278
		14.07	*21.38*	*0.94*	*0.98*	*2.43*	*4.56*
17	Pilakhani (2)	510	266	33	67	208.00	324
		25.44	*21.88*	*1.36*	*1.39*	*5.87*	*5.31*
18	Sarsawa Govindpur / Shiv Sharma	312	186	26	78	50.00	260
		15.56	*15.31*	*1.12*	*1.62*	*1.41*	*4.21*
19	Sarsawa	298	164	19.5	95	38.00	270
		14.87	*13.49*	*o.82*	*1.98*	*1.07*	*4.43*
20	Umahi / Ramu Chaduhari	282	148	6.6	60	38.00	285
		14.07	*12.17*	*0.28*	*1.25*	*1.07*	*4.67*
21	Missian Compound / Mangeram Kalra	163	17	6.5	2	14.00	268
		8.13	*1.40*	*0.21*	*0.01*	*0.30*	*4.30*
22	Avas Vikas / Sunil Pundir	165	35	28.9	18	53.00	250
		8.23	*2.88*	*1.1*	*0.37*	*1.50*	*4.10*
23	Officer Colony / Rakesh Pathak	226	49	73.3	65	87.00	268
		11.28	*4.03*	*2.99*	*1.35*	*2.45*	*4.39*
24	Vikas Bhawan	196	19	12	5	21.00	226
		9.78	*1.56*	*0.43*	*0.10*	*0.59*	*3.70*
25	Malhipur	180	30	22.6	33	35.00	183
		8.98	*2.47*	*0.87*	*0.69*	*0.99*	*3.00*
26	Nazar Pura / Mohamad Kasil	130	171.00	23.50	NIL	35.00	340
		9.48	*14.06*	*0.98*	*NIL*	*0.99*	*5.57*
27	Avas Vikas	150	132.00	32.90	NIL	36.00	289
		7.48	*10.85*	*1.38*	*NIL*	*0.85*	*4.74*
28	Haquit Nagar / Deep Seth	120	233.00	24.30	NIL	40.00	300
		5.98	19.16	1.03	NIL	1.13	4.92
29	Railway Colony / Hunny Ahuja	137	96.00	26.00	NIL	33.00	264
		6.83	*7.89*	*0.99*	*NIL*	*0.93*	*4.33*
30	Labour Colony / Krishna Verma	250	211.00	22.50	NIL	46.00	321
		12.47	*17.35*	*0.95*	*NIL*	*1.30*	*5.26*

31	Tapri R.S.	128	83.00	28.70	NIL	33.00	254
		6.38	*6.82*	*1.22*	*NIL*	*0.93*	*4.16*
32	Tapri Khurd	142	50.00	44.20	NIL	39.00	273
		7.08	*4.11*	*1.87*	*NIL*	*1.10*	*4.47*
33	Nawada / Kuldeep Chaduhari	218	60.00	19.00	NIL	68.00	236
		10.87	*4.93*	*0.79*	*NIL*	*1.92*	*3.87*
34	Chunheti	83	152.00	15.90	NIL	41.00	329
		4.14	*12.50*	*0.68*	*NIL*	*1.16*	*5.39*
35	Landhaura(gujar)	98	92.00	24.90	NIL	27.00	288
		4.89	*7.56*	*1.03*	*NIL*	*0.76*	*4.72*
36	Sarsawa / Chotu Singh	218	128.00	40.40	NIL	42.00	338
		10.87	*10.52*	*1.71*	*NIL*	*1.18*	*5.54*
37	Sarsawa	140	140.00	47.10	NIL	48.00	291
		6.99	*11.51*	*1.92*	*NIL*	*1.35*	*4.77*
38	Pilakhani / Sachi Kumar	682	72.00	34.00	NIL	305.00	390
		34.03	*5.92*	*1.39*	*NIL*	*8.60*	*6.39*
39	Sarsawa	340	96.00	28.60	NIL	65.00	342
		16.96	*7.89*	*1.16*	*NIL*	*1.83*	*5.61*
40	Pilakhni	166	54.00	30.20	NIL	36.00	190
		8.28	*4.44*	*1.11*	*NIL*	*1.02*	*3.11*
41	Nagal (Dispensary)	180	4.00	25.70	NIL	42.00	297
		8.98	*0.32*	*1.02*	*NIL*	*1.18*	*4.87*
42	Bhat Kheri	79	69.00	25.20	NIL	44.00	247
		3.94	*5.67*	*0.97*	*NIL*	*1.24*	*4.05*
43	Nagal	108	72.00	22.70	NIL	46.00	261
		5.38	*5.92*	*0.92*	*NIL*	*1.30*	*4.29*
44	Shekhpura Qadim	*130*	*80.00*	*17.10*	*NIL*	*28.00*	*270*
		8.48	*6.58*	*0.69*	*NIL*	*0.79*	*4.43*
45	Chak Haraiti / Jiten Rana	124	72.00	32.40	NIL	39.00	252
		6.18	*5.92*	*1.37*	*NIL*	*1.10*	*4.13*
46	Paper Mill	199	26.00	33.40	NIL	10.00	220
		9.93	*2.14*	*1.37*	*NIL*	*0.28*	*3.61*
47	Rasulpur / Pankaj Gupta	142	23.00	51.20	NIL	14.00	220
		7.09	*1.89*	*2.12*	*NIL*	*0.39*	*3.61*
48	Malhipur	156	64	21.50	NIL	42.00	234
		7.78	*5.26*	*0.79*	*NIL*	*1.18*	*3.84*
49	Manav Mandir / Manish Kumar	137	97.00	17.40	NIL	28.00	390
		6.84	*7.98*	*0.71*	*NIL*	*0.79*	*6.39*
50	Avas Vikas	204	56.00	34.70	NIL	52.00	270
		10.18	*4.61*	*1.39*	*NIL*	*1.47*	*4.43*

in respect of groundwater samples of Saharanpur study area have been displayed in Table 3.

Colour, Odour and Taste

All the analyzed samples except a few ones are colourless, whereas all the samples are odourless and tasteless. The temperature ranges from 21°C - 23°C Table 3.

Hydrogen Ion Concentration (pH)

The pH values of groundwater in Saharanpur area, reveal variation within range from 6.80 to 8.00 except those samples having pH value less than 7.0, are acidic and recoded from Pilakhani (1), Pilakhani (2), and Sarsawa Govindpur. These samples are unsuitable for drinking purpose and need proper treatment.

Electric Conductivity

Electric conductivity in study area varies from 263 to 1259 micro mho/cm. Most of samples are in range of 263 to 986 micro mho/cm, except samples from Pilakhani that show m value of 1259 micro mho/cm.

Total Dissolved Solids

Total dissolved solids in Saharanpur groundwater reveal a fairly long range of variation from 284 - 1245 ppm and are within recommended standard limits indicating the favorable quality.

Chemical Parameters

The computed ionic concentrations of groundwater samples of the study area are recorded (Table 4) and graphically represented (Fig. 3).

Trilinear Diagram

The Trilinear diagram is a graphic representation of the nature of given water sample and exhibits the relationship to other samples. Piper (1944) applied Trilinear diagram to represent cation and anion concentrations of water analyzed data. He also combined both Trilinear diagrams into a single summary diagram with the shape of a diamond. This diamond has four sides, two for cations and two for anions. However, it also has only two independent axes, one for cation (Ca + Mg), and one for anion ($Cl^- + SO^-_4$). If the (Ca + Mg) percentage is known,

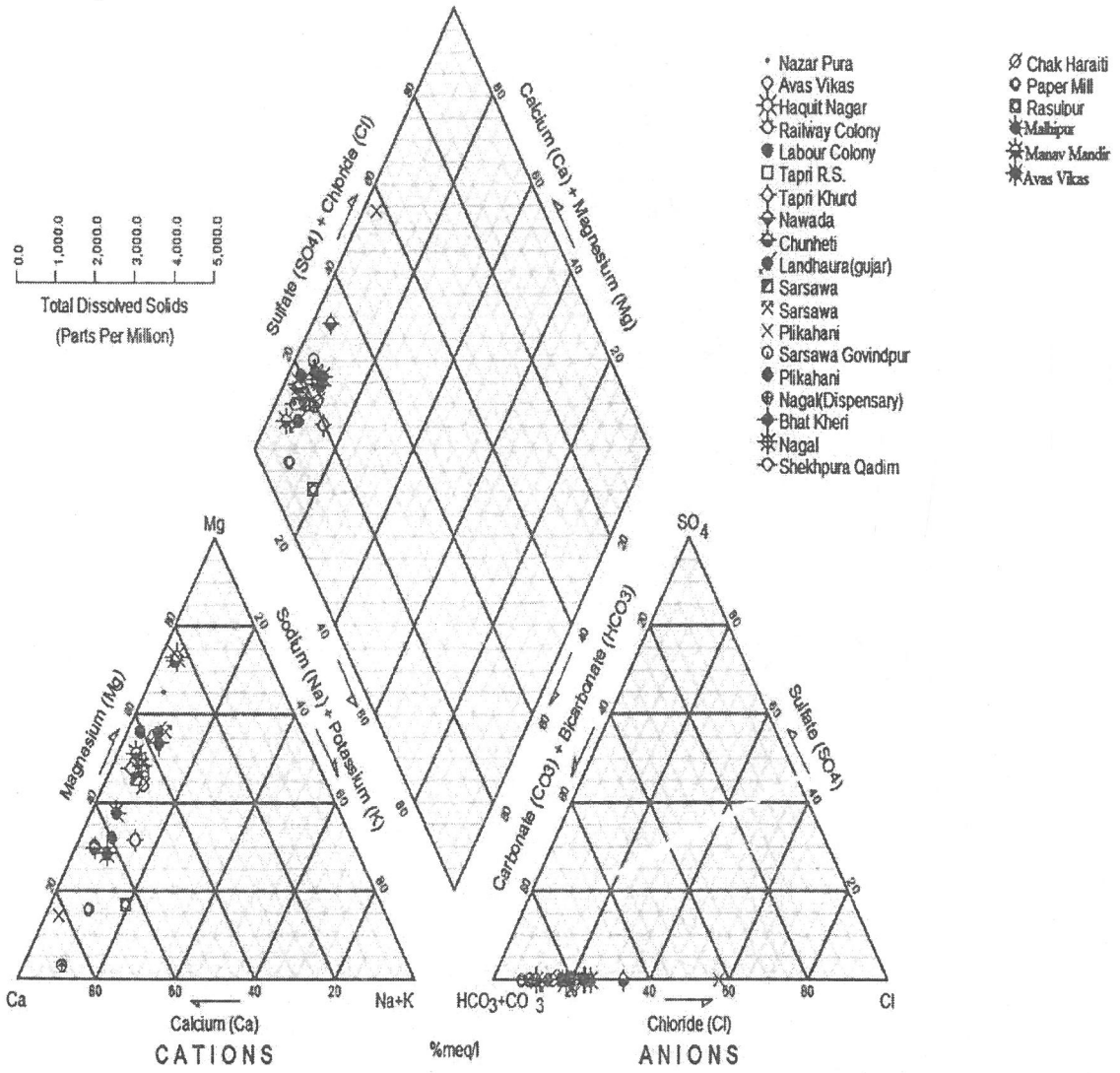


Fig 3. Ground water well samples of study area plotted on Piper's Trilinear diagram.

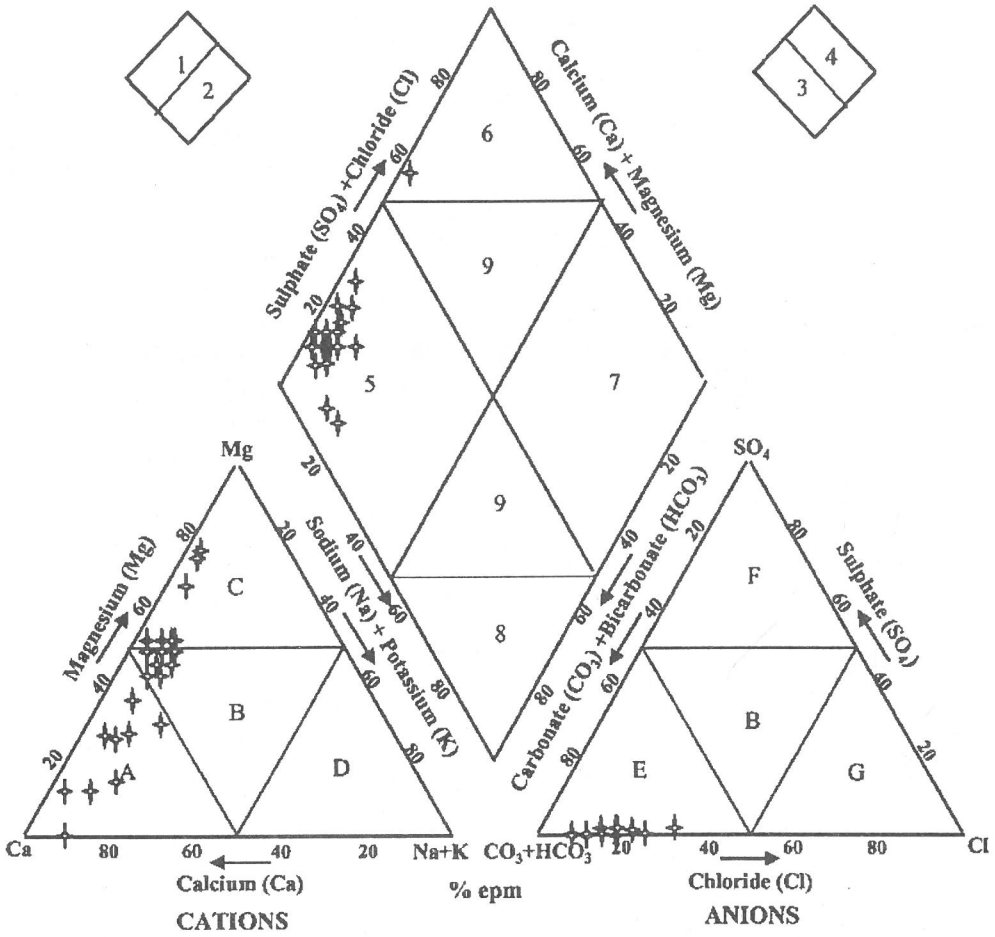
so is the (Na + K) percentage, as one is 100% minus the other, and similarly for the anions. The collection of these three diagrams in the format is called a Piper's diagram. The Piper's diagram provides a visual representation of the concentrations of major ions in water (Hem, 1970).

Hydrochemical Facies Analysis (HFA) technique was developed in the 1960's as a tool for categorizing waters based on their major ion composition (Freeze and Cherry, 1979). One form of HFA is the Piper's diagram, in which major cations and major anions are plotted on ternary diagrams in order to illustrate which cations and anions dominate. When plotted in this fashion, the data can be used to illustrate evolution of water quality as it migrates through the ground (typically from bicarbonate-rich water to chloride-rich water) or as it mixes with water of a different composition. Five distinct chemical facies of waters have been recognized on the Trilinear diagrams (Back and Hanshaw, 1965). In recent years, HFA concept has been expanded to include minor constituents of groundwater, such as petroleum hydrocarbons (Cho *etal.*, 2003). In order to know seasonal variations of chemical parameters in groundwater, the water is classified as monsoon, winter and summer water type.

Groundwater chemistry is examined by plotting the cations and anions on Piper's Trilinear diagram (Piper, 1953; Handa, 1965; Davis and De Weist 1966; Barde and Asodekar, 2002). The Trilinear plots have been used to characterize the transport of benzene, toluene, and xylene plumes (Lipson and Siegel, 2000). Nine different areas of ground water types can be distinguished by the position of their plotting in certain sub-areas of diamond-shaped field (Karanth, 2003).

The chemical data of water samples of Saharanpur study area (Table 4) are represented on a Trilinear diagram (Fig. 3). The Trilinear diagram provides a grouping of the different water. The plots of chemical analysis data of tube wells of study area (Fig. 3) reveal that in cation triangle 16 samples fall in A - calcium type, 3 samples belong to B - no dominant type and rest 6 samples fall in C - magnesium type. In anion triangle, all samples are in E bicarbonate type. In central diamond, all samples are categorized to area 5 - carbonate hardness exceeds 50%, i.e. chemical properties of the water are dominated by alkaline earths and week acids

Back and Hanshaw (1965), Sadashivaiah *et al.*, (2008)



Legend A – Calcium type, B - No Dominant type, C - Magnesium type, D – Sodium and potassium type, E – Bicarbonate type, F – Sulphate type, G – Chloride type

Fig 4. Classification diagram for anion and cation facies in the form of major ion percentages (Back and Hanshaw, 1965; Sadashivaiah *et al.*, 2008).

proposed subclasses of the Trilinear diagram to represent distinct composition class of hydrogeochemical facies (Fig. 4). This diagram distinctly exhibits predominance of cation and anion concentrations in groundwater of Saharanpur area, which is Ca – Mg – CO_3 H – CO_3 type hydrochemical facies. The majority of groundwater samples in diamond shaped figure fall in area 5- carbonate hardness exceeds 50%, i.e. chemical properties of the water are dominated by alkaline earths and week acids.

Groundwater Quality for Domestic Application

To evaluate the suitability of groundwater for domestic purpose, the hydrochemical parameters of groundwater samples of Saharanpur area have been compared with the approved specification of Indian Council of Medical Research I.C.M.R., (1975), Bureau Indian Standard (1983), and World Health Organization (1993) for water quality. The limits of total dissolved solids and chloride content are relaxable if sources of better quality of water are not available (Karanth, 2003).

The computed values of physico-chemical parameters of Saharanpur groundwater have been compared with the prescribed standards (Table 5). The physical parameters indicate that colour of sample no 4 - Nagal (150.00), 14 - Haquit Nagar (200.00), 18 - Sarsawa Govindpur (300.00) and 38 - Pilakhani (500.00) is not fair as other samples. The comparison of chemical parameters with recommended limits reveals that except Ca in sample Nos, 1, 8 - 11, 13, 14, 16 - 20, 23, 30, 33, 36, 38, 39, 59; Mg in sample Nos. 2, 16; and SO_4 in sample No. 17, all other samples are under the prescribed desirable limits of ionic concentration and indicate suitable quality.

Conclusion

The delineation of chemical quality of groundwater resource of Saharanpur city and adjoining area for the human domestic consumption has been elaborated in extensive detail. The interpretation of chemical parameters and comparison of determined parameters of Saharanpur groundwater with the standard prescribed limits recommended by Indian Council of Medical Research (1975), Bureau of Indian Standards (1983) and World Health Organization (1993), reflect suitability of groundwater for the of domestic and drinking purpose, with the exception of the colour, and pH values less than

Table 5. Comparison of physico-chemical parameters of ground water samples, Saharanpur city and adjoining areas, western Uttar Pradesh, India.

Quality/ constituents	ICMR 1975	Indian standards (B.I.S.., 1983)		Well waters of study area		
	Permissible limit	Highest desirable	Maximum permissible	Maximum permissible	Concentration range (mg/l)	Exceeding limit sample no.
Physical						
Colour	-	-	-	-	10-500	4,14,18,38
Taste	-	-	UO	-	TL	-
Odour	-	-	UO	-	OL	-
TDS	500-1500	500	800	1500	258-1245	-
PH	-	6.5-8.5	6.5-9.2	6.5-9.2	6.80-8.0	1,5,7,8,10,11,14.15-19,25,28,30,31,33,36, 39,40,42,44,49.
Chemical						
Ca (mg/l)	-	75	200	200	79 - 682	38,39,50.
Mg (mg/l)	50-100	30	100	150	17- 290	2,16
SO_4 (mg/l)	200-400	150	1000	400	0 - 107	-
Cl (mg/l)	200-1000	250	-	600	10- 208	17

7.5 indicating acidic nature at a few locations. The comparison of chemical parameters with recommended limits reveals that except sample no, 1, 8 -11, 13, 14, 16-20, 23, 30, 33, 36, 38, 39, 59 for C; sample no.2, 16 for Mg; and sample no. 17 for SO_4, all other samples are within permissible limits. In general, the groundwater is of Ca-Mg-CO_3-HCO_3 type and favourable for human domestic and drinking applications after reducing excess concentration of Ca, Mg, SO_4, and HCO_3. The presence of higher carbonate concentration may cause health hazard resulting in a major problem for inhabitants.

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