Proc Indian Natn Sci Acad **80** No. 1 March 2014 pp. 123-142

10.16943/ptinsa/2014/v80i1/55091

Research Paper

Groundwater Quality in Parts of Central Ganga Basin, Aligarh City, Uttar Pradesh, India

S M WASIM*, S KHURSHID, Z A SHAH and D RAGHUVANSHI
Department of Geology, Aligarh Muslim University, Aligarh 202002 (U.P.), India

(Received 17 July 2012; Revised 30 October 2012; Accepted 29 August 2013)

Hydrochemistry of groundwater in Aligarh city of Uttar Pradesh, India was used to determine its suitability for drinking and irrigation purpose. Physical and chemical parameters of groundwater such as electrical conductivity, pH, total dissolved solids (TDS), Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, CO_3^{2-} and SO_4^{2-}, were determined in one hundred groundwater samples collected from open wells as well as hand pumps in 2010. Ionic concentrations of the groundwater vary spatially and temporarily and the water is alkaline in nature. The higher values of some parameters at certain locations indicate contamination of the groundwater, making it unsuitable for specific applications. Twenty five percent of the wells lie under the medium salinity zone (EC 750-2250 micro mhos/cm). The Sodium Absorption Ratio (SAR) values range between 0.26 to 15.5 indicating that some water samples fall under the category of medium salinity hazard and are not suitable for irrigation. The groundwater of the area has also been classified on the basis of the Piper diagram. Many of the samples fall in the magnesium and sodium or potassium type, and 50% samples fall in no dominant type. As per US Salinity Laboratory Classification for irrigation water, most of the water samples fall under C_2-S_1 class (medium salinity and low SAR), eighteen locations fall under the category C_3-S_2 class (medium salinity and low SAR) and one location Luxmi Nagar shows C_3-S_3 (high salinity and high SAR). The major reason for the decline in water quality is the dumping of large amount of acid wastes by illegal lock factories, and another important source of pollution is slaughterhouse where at least 2500 buffaloes are slaughtered daily.

Key Words: Groundwater; Chemical Characters; Anthropogenic Activities; Groundwater Contamination; Aligarh

1. Introduction

Water quality plays an important role in promoting agricultural production and standard of human health. Innumerable large towns and many new megacities in India derive a major component of their domestic, irrigation and industrial water supply from groundwater, both from municipal well fields and from large numbers of private boreholes. The excessive withdrawal of groundwater has affected its quantity and quality. The groundwater quality also yields information about the environment through which the water has circulated. Each groundwater system has a unique chemistry, acquired as a result of chemical alteration of meteoric water recharging the system (Drever, 1982). The chemical alteration of the rain water depends on several factors such as soil-water interaction, dissolution of mineral species and anthropogenic activities (Umar and Ahmed, 2007). The study of relatively large number of groundwater samples from a given area offers clues to various chemical alterations which the meteoric groundwater undergoes, before acquiring distinct chemical characteristics. Most of the inland areas of the Indian sub-continent have Ca-Mg-HCO_3 type of groundwater (Datta and Tyagi, 1996). The cationic concentration is related to both soil-water interaction and anthropogenic factors. Such direct relationship between lithology and the relative abundances of cations is easily discernible in hard rock areas (Faure,

**Author for Correspondence: E-mail: w4wasimalig@gmail.com*

1998). The development of groundwater resources has increased manifold in the highly productive Gangetic plains, which host thick Quaternary deposits possessing multi-tier aquifer system. In complex multi-layered alluvial formations, the shallowest phreatic aquifer is often most vulnerable to anthropogenic pollution and most susceptible to saline water intrusion. However in a groundwater system in an alluvium-covered area, clues may not be simple due to masking of chemical alteration trends by anthropogenic influences (Umar and Absar, 2003).

Knowledge on hydrochemistry is important to assess the quality of groundwater for understanding its suitability for domestic, irrigation and industrial needs. Various researchers carried out studies on the hydrochemical characteristics of groundwater and quality of groundwater in different basins as well as in urban areas (Raju *et al*. 2007). Further, recent advances in analytical methods have led to the determination of toxic trace elements which can have an impact on human health.

The objective of the present work is to discuss the major ion chemistry of groundwater of Aligarh district. In this case, the methods proposed by Piper, Back, Wilcox, Todd as well as USSL classifications have been used in this study.

2. Study Area

The study area in Aligarh district is located between latitudes 27° 53' 0" to 27° 88' 0" N longitude 78° 5' 0" to 78° 08' 0" E (Fig. 1). It has an average elevation of 178 meters above mean sea level. The city is situated in the interfluves of the Ganges and the Yamuna rivers. The area falls in the sub-tropical climate zone. May and June are the hottest months of the year. The average temperature range is 28°-30°C. The monsoon starts in late June, continues till early October with high humidity levels, with annual rainfall of 800 mm and the average evapotranspiration of 1900 mm (Umar and Ahmad 2000). The study area covers 5498 sq. kms with a population of 6,67,732 (Census 2001). The major sources of employment are agriculture, industries and animal husbandry. Aligarh city is famous as an industrial city. The major industries are lock making and brass, apart from chemical, hardware goods, automobile parts, bulk production of zinc, die cast parts etc. which engage 80 % of the workers.

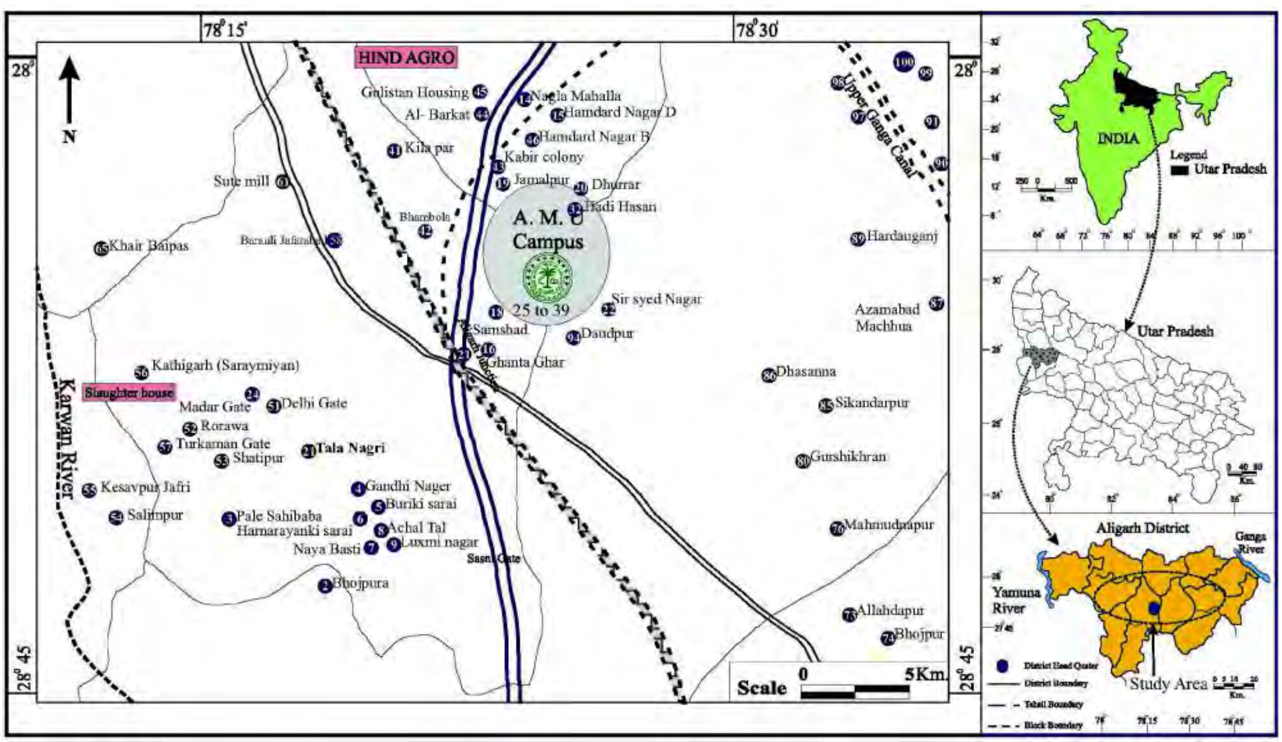

Fig. 1: Location map of the Aligarh City

3. Geology

The subsurface geology comprises Bundelkhand granite (3000 Ma) as the basement complex, which is unconformably overlain by the rocks of the upper Vindhyans (upper Proterozoic) and is finally overlain by the Quaternary alluvium. The Quaternary alluvium consists of alternate beds of sand and clay down to 620 m bgl that contains several aquifer systems in the central Ganga Basin. Various grades of sand form the granular zones with size fractions ranging from fine through medium to coarse micaceous sands (Umar and Ahmad 2000).

4. Hydrogeology

Hydrogeological investigation has been carried out to understand the nature of aquifers and their mode of occurrence. The availability of groundwater in alluvial zones is controlled by the presence of sand and clay zones. The hydrogeological cross-sections show that there occurs a single-tier aquifer system down to 124 mbgl, however in places it is interlayered with the two clay beds showing a three-tier aquifer system. By and large these aquifers appear to merge with each other and behave as a single-bodied aquifer system. The depth to water level in the area varies between 2-16 mbgl. However, the shallow water level is recorded close to the lower Ganga canal. The regional groundwater flow is in a NW-SE direction (Umar 1990). Groundwater is extracted from both dug wells and deep bore wells. The diameter of the dug wells ranges from 2 to 7 m, while depth varies from 7 to 32 m. The source of recharge to groundwater is rainfall. Because of fast urbanization and intensive pumping, the water level shows lowering trends in some parts of the study area.

5. Methodology

A total of one hundred groundwater samples from dug wells and hand pumps of the study area were collected during April and May 2010 and analyzed to understand the chemical variations of the groundwater. Pre-cleaned (acid washed) polyethylene containers of one liter capacity were used for sampling. The sampling locations are shown in Fig. 1. The physico-chemical characteristics of groundwater samples were determined using the standard analytical methods as suggested by the American Public Health Association (APHA, 1989, 1995), and the concentrations of major ions are given in Table 1. The pH and electrical conductivity were measured with portable ion meters. Total hardness and calcium were estimated by EDTA titrimetric method, and magnesium estimated by the difference of the hardness and calcium. Total alkalinity, carbonate and bicarbonate, and chloride were estimated by titrimetric method. Sodium and potassium have been estimated by flame photometry. The sulphate estimations were done gravimetrically. Total dissolved solids were estimated by summing up all cations and anions. The accuracy of the chemical analysis was verified by calculating ion-balance errors where the errors were generally around 10%.

6. Results and Discussion

In water resources management, water quality is as significant as the quantity of water. Ranges of chemical parameters in groundwater of Aligarh and their comparison with WHO 1993 and ISI 1991 standards are presented in Table 2.

6.1 Classification of Groundwater

As water flows through an aquifer, it assumes a characteristic chemical composition as a result of interaction with the lithologic framework. The term hydrochemical facies is used to distinguish groundwater in an aquifer on the basis of their differing chemical composition. The facies are functions of the lithology, solution kinetics and flow patterns of the aquifer. Hydrochemical facies were classified on the basis of dominant ions using the Piper's trilinear diagrams (Piper, 1953) and the plots to determine the water type of Aligarh district are presented in Table 6.

The classification for cation and anion facies in terms of major ion percentages and water types is done according to the domain in which they occur on the diagram segment (Back, 1966). From the cationic and anionic triangular field of the Piper diagram, it is observed that 12% of groundwater

Table 1: Geochemical analysis of groundwater samples of the study area

S.No.	LOCATION	pH	Ec	TDS	TH	Na+	K+	Ca+	Mg+	Cl-	SO4	HCO-3	CO-3
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Upper Fort	8.33	300	400	284	206 (8.96)	16.66 (0.43)	54.5 (2.72)	36.05 (2.97)	59.54 (1.68)	164.6 (3.4)	120 (1.96)	200 (6.66)
2	Bhojpura	7.97	1000	1600	392	672.8 (29.27)	60 (1.53)	147.49 (7.36)	5.84 (0.48)	400.44 (11.28)	246.9 (5.14)	350 (5.73)	100 (3.33)
3	Pale Sahibaba	7.83	900	1500	380	640.8 (27.87)	62 (1.59)	140.37 (7.00)	6.2 (0.51)	385.2 (10.86)	200.8 (4.18)	282 (4.62)	160 (5.33)
4	Gandui Nager	8.21	980	1200	120	605.71 (26.35)	82 (2.1)	137.2 (6.85)	5.1 (0.42)	402.4 (11.34)	210.7 (4.38)	290 (4.75)	182 (6.06)
5	Buriki Sarai	8.05	920	1400	400	402.81 (17.52)	71 (1.82)	120.7 (6.02)	5.8 (0.48)	285.4 (8.04)	185.8 (3.86)	180 (2.95)	102 (3.39)
6	Harnarayanki Sarai	7.97	940	1524	337	504.89 (21.96)	54 (1.38)	140.1 (6.99)	7.04 (0.58)	300.5 (8.49)	205.1 (4.27)	195 (3.19)	120 (3.99)
7	Naya Basti	8.3	900	1000	320	287.14 (12.49)	21.66 (0.55)	43.28 (2.16)	51.64 (4.24)	113.6 (3.21)	164.6 (3.42)	440 (7.12)	180 (5.99)
8	Achal Tal	8.48	1300	1800	576	720.47 (31.34)	103.33 (2.63)	137.87 (6.88)	56.52 (4.65)	420.31 (11.85)	429.2 (8.93)	400 (6.55)	460 (15.33)
9	Luxmi Nager	7.98	1200	1600	444	682.38 (29.68)	34.16 (0.87)	8.01 (0.39)	79.44 (6.53)	394.76 (11.14)	411.5 (8.56)	180 (2.95)	200 (6.66)
10	Sasni Gate	7.81	1000	1400	500	549.04 (23.88)	56.66 (1.45)	32.06 (1.59)	102.33 (8.39)	315.24 (8.88)	493.8 (10.28)	150 (2.45)	180 (5.99)
11	Mukandipur	7.75	982	1320	482	520.08 (22.62)	58.71 (1.5)	28.07 (1.4)	98.2 (8.08)	280.2 (7.89)	450.1 (9.37)	1480 (24.25)	182 (6.06)
12	Parhawali	7.4	960	1280	382	480.98 (20.92)	52.81 (1.35)	27.08 (1.35)	48.8 (4.01)	200.1 (5.64)	380.2 (7.91)	108 (1.77)	172 (5.73)
13	Kuwarsi	8.23	300	400	296	263.33 (11.45)	11.66 (0.3)	20.84 (1.04)	59.44 (4.89)	48.53 (1.37)	329.2 (6.85)	0	320 (10.66)
14	Nagla Muhalla	8.04	290	410	300	243.77 (10.61)	9.88 (0.25)	26.89 (1.34)	60.7 (4.99)	40.1 (1.13)	300.1 (6.24)	80 (1.31)	310 (10.33)
15	Hamdard Nager D	8.3	300	400	328	182.39 (7.93)	11.66 (0.3)	20.84 (1.04)	47.24 (3.88)	28.4 (0.80)	82.3 (1.17)	0	420 (13.99)
16	Ghanta Ghar	8.34	200	-400	224	134.76 (5.86)	11.66 (0.3)	25.65 (1.27)	38.98 (3.21)	8.52 (0.24)	229.2 (4.77)	50 (0.81)	100 (3.33)
17	Railway Station	8.61	500	600	396	382.38 (16.63)	15 (0.38)	14.42 (0.72)	87.71 (7.21)	96.56 (2.72)	82.3 (1.71)	60 (0.98)	400 (13.32)
18	Samshad market	8.7	700	400	380	625.23 (27.2)	25.83 (0.66)	41.68 (2.08)	67.24 (5.53)	142 (4.00)	493.8 (10.28)	360 (5.90)	200 (6.66)
19	Jamalpur	8.55	500	600	560	387.14 (16.84)	18.23 (0.47)	11.22 (0.56)	129.62 (10.69)	139.16 (3.92)	329.2 (6.85)	400 (6.55)	120 (3.99)
20	Dhurra	8.32	510	570	520	482.98 (21.01)	19.81 (0.51)	18.27 (0.91)	137.2 (11.27)	159.04 (4.48)	476.1 (9.91)	480 (7.86)	190 (6.33)

The values with brackets are in 'epm', without brackets 'ppm'.

Table 1 contd ....

1	2	3	4	5	6	7	8	9	10	11	12	13	14
21	Talanagri	8.19	700	1200	756	349.04 (15.18)	20.83 (0.53)	11.22 (0.55)	177.37 (14.56)	1283.4 (36.19)	546.9 (11.38)	440 (7.21)	100 (3.33)
22	Sir Syed Nager	8.4	300	400	200	253.8 (11.04)	11.66 (0.3)	17.63 (0.87)	42.88 (3.53)	28.4 (0.80)	329.2 (6.85)	80 (1.31)	220 (7.33)
23	Vikash Nager	8.03	400	200	464	234.76 (10.21)	12.49 (0.32)	38.47 (1.92)	79.66 (6.55)	45.44 (1.28)	2496.9 (51.98)	120 (1.96)	280 (9.33)
24	Madar Gate	6.9	1100	704	516	154 (6.69)	14.25 (0.37)	31.2 (1.55)	22.36 (1.84)	278 (7.84)	359.34 (7.48)	460 (7.53)	0
25	V.M. Hall	7.45	200	800	528	19.23 (0.83)	0 (00)	27.25 (1.35)	112.07 (9.21)	56.8 (1.60)	82.3 (1.71)	100 (1.63)	180 (5.99)
26	S.S. Hall	8.11	300	1000	332	20.3 (0.88)	14.54 (0.37)	35.27 (1.75)	59.44 (4.88)	51.12 (1.44)	411.5 (8.56)	160 (2.62)	140 (4.66)
27	S.S. North Hall	8.13	229	980	338	14.81 (0.64)	21.97 (0.56)	35.08 (1.75)	61.81 (5.08)	51.02 (1.44)	409.8 (8.53)	162 (2.65)	143 (4.76)
28	Aftab Hall	7.57	300	200	347	73.07 (3.18)	29.09 (0.74)	17.63 (0.88)	74.06 (6.09)	48.08 (1.35)	411.5 (8.57)	168 (2.75)	149 (4.96)
29	R.M. Hall	7.47	400	1000	448	71.55 (3.11)	18.18 (0.47)	22.44 (1.11)	95.5 (7.85)	88.08 (2.48)	329.2 (6.85)	260 (4.26)	180 (5.99)
30	M.M. Hall	7.47	400	1200	268	143.3 (6.23)	20.9 (0.53)	27.25 (1.35)	35.08 (2.89)	34.08 (0.96)	576.8 (12)	100 (1.63)	200 (6.66)
31	Habib Hall	7.65	300	1134	328	34.6 (1.56)	12.72 (0.32)	22.44 (1.12)	66.27 (5.45)	253.56 (7.16)	493.8 (10.28)	110 (1.80)	200 (6.66)
32	Hadi Hasan	7.63	300	4600	304	34.6 (1.50)	14.54 (0.37)	24.04 (1.2)	59.44 (4.88)	14.2 (0.40)	411.5 (8.56)	230 (3.77)	160 (5.33)
33	Nadeem Tarin	7.58	300	600	364	50 (2.17)	11.8 (0.3)	117.63 (5.86)	77.96 (6.42)	247.08 (6.96)	411.5 (8.56)	116 (1.90)	116 (3.86)
34	Sulaiman Hall	7.5	220	480	530	41.81 (1.82)	22.81 (0.58)	30.5 (1.52)	32.71 (2.69)	49.2 (1.39)	401.9 (8.36)	162 (2.65)	162 (5.39)
35	Sir Ziauddin Hall	7.48	200	820	538	20.81 (0.90)	4.21 (0.11)	26.04 (1.29)	25.81 (2.12)	56.6 (1.59)	98.6 (2.05)	120 (1.96)	173 (5.76)
36	Minto Circle	7.49	215	825	537	22.97 (0.99)	9.81 (0.25)	24.59 (1.22)	24.91 (2.05)	52.4 (1.48)	102.8 (2.14)	109 (1.78)	171 (5.69)
37	Allma Iqbal Hall	7.77	300	200	340	65.38 (2.84)	16.36 (0.42)	24.04 (1.19)	43.87 (3.61)	253.56 (7.16)	493.8 (10.28)	210 (3.44)	160 (5.33)
38	Geology Dept.	7.67	280	240	420	42.81 (1.86)	23.82 (0.61)	28.08 (1.40)	34.81 (2.86)	43.2 (1.21)	421.8 (8.78)	205 (3.35)	152 (5.06)
39	S.N. Hall	8.2	500	320	336	95 (4.13)	14.75 (0.38)	24.05 (1.20)	26.02 (2.14)	253 (7.14)	444 (9.24)	660 (10.82)	60 (1.99)
40	Usman Para	7.7	1100	704	592	140 (6.09)	12.25 (0.31)	31.8 (1.58)	26.9 (2.21)	300 (8.46)	441.9 (9.20)	420 (6.88)	0
41	Kila par	7.98	300	400	256	34.6 (1.50)	61.8 (1.58)	22.44 (1.11)	48.72 (4.01)	14.2 (0.40)	329.2 (6.85)	180 (2.95)	120 (3.99)
42	Bhambola	8.16	300	200	300	11.53 (0.50)	23.63 (0.6)	28.85 (1.43)	57.5 (4.73)	34.08 (0.96)	82.3 (1.17)	120 (1.96)	200 (6.66)

Table 1 contd ....

1	2	3	4	5	6	7	8	9	10	11	12	13	14
43	Kabir Colony	8.27	300	80	228	34.6 (1.50)	11.8 (0.3)	30.46 (1.51)	61.39 (5.05)	53.06 (1.49)	329.2 (6.85)	90 (1.47)	160 (5.33)
44	Al-Barkat	8.1	400	200	324	50 (2.17)	10.9 (0.28)	30.46 (1.51)	60.42 (4.97)	56.8 (1.60)	493.8 (10.28)	210 (3.44)	140 (4.66)
45	Gulistan Hosing (A R)	8.2	200	800	348	34.6 (1.50)	10.9 (0.28)	35.27 (1.75)	63.34 (5.21)	19.88 (0.56)	329.2 (6.85)	180 (2.95)	140 (4.66)
46	Hamdard Nagar B	8.11	200	400	272	19.23 (0.84)	10.9 (0.28)	35.27 (1.75)	44.82 (3.68)	34.4 (0.97)	411.5 (8.56)	80 (1.31)	200 (6.66)
47	Rathgawan	8.12	220	282	262	35.04 (1.52)	12.2 (0.31)	35.87 (1.78)	68.34 (5.62)	20.21 (0.57)	405.8 (8.45)	182 (2.98)	210 (6.99)
48	Shia Khas	7.98	210	360	282	34.71 (1.51)	10.81 (0.28)	27 (1.34)	63.8 (5.25)	21.87 (0.62)	282.9 (5.89)	184 (3.01)	130 (4.33)
49	Amrauli	7.82	240	422	270	33.89 (1.47)	11.51 (0.29)	34.32 (1.71)	61.2 (5.03)	20.18 (0.57)	322.8 (6.72)	172 (2.81)	180 (5.99)
50	Manzur Garhi	8.01	270	396	358	38.71 (1.68)	12.85 (0.33)	40.82 (2.03)	63.82 (5.25)	21.72 (0.61)	404.9 (8.43)	151 (2.47)	195 (6.49)
51	Delhi Gate Thana	7.34	1900	3400	204	150 (6.52)	154.54 (3.96)	81.76 (4.08)	0 (00)	372.04 (10.49)	1646 (34.26)	220 (3.60)	60 (1.99)
52	Rorawar	7.41	1700	3200	200	148 (6.44)	164.72 (4.22)	80.76 (4.02)	5.37 (0.44)	340.21 (9.59)	1400 (29.14)	205 (3.35)	65 (2.16)
53	ShatiPur	7.32	1300	1800	210	153.71 (6.68)	154.98 (3.96)	78.76 (3.93)	8.37 (0.69)	342.81 (9.68)	918 (19.11)	220 (3.60)	82 (2.73)
54	Salimpur Maufi	7.82	1800	2100	240	151.79 (6.60)	156.28 (3.99)	82.12 (4.09)	11.89 (0.98)	280.91 (7.93)	1100 (22.90)	235 (3.85)	69 (2.29)
55	Kesavpur Jafri	7.71	2100	4200	245	162.72 (7.07)	168.82 (4.32)	87.21 (4.35)	18.89 (1.55)	360.81 (10.18)	1221 (25.42)	210 (3.44)	72 (2.39)
56	Kathigarh Saraymiyan	7.31	1000	1400	200	188.46 (8.2)	76.36 (1.95)	22.44 (1.12)	96.48 (7.94)	264.12 (7.45)	246.9 (5.14)	280 (4.58)	40 (1.33)
57	Turkaman Gate	7.28	1400	1050	452	142.3 (6.19)	20.9 (0.53)	22.44 (1.12)	35.08 (2.89)	411.8 (11.62)	411.5 (8.56)	460 (7.54)	20 (0.66)
58	Barauli Jafarabad	7.6	300	600	288	34.7 (1.51)	10.9 (0.28)	17.63 (0.87)	59.44 (4.89)	25.56 (0.72)	82.3 (1.71)	200 (3.27)	140 (4.66)
59	Sarsaul	7.54	300	800	344	34.6 (1.50)	15.45 (0.4)	14.42 (0.72)	75.53 (6.21)	25.56 (0.72)	246.9 (5.14)	140 (2.29)	240 (7.99)
60	Elampur	7.32	320	840	360	32.82 (1.43)	14.32 (0.37)	18.32 (0.91)	64.32 (5.29)	22.32 (0.63)	222.8 (4.63)	120 (1.97)	242 (8.06)
61	Sute Mill	7.82	300	820	389	34.89 (1.52)	12.89 (0.33)	14.42 (0.72)	78.53 (6.46)	25.89 (0.73)	214.9 (4.47)	142 (2.37)	210 (6.99)
62	Banna Devi	7.67	300	800	68	26.92 (1.17)	10.9 (0.28)	19.23 (0.95)	4.87 (0.40)	51.12 (1.44)	329.2 (6.85)		
63	Bhikhampur	7.77	300	600	304	28.72 (1.25)	11.32 (0.29)	18.81 (0.93)	5.37 (0.44)	52.72 (1.48)	381.8 (7.94)	210 (3.44)	89 (2.96)
64	Sikander Pur	7.68	300	640	68	32.71 (1.42)	14.32 (0.37)	21.71 (1.08)	9.84 (0.81)	53.81 (1.51)	322.9 (6.72)	205 (3.35)	72 (2.39)

Table 1 contd ....

1	2	3	4	5	6	7	8	9	10	11	12	13	14
65	Khair Baipas	7.77	300	600	304	26.92 (1.17)	11.8 (0.3)	17.63 (0.87)	120.07 (9.87)	31.24 (0.88)	493.8 (10.28)	200 (3.27)	120 (3.99)
66	Panaithi	9	600	800	440	175 (7.61)	80 (2.05)	45.29 (2.26)	174.05 (14.31)	124.96 (3.52)	229.2 (4.77)	210 (3.44)	70 (2.33)
67	Dumehro	8.1	200	200	444	71.43 (3.12)	23.33 (0.6)	22.44 (1.12)	277.18 (22.79)	17.04 (0.47)	493.8 (10.28)	330 (5.40)	0
68	Hakim Garhi	8.1	240	200	441	68.32 (2.97)	22.81 (0.58)	23.81 (1.19)	240.39 (19.74)	18.21 (9.40)	451.7 (5.08)	310	0
69	Edalpur	8.4	200	200	308	246.43 (10.72)	33.33 (0.85)	28.86 (1.44)	179.37 (14.72)	25.56 (0.72)	658.4 (13.70)	70 (1.14)	70 (2.33)
70	Ukawali	8.2	210	240	302	211.98 (9.22)	31.71 (0.81)	29.42 (1.46)	172.65 (14.23)	24.32 (0.68)	682.4 (14.20)	72 (1.18)	70 (2.33)
71	Bahadur Garhi	8.12	200	250	304	204.81 (8.91)	33.44 (0.85)	32.42 (1.62)	168.98 (13.90)	23.82 (0.67)	622.8 (12.96)	68 (1.11)	78 (2.59)
72	Shaikha	8.17	600	1000	240	282.14 (12.27)	100 (2.56)	19.23 (0.95)	81.75 (6.73)	82.36 (2.32)	658.4 (13.70)	490 (8.03)	0
73	Allahdapur	8.19	1000	200	220	53.57 (2.33)	13.33 (0.34)	28.86 (1.44)	134.5 (11.10)	11.36 (0.32)	905.3 (18.84)	0	40 (1.33)
74	Bhojpur	8.72	983	300	212	54.98 (2.39)	11.98 (0.31)	29.89 (1.49)	130.5 (10.77)	13.62 (0.38)	871.8 (18.15)	8 (0.13)	42 (1.39)
75	Khwaja Chowk	7.3	1400	896	712	190 (8.26)	76.5 (1.96)	30.8 (1.53)	24.67 (2.03)	257 (7.24)	588.4 (12.25)	421 (6.90)	0
76	Mahmudnapur	8.11	800	1000	224	307.14 (13.36)	35 (0.89)	16.03 (0.79)	50.1 (4.12)	105.08 (2.96)	493.8 (10.28)	580 (9.50)	0
77	Bhataulia	8.07	300	600	288	114.28 (4.97)	26.66 (0.68)	19.24 (0.96)	152.96 (12.58)	49.76 (1.40)	329.2 (6.85)	290 (4.75)	20 (0.66)
78	Khitkari	8.71	340	680	270	98.71 (4.29)	21.71 (0.55)	21.82 (1.08)	154.64 (12.75)	40.81 (1.15)	320.2 (6.66)	290 (4.75)	25 (0.83)
79	Khanampur	8.12	500	800	312	171.42 (7.46)	40 (1.02)	20.84 (1.03)	134.5 (11.10)	76.68 (2.16)	329.2 (6.85)	410 (6.72)	0
80	Gurshi khran	8.14	600	800	276	100 (4.35)	123.33 (3.15)	28.86 (1.44)	65.93 (5.42)	124.96 (3.52)	329.2 (6.85)	210 (3.44)	50 (1.66)
81	Rushsupur	8.17	500	800	388	214.28 (9.32)	60 (1.53)	20.84 (1.03)	166.15 (13.65)	96.56 (2.72)	329.2 (6.85)	540 (8.85)	0
82	Budbansi	7.97	600	800	280	214.28 (9.32)	58.33 (1.49)	24.05 (1.20)	155.6 (12.83)	102.24 (2.87)	164.6 (3.43)	560 (9.17)	0
83	Latifpur Mojra	7.86	640	842	360	209.98 (9.13)	53.71 (1.37)	25.82 (1.28)	145.8 (12.01)	104.84 (2.96)	102.4 (2.13)	488 (7.99)	8 (0.26)
84	Nayla Itawali	7.58	650	850	382	204.71 (8.90)	54.81 (1.4)	32.82 (1.64)	147.9 (12.17)	102.81 (2.90)	182.82 (3.80)	498 (8.16)	10 (0.33)
85	Sikandarpur	7.97	600	800	396	221.43 (9.63)	56.66 (1.45)	20.84 (1.04)	163.51 (13.49)	105.08 (2.96)	411.5 (8.56)	560 (9.17)	0
86	Dhasanna	8.01	610	820	379	207.98 (9.05)	59.71 (1.53)	22.81 (1.14)	158.91 (13.07)	108.11 (3.04)	400.82 (8.34)	569 (9.32)	10 (0.33)

Table 1 contd ....

1	2	3	4	5	6	7	8	9	10	11	12	13	14
87	Azamabad	7.99	700	1200	420	260.71 (11.34)	41.66 (1.07)	20.84 (1.04)	158.3 (12.99)	127.8 (3.61)	329.2 (6.85)	590 (9.67)	0
88	Chhirawali	8.31	700	510	418	257.47 (11.2)	40.72 (1.04)	21.72 (1.08)	149.71 (12.34)	131.8 (3.72)	342.2 (7.12)	558 (9.14)	18 (0.59)
89	Hardauganj	8.22	700	1000	364	257.14 (11.18)	41.66 (1.07)	16.03 (0.79)	131.86 (10.86)	116.44 (3.27)	329.2 (6.85)	610 (9.99)	0
90	Shahpur	8.25	600	800	400	228.57 (9.94)	40 (1.02)	17.63 (0.87)	171.42 (14.06)	99.4 (2.80)	82.3 (1.71)	560 (9.17)	0
91	Aurangabad	8.21	700	800	408	211.98 (9.22)	42 (1.07)	18.92 (0.94)	168.71 (13.90)	108.08 (3.04)	100.2 (2.08)	558 (9.14)	0
92	Mirpur	8.25	700	400	408	257.14 (11.18)	41.66 (1.07)	20.84 (1.04)	155.59 (12.83)	1522.11 (42.92)	658.4 (13.70)	560 (9.17)	0
93	Kalai	8.31	750	450	406	204.98 (8.92)	42.71 (1.09)	22.82 (1.14)	152.98 (12.58)	124.82 (3.52)	700.2 (14.57)	568 (9.30)	14 (0.46)
94	Daudpur	8.02	720	400	402	209.74 (9.12)	45.74 (1.17)	23.84 (1.19)	148.71 (12.26)	120.81 (3.41)	620.2 (12.91)	558 (9.14)	12 (0.39)
95	Girahapur	8.25	710	600	388	222.71 (9.68)	44.67 (1.14)	28.91 (1.44)	139.81 (11.51)	121.82 (3.44)	582.8 (12.13)	568 (9.30)	22 (0.73)
96	Ukbalana	8.25	700	800	376	557.14 (24.23)	42.5 (1.09)	17.63 (0.87)	131.86 (10.85)	124.96 (3.52)	493.8 (10.28)	590 (9.67)	0
97	Bhimgarh	8.24	700	800	376	264.28 (11.5)	38.33 (0.98)	14.42 (0.72)	134.5 (11.10)	122.12 (3.44)	576.1 (11.99)	990 (16.22)	0
99	Naraul	8.24	700	600	384	264.28 (11.5)	41.66 (1.07)	17.63 (0.88)	139.77 (11.51)	122.12 (3.44)	329.2 (6.85)	510 (8.36)	40 (1.33)
100	Lohara	8.27	700	800	432	260.71 (11.34)	40.83 (1.04)	8.02 (0.40)	158.23 (12.99)	136.32 (3.83)	493.8 (10.28)	580 (9.51)	0

Table 2: Range of chemical parameters in groundwater of Aligarh

S.No.	Water quality parameters	WHO (1993)		ISI (1991)		Concentration in study area		
		Highest desirable level	Max. desirable level	Highest desirable level	Max. permissible level	Mini	Maxi	Average
1	pH	7.0 to 8.5	6.5 to 9.2	6.5 to 8.5	No relaxation	6.9	9	7.98
2	Ec (uS/cm at 25^{o}C	-	-	-	-	200	2100	606.4
3	TDS (mg/l)	500	1500	500	1000	80	4200	861
4	TH (mg/l)	100	500	300	600	68	756	356
5	Ca (mg/l)	75	200	75	200	8.02	147.49	36.04
6	Mg (mg/l)	30	150	30	100	0	277.18	86.5
7	Na (mg/l)	-	200	-	200	11.53	720.47	198.7
8	K (mg/l)	-	-	-	-	0	168.82	38.8
9	HCO_3	-	-	-	-	0	1480	301
10	Cl (mg/l)	200	600	250	1000	8.52	1522.11	154
11	SO_4 (mg/l)	200	400	150	400	82.30	2496.90	436.2

Table 3: Irrigation water quality classification (after Richard, 1954)

Water class	Salinity Hazard		Alkali Hazard	
	Electrical conductivity (µS/cm)	Number of samples	Sodium adsorption ratio (epm)	Number of samples
Excellent	Up to 250	16	Up to 10	94
Good	250-750	59	10-18	6
Fair/ Medium	750-2250	25	18-26	-
Poor/ Bad	>2250	00	>26	-

samples fall in the no-dominant type, whereas 45% and 43% of the sample are in Mg-Na+K type in cation facies. Conversely, 50% samples fall in to the no-dominant type and other 30% bicarbonate type, 18% chloride type and 2% sulphate type in anion facies (Table 5). The diamond shaped field between the two triangles is used to represent the composition of water with respect to both cations and anions. The points for both the cations and anions are plotted on the appropriate triangular diagrams. The positions of the points are projected parallel to the magnesium and sulphate axes respectively until they intersect in the center field. The plot of chemical data on diamond shaped trilinear diagram (Fig. 2) reveals that the majority of groundwater samples fall in the fields of 1, 3, 4 suggesting that alkaline earth exceeds alkalies in 61% samples, alkalies exceeds alkaline earths in 39% samples, and strong acids exceed weak acids in 74% samples respectively (Table 6). From the plot, it is apparent that the total hydrochemistry is dominated by alkaline earth and strong acids. The groundwater samples having high sulphate concentrations fall in the field 9. However, in some of the groundwater samples that fall in 3 and 7, non-carbonate alkali exceed 50%, and weak acid exceed strong acid (26%), and none of the cation and anion pairs exceed 50%.

6.1.1 Gibb's Diagram: The source of the dissolved ions in the groundwater can be understood by Gibbs diagram (Gibbs 1970). It is a plot of $(Na^{+}+ K+)/(Na^{+}+K^{+}+ Ca^{2+})$ vs. TDS and $Cl^{-}/(Cl^{-}+ HCO^{-}_{3})$ vs. TDS. Gibb's diagram is used to understand the relationship of the chemical components of water from their respective lithologies. In the Gibb's diagram, three distinct fields namely precipitation dominance, evaporation dominance and rock dominance are shown (Fig. 3a and 3b). The plots of the present study indicate rock dominance over the chemistry of groundwater in area. It suggests that the chemistry of groundwater of the area is largely governed by interaction between aquifer lithology and groundwater. The diagram also reveals that the groundwater of the area is suitable for irrigation purposes in its natural form, but four to five samples fall in evaporation dominance so they are not suitable for irrigation purpose. Anthropogenic activities may also increase the TDS values (Karanth 1987).

6.2 Classification of Groundwater for Domestic Purposes

The water used for drinking purpose should be colourless, and free from turbidity and microorganisms (Karanth, 1989). Chemically, the water should be soft with less dissolved solids and free from poisonous constituents. To ascertain the suitability of groundwater for drinking and public health purpose, hydrochemical parameters of the waters of the study area are compared in Table 2 with the guideline standards of World Health organization (WHO, 1993) and Indian Standard Institution (ISI, 1991). The study clearly indicates that groundwater in sizeable part of the study area is not suitable for drinking and other domestic purposes as they exhibit concentrations above the various desirable and permissible limits.

The pH value of groundwater ranges from 6.9 to 9 with an average value of 7.98 which indicates

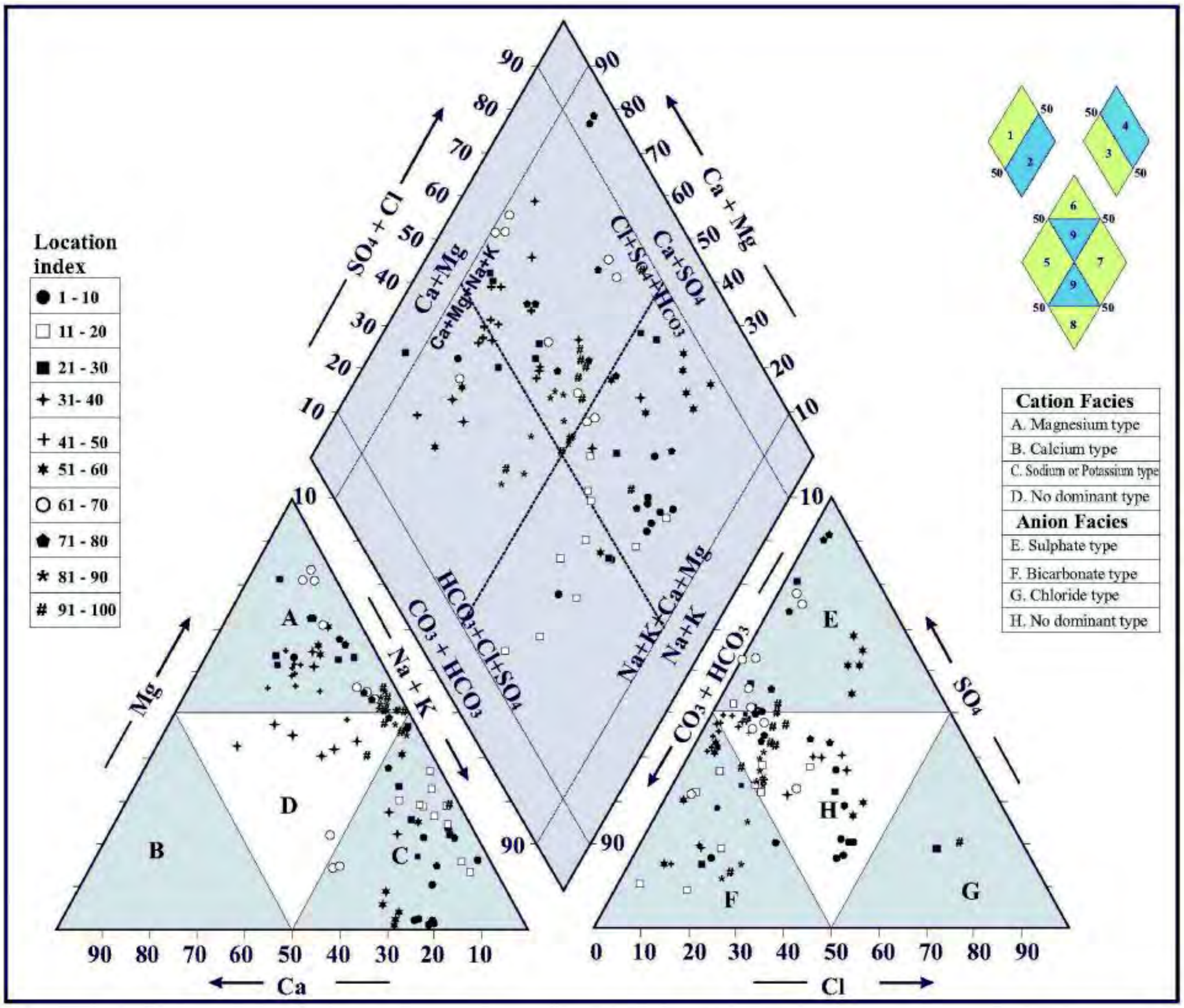

Fig. 2: Trilinear diagram of groundwater samples (after Piper, 1953)

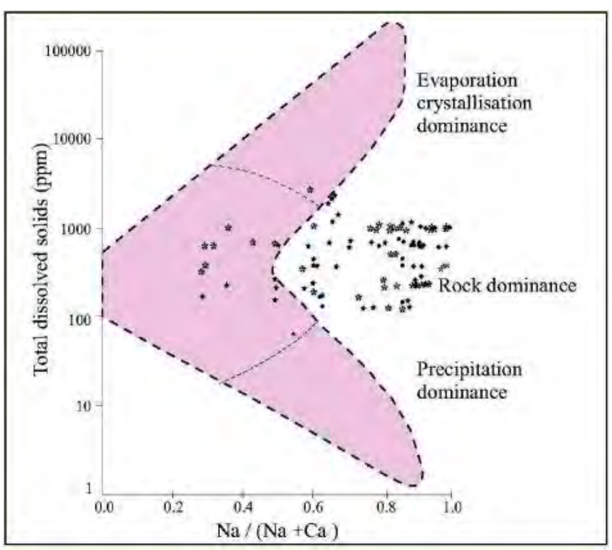

Fig. 3(a): Na/(Na+Ca) as a function of TDS (after Gibbs, 1970)

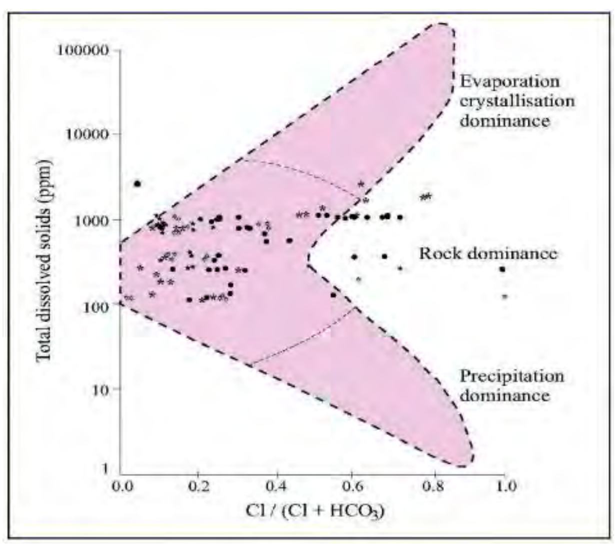

Fig. 3(b): Cl/(Cl+HCO3) as a function of TDS (after Gibbs, 1970)

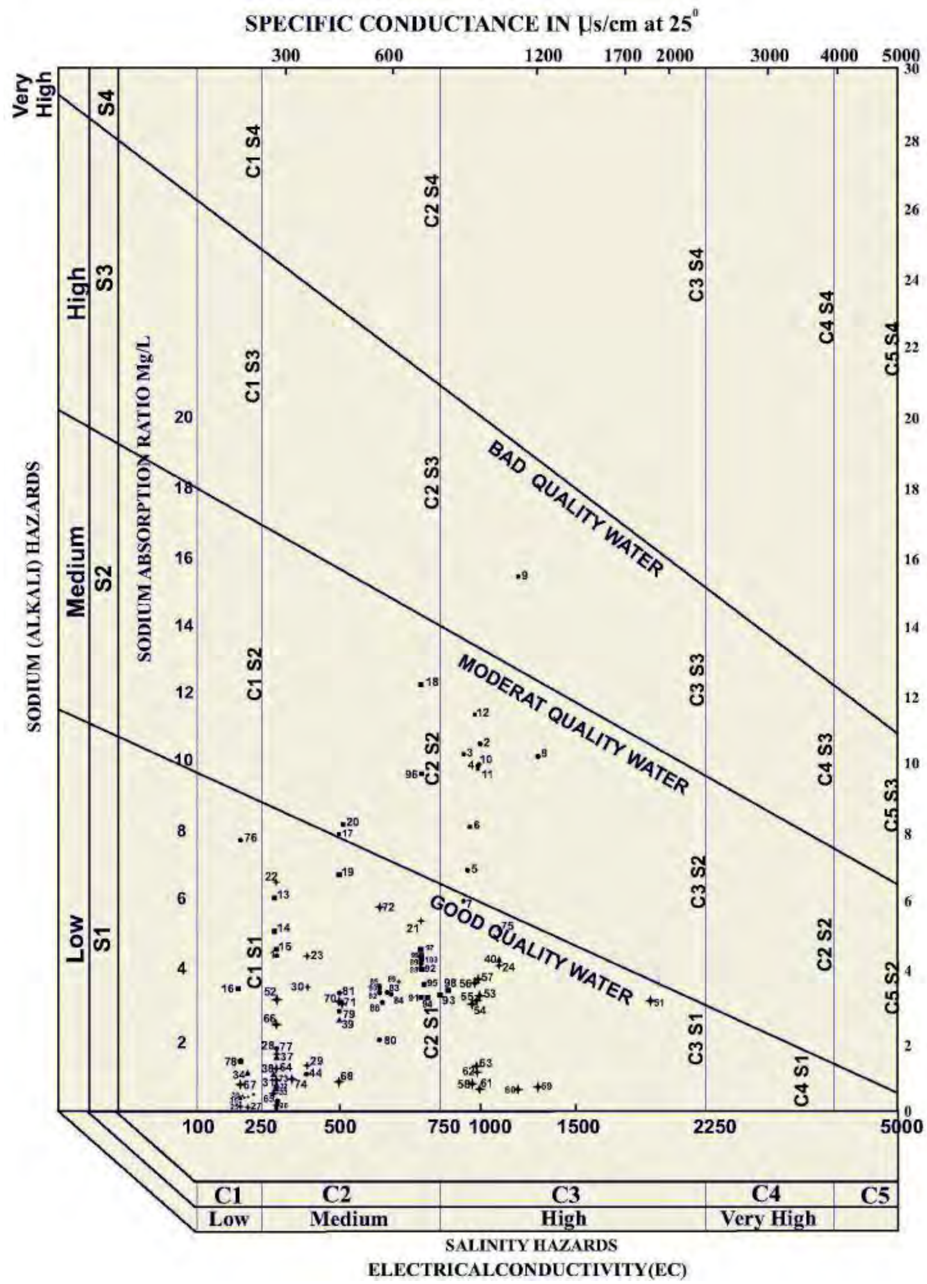

Fig. 4: Rating of groundwater samples in relation to salinity hazard and sodium hazard (after Richard, 1954)

that the groundwaters are slightly alkaline in nature. The TDS value ranges from 80 to 4200 mg/l with an average of 860.9 mg/l. As per the classification proposed by Davis and Dewiest, (1966) based on TDS, four groundwater categories can be identified, viz: TDS up to 500 mg/l as desirable for drinking; 500 to 1000 mg/l as permissible for drinking; up to 3000 mg/l useful for agricultural purpose, and above 3000 mg/l as unfit for drinking and irrigation purpose. Based on TDS classification, it is observed that out of the 100 groundwater samples, 32 are within desirable and 46 are within permissible limits for drinking and about 96 samples are useful for irrigation purposes and only 4 samples (32, 51, 52, and 55) are dangerous for drinking as well as irrigation purpose. As per the Fetter (1990) classification of water based on the total dissolved solids, 78% of the samples come under fresh water (TDS < 1000 mg/l) and 22% under brackish water (TDS > 1000 mg/l) categories. Among the cationic (Ca, Mg, Na and K) concentration, sodium is the most dominant cation (11.53 to 720.47 mg/l) followed by calcium (8.02 to 147.49 mg/l), magnesium (0 to 277.18 mg/l) and potassium (0 to 168.82 mg/l). Among the anionic (HCO_3, SO_4, Cl and CO_3) concentrations, bicarbonate is the most dominant anion (0 to 1480 mg/l) followed by chloride (8.52 to 1522.11 mg/l), sulphate (82.30 to 2496.30 mg/l) and carbonate (0 to 460 mg/l).

6.3 Suitability of Groundwater for Irrigation Purposes

Assessment of the suitability of groundwater for irrigation purpose requires consideration of the total dissolved solids, the concentrations of certain constituents and substances which may be toxic to plants. The important characteristics or properties of groundwater to be considered for irrigation use are electrical conductivity, salinity, percent sodium, sodium adsorption ratio, residual sodium carbonate and permeability index.

6.3.1 Salinity : The EC and Na concentrations are important in classifying irrigation water. The electrical conductivity values range from 200 to 2100 uS/cm with an average of 606.4 uS/cm (Table 2). A high salt content (high EC) in irrigation water leads to formation of saline soil. This affects the salt intake capacity of the plants through their roots. On the basis of electrical conductivity values, Richards (1954) classified irrigation water in to four groups (Table 3).

As per Richards (1954) classification, 16 samples are excellent, 59 samples are good and 25 samples are medium in salinity. Groundwater samples falling in medium salinity hazard can be used, if a moderate amount of leaching occurs. High salinity waters cannot be used on soil with restricted drainage. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Saleh *et al*., 1999).

6.3.2 Percent Sodium (%Na): Sodium concentration is important in classifying irrigation water, because sodium reacts with soil to reduce its permeability. Excess sodium in waters produces undesirable effects of changing soil properties and reducing soil permeability (Kelley, 1951). Hence, the assessment of sodium concentration is of utmost importance while considering the suitability of irrigation water. In all natural waters percent of sodium content is a parameter to evaluate its suitability for agricultural purposes (Wilcox, 1948), sodium combining with carbonate can lead to the formation of alkaline soils, while sodium combining with chloride form saline soils. Both these soils do not help in the growth of plants.

Sodium content is usually expressed in terms of percent sodium (%Na). The calculated values of percent sodium range from 7.27 to 81.11 with an average of 46.15 (Table 4). A maximum of 60% sodium in groundwater is allowed for agricultural purposes (Ramakrishna, 1998). The percent sodium is obtained by the following equation:

$$\%Na = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} (epm)$$

The chemical quality of groundwater samples was studied from plots of percentage of sodium and electrical conductivity in the Wilcox diagram (Fig. 5). The Wilcox diagram revealed that out of 100 samples, 72 percent belonged to excellent to good category, followed by 8 percent belonging to 'good to permissible' category and 20 percent to 'permissible to doubtful' categories for irrigation (Table 5). The agricultural crop yields are generally low in lands irrigated with waters belonging to 'doubtful to unsuitable' category. This is probably due to the presence of excess sodium salts, which cause osmotic effects on soil-plant system. When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg and Ca ions. This exchange process of Na in water for Ca and Mg in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Saleh *et al*., 1999).

Table 4: Characteristic ratio and indices of groundwater samples of the study area

Water type	Sample Number	Total number of sample
	Piper triangle fields classification (Fig. 2)	
(I) Cation Facies		
A. Magnesium	....	45
B. Calcium type	....	00
C. Sodium or Potassium	....	43
D. No dominant type	....	12
(II) Anion Facies		
E. Sulphat type	....	2
F. Bicarbonate type	....	30
G. Chloride type	....	18
H. No dominant type	....	50
	Wilcox classification (Fig. 5)	
Excellent to good	1'13,14,15,16,17'19,20,21,22,23,25,26,27,28,29,30,31,32,33,34,35, 36,37,38,39,41,42,43,44,45,46,47',48,49,50,52,64,65,66,67,68,69,70, 71,72,73,74,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93, 94,95,96,97,99,100	72
Good to Permissible	56.58.59,60,61,62,63,98	8
Permissible to Doubtful	2,3,4,5,6,7,8,9,10,11,12,18	20
Doubtful to undoubtful	–	–
Unsuitable	–	–
	U S Salinity Laboratory classification (Fig. 4)	
C1 S1	16,25,27,34,35,36,67,76,78	15
C2 S1	1'13,14,15,19,21,23,26,27,28,29,30,31'32,33,37,38,39,44,52,64,65, 66,68.69.70,71'72,73,74,77,79,80,81,82,83,84,85,88,89,90,91,92, 94,95,97,99,100	53
C2 S2	17,18,20,96	4
C3 S1	7,24,40,51,53,54,55,56,57,58,59,60,61,62,63,75,93,98.	18
C3 S2	2,3,4,5,6,8,10,11'12	9
C3 S3	9	1

6.3.3 Sodium Adsorption Ratio (SAR): The degree to which irrigation water tends to enter into cation exchange in soil can be indicated by the sodium adsorption ratio (USSL, 1954). It is expressed as:

$$SAR=\frac{Na^{+}}{Ca^{2+}+Mg^{2+}/2}(epm)$$

Since sodium replaces adsorbed calcium and magnesium in soil, excess sodium in groundwater gets adsorbed on soil particles, thus changing soil properties and also reducing soil permeability (Ayers and Bronson, 1975). USSL (1954) proposed to plot SAR against EC for rating irrigation water (Fig. 4). Sixteen classes in the diagram indicate the extent up

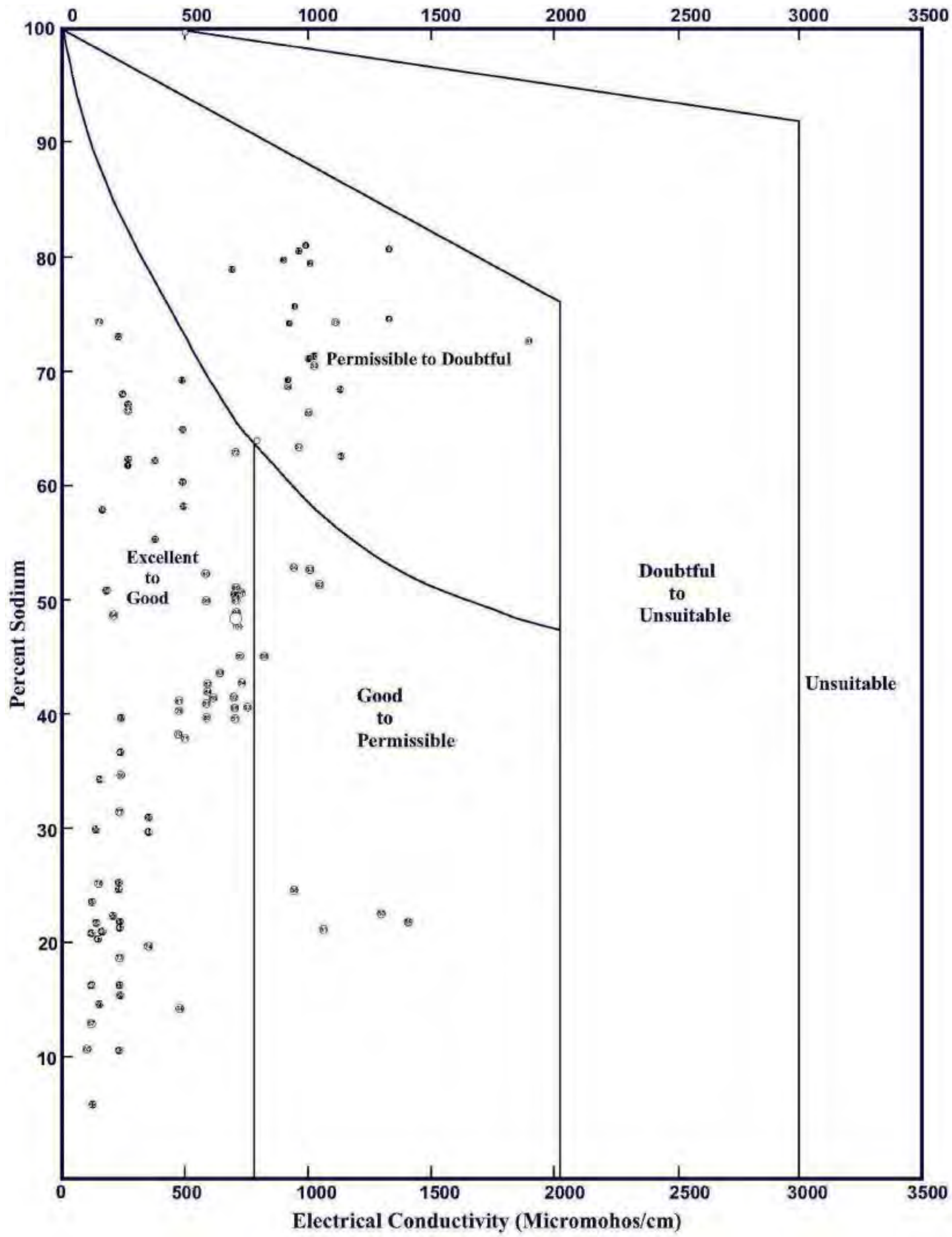

Fig. 5: Rating of groundwater samples on the basis of electrical conductivity and percent sodium (after Wilcox, 1948)

to which the waters can affect the soil. The diagram indicates the extent up to which the waters can affect the soil in terms of salinity hazard. These classes are: low salinity (C_1), medium (C_2), high (C_3), and very high salinity (C_4) and similarly sodium hazard as low (S_1), medium (S_2), high (S_3), and very high (S_4). The groundwater samples of the study area fall in six categories, the first one is C_1S_1 15% (low saline and low SAR), C_2S_1 53% (medium saline and low SAR), C_2S_2 (4%) (Medium saline and medium SAR), C_3S_1 18% (high saline and low SAR), C_3S_2 9% (high saline and medium SAR), C_3S_3 1% (high saline and high SAR) categories, hence some samples are not suitable for irrigation purpose. The analyzed data indicate risk of sodification (Table 5).

6.3.4 Permeability Index (PI): The classification of irrigation waters has been attempted on the basis of permeability index, as suggested by Doneen 1962. It is defined as:

$$\text{P.I.} = \frac{Na^{+}\sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{2+}} \times 100(\text{epm})$$

The groundwater samples of the study area dominantly fall in the field of class-I (81%) while 15% of the samples fall in class-II. This indicates that the groundwater samples are generally suitable for irrigation purposes, but 4% of the samples fall in class-III and are not suitable for irrigation purpose. This water is highly saline so it will affect irrigation activity. This is due to dilution and medium to high value of permeability index.

6.3.5 Kelley's Ratio (KR): Kelley's ratio is used to find whether the groundwater is suitable for irrigation or not. It is the ratio of sodium ion to calcium and magnesium ion in epm (Kelley, 1951) and expressed as:

$$\text{K.R.} = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}(\text{epm})$$

Groundwater having Kelley's ratio more than 1 is generally considered unfit for irrigation. Kelley's ratio varies from 0.09 to 4.2 (Table 4). According to this 36 % samples out of hundred samples are found to be unfit for irrigation.

6.3.6 Residual Sodium Carbonate (RSC): It refers to the residual alkalinity and is calculated for irrigation water using the following formula:

$$\text{RSC} = (CHO_3^{-} + CO_3^{--})\text{-}Ca^{2+} + Mg^{2+}(\text{epm})$$

The RSC values > 1.25 mg/l are considered as safe for irrigation, while those from 1.25 mg/l to 2.5 mg/l are marginally suitable for irrigation. If RSC values are > 2.5 the groundwater is unsuitable for irrigation (Richards, 1954). The RSC values of groundwater samples of the study area range from –18.49 to 20.81 with an average of –0.2746 (Table 4). The classification of groundwater for irrigation purpose according to the RSC values indicates that 52% of the water samples are in the safe category, 13% are marginally safe and 35% are unsuitable for irrigation purpose (Table 7). Continued usage of high residual sodium carbonate water affects the yield of crops.

6.3.7 Corrosivity Ratio (CR): It is defined as alkaline earth and alkalis and is expressed as:

$$\text{C.R.} = \frac{Cl^{-}/35.5 + 2\left(\frac{SO_4^{--}}{96}\right)}{2\left(\frac{CHO_3^{--} + CO_3^{--}}{96}\right)}(\text{epm})$$

The groundwater with corrosivity ratio < 1 is considered to be safe for transport of water in any type of pipe, whereas CR >1 indicates its corrosive nature and hence should not be transported through metal pipes (Balasubramanain, 1986). The calculated values of groundwater samples are presented in Table 4, which suggest that 97% of the samples are safe, whereas 3% of samples are corrosive in nature and need noncorrosive pipes (PVC) for transporting and lifting of groundwater.

6.4 Anthropogenic Activities and Groundwater Contamination in the Area

The two sources that constitute the main anthropogenic inputs to the groundwater system include slaughter houses and lock factories (Fig. 1). Although slaughter-houses comprise an important economic activity to the operators as well as livestock producers, they however represent a major environmental challenge particularly water, soil and land pollution. The major waste associated with slaughter house operations are blood, dung and slurry which are washed into waterways or disposed off on land leading to pollution of the respective components of the environment (Koech *et al*., 2012).

The impact of slaughterhouses on groundwater regime has been investigated by many workers (Adegbola *et al*., 2012). Untreated slaughter house waste water comprises a mixture of fats, proteins and

Table 5: Geochemical classification of groundwater of Aligarh (UP), India

Sr.	Lcation	SAR	K.R.	%Na	RSC	C.R.	P.I.	Sr.	Lcation	SAR	K.R.	%Na	RSC	C.R.	P.I.
1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1	Upper Fort	2.65	1.5	62.26	2.9	0.03	70.7	51	Delhi Gate Thana	2.28	1.5	71.99	1.52	0.14	79.4
2	Bhojpura	7.39	3.7	79.7	1.2	0.04	85.3	52	Rorawar	2.15	1.4	70.44	1.05	0.13	75.8
3	Pale Sahibaba	7.18	3.7	79.67	2.4	0.04	84.8	53	ShatiPur	2.19	1.4	69.74	1.72	0.09	75.9
4	Gandhi Nager	6.91	3.6	79.65	3.5	0.04	84.8	54	Salimpur Maufi	2.07	1.3	67.6	1.07	0.09	73.3
5	Buriki Sarai Harnarayanki	4.85	2.6	74.84	-0.15	0.05	80	55	Kesavpur Jafri Kathigarh	2.05	1.2	65.86	-0.06	0.12	68.7
6	Sarai	5.64	2.9	75.51	-0.37	0.05	80.4	56	Saraymiyan	1.92	0.9	52.85	-3.13	0.03	59.9
7	Naya Basil	3.48	1.9	67.06	6.8	0.01	80.3	57	Turkaman Gate	2.18	1.5	62.66	4.19	0.03	87.6
8	Achal Tal	6.5	2.7	74.66	10.35	0.04	79	58	Barauli Jafarabad	0.44	0.2	23.67	2.17	0.01	45.6
9	Luxmi Nager	7.97	4.2	81.51	2.68	0.08	85.7	59	Sarsaul	0.4	0.2	21.53	3.36	0.03	35.8
10	Sasni Gate	5.34	2.3	71.71	-1.53	0.09	75.1	60	Elampur	0.4	0.2	22.42	3.83	0.03	37
11	Mukandipur	5.19	2.3	71.79	20.84	0.01	85.8	61	Sute Mill	0.4	0.2	20.47	2.15	0.02	35
12	Parhawali	6.38	3.8	80.58	2.14	0.09	84.6	62	Banna Devi Thana	0.7	0.8	51.59	5.07	0.02	122.9
13	Kuwarsi	3.32	1.9	66.47	4.74	1.7	65.2	63	Bhikhanipur	0.75	0.9	52.7	5.02	0.03	118
14	Nagla muhalla	2.97	1.6	63.15	5.31	0.06	69.3	64	Sikander Pur	0.73	0.7	48.58	3.86	0.03	98
15	Hamdard Nager D	2.52	1.6	62.58	9.07	0.42	61.7	65	Khair Baipas	0.25	0.1	12.04	-3.47	0.04	25
16	Ghanta Ghar	1.95	1.3	57.86	-0.33	0.06	65.7	66	Panaithi	1.32	0.4	36.81	-10.79	0.03	39.1
17	Railway Station	4.17	2	68.2	6.38	0.05	71.7	67	Dumehro	0.44	0.1	13.41	-18.49	0.02	20.1
18	Samshad market	6.97	3.5	78.54	4.96	0.03	85.1	68	Hakim Garhi	0.45	0.1	14.51	-15.85	0.02	21.8
19	Jamalpur	3.54	1.5	60.59	-0.69	0.02	69	69	Kdalpur	1.88	0.6	41.71	-12.68	0.13	43.8
20	Dhurra	4.25	1.7	63.85	2.01	0.02	71.7	70	Ukawali	1.64	0.5	38.98	-12.19	0.13	41.3
21	Tala'nagri	2.76	1	50.96	-4.57	0.09	58.9	71	Bahadur Garhi	1.59	0.5	36.61	-11.8	0.13	40.7
22	Sir Syed Nager	3.7T	2.5	72	4.23	0.06	78.8	72	Shaikha	3.12	1.5	65.85	0.34	0.02	75.6
23	Vikash Nagar	2.48	1.2	55.41	2.82	0.28	62.1	73	Allahdapur	0.46	0.1	17.55	-11.21	30.1	15.6
24	Madar Gate	2.56	1.9	67.51	4.14	0.02	93.5	74	Bhojpur	0.48	0.1	18.03	-10.74	1.41	18.7
25	V.M. Hall	0.18	0.07	7.33	-2.93	0.02	18.5	75	Khwaja Chowk	3.09	2.3	74.12	3.33	0.03	92
26	S.S. Hall	0.24	0.1	15.87	0.64	0.04	33.2	76	Mahmudnapur	4.25	2.7	74.33	4.58	0.02	89.9
27	S.S. North Hall	0.17	0.09	15	0.58	0.04	30.4	77	Bhataulia	0.95	0.3	29.45	-8.15	0.02	38.6
28	Aftab Hall	0.85	0.4	35.99	0.74	0.04	47.6	78	Khitkari	0.81	0.3	25.94	-8.25	0.02	35.7
29	R.M. Hall	0.73	0.3	25.5	1.28	0.02	42.8	79	Khanampur	1.51	0.6	41.11	-5.42	0.02	51.2
30	M.M. Hall	2.13	1.4	61.44	4.05	0.08	71.6	80	Gurshi khran	1.17	0.6	52.2	-1.75	0.04	55.3

Table 5 contd ....

1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
31	Habib Hall	0.41	0.2	21.77	1.89	0.11	35.2	81	Rushsupur	1.71	0.6	42.48	-5.84	0.01	51.2
32	Hadi Hasan	0.43	0.2	23.56	3.01	0.02	45.4	82	Budbansi	1.75	0.6	43.52	-4.85	0	52.8
33	Nadeem Tarin	0.43	0.1	16.77	-6.51	0.1	24.5	83	Latifpur Mojra	1.77	0.6	44.14	-5.03	0.01	53.3
34	Sulaiman Hall	0.62	0.4	36.31	3.84	0.04	57.1	84	Nayla Itawali	1.69	0.6	42.73	-5.31	0.01	51.7
35	Sir Ziauddin Hall	0.34	0.2	22.84	4.31	0.02	53.3	85	Sikandarpur	1.78	0.6	43.26	-5.35	0.01	52.4
36	Minto Circle	0.39	0.3	27.62	4.21	0.02	54.6	86	Dhasanna Azamabad	1.69	0.6	42.65	-4.55	0.01	52
37	AHma Iqbal Hatl	0.91	0.5	40.41	3.96	0.06	61.3	87	Maehha	2.14	0.8	46.92	-4.36	0.01	56.9
38	Geology Dept.	0.63	0.4	36.68	4.16	0.03	60.3	88	Chhirawali	2.16	0.8	47.69	-3.67	0.01	57.7
39	S.N. Hall	1.59	1.2	57.46	9.47	0.02	99.3	89	Hardauganj	2.31	0.9	51.28	-1.66	0.01	62.8
40	Usman Para	2.2	1.6	62.76	3.08	0.03	88.1	90	Shahpur	1.81	0.6	42.32	-5.76	0.01	52.1
41	Kila par	0.47	0.2	37.57	1.82	0.03	48.6	91	Aurangabad	1.69	0.6	40.95	-5.7	0.01	50.8
42	Bhanibola	0.14	0.08	15.19	2.46	0.02	28.5	92	Mirpur	2.12	0.8	46.89	-4.69	0.08	56.7
43	Kabir Colony	0.41	0.2	21.56	0.23	0.06	33.6	93	Kalai	1.7	0.6	42.17	-3.94	0.02	52.8
44	Al-Barkat Gulistan Hosing	0.6	0.3	27.43	1.61	0.04	46.5	94	Daudpur	1.75	0.6	43.35	-3.9	0.02	53.8
45	(A.R)	0.4	0.2	20.38	0.64	0.03	38	95	Girahapur	1.9	0.7	45.52	-2.91	0.02	56.2
46	Hamdard Nagar B	0.25	0.1	16.99	2.53	0.08	31.5	96	Ukbalana	5	2	68.32	-2.06	0.02	76
47	Rathgawan	0.39	0.2	19.86	2.57	0.03	36.3	97	Bhimgarh	2.36	0.9	51.34	4.4	0.01	66.5
48	Shia Khas	0.41	0.2	21.3	0.75	0.02	40	98	Qesimpur Minor	2.05	0.7	45.07	-5.94	0.02	54
49	Amrauli	0.4	0.2	20.76	2.07	0.03	38.3	99	Naraul	2.3	0.9	50.33	-2.7	0.01	60.2
50	Manzur Garhi	0.44	0.2	21.65	1.68	0.04	36.3	100	Lohara	2.19	0.8	48.03	-3.89	0.02	58.3

fibers, resulting in a high content of organic matter and causes a contaminating effect to the rivers and sewage systems. It also increases nitrogen, phosphorus, solids and BODS levels of the receiving water body, potentially leading to eutrophication (Benka-Coker and Ojioro, 1995; Caixeta *et al*., 2002; Kobya *et al*., 2005; AL-Mutairi, 2006). Slaughterhouse wastewater also contains insoluble and slowly biodegradable suspended solids (Sayed *et al*., 1988). Increased suspended particulate matter can reduce light penetration into water body, and it may also alter benthic spawning grounds and feeding habitats (USEPA, 2002a).

Fig. 6 indicates that Na concentration exceeds equivalent Cl concentration in all the samples suggesting that additional sources of Na may be present. The significant deviation of samples from 1:1 line on Na vs Cl plot clearly indicate that Na is contributed to the groundwater system from various sources other than those of geogenic. The main source of Na in the study area to which perhaps more emphasis should be given are slaughterhouses. These slaughterhouses, located on the south-west of study area generate large amount of liquid wastes (especially blood) which are buried indiscriminately without taking environmental status under consideration. The wells which are affected most include well 21, 24, 51, 52, 53, 56 and 57. This contaminated water has polluted groundwater and therefore wells and drinking water.

Table 6: Characterization of groundwater on the basis of Piper trilinear diagram

Subdivision of the diamond shaped field	Characteristics of corresponding subdivision of diamond shaped field	No of sample in different fields
1	Alkaline earth (Ca+ Mg) exceeds alkalies (Na+K)	61
2	Alkalies exceeds alkaline earths	39
3	Weak acid ($Ca+HCO_3$) exceeds strong acid (SO_4+Cl+F)	26
4	Strong acid exceed weak acids	74
5	Carbonate hardness (Secondary alkalinity) exceeds 50%	17
6	Non-Carbonate hardness (Secondary salinity) exceeds 50%	06
7	Non-Carbonate alkali (Primary salinity) exceeds 50%	30
8	Carbonate alkali (Primary salinity) exceeds 50%	00
9	None of the cation and anion pairs exceed 50%	47

Table 7: Residual sodium carbonate classification

RSC (epm)	Water category	Number of samples
< 1.25	Safe	52
1.25 to 2.5	Marginal siuitable	13
>2.5	Unsuitable	35

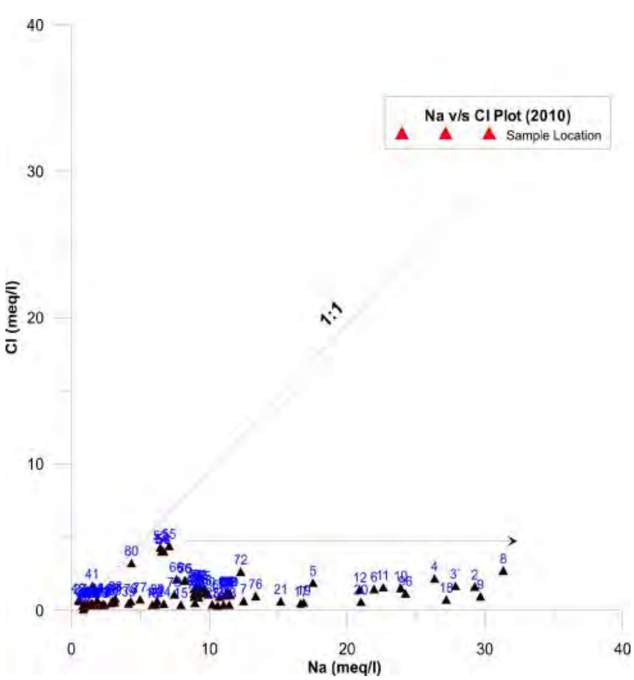

Fig. 6 Sodium versus Chloride in groundwater samples of the study area

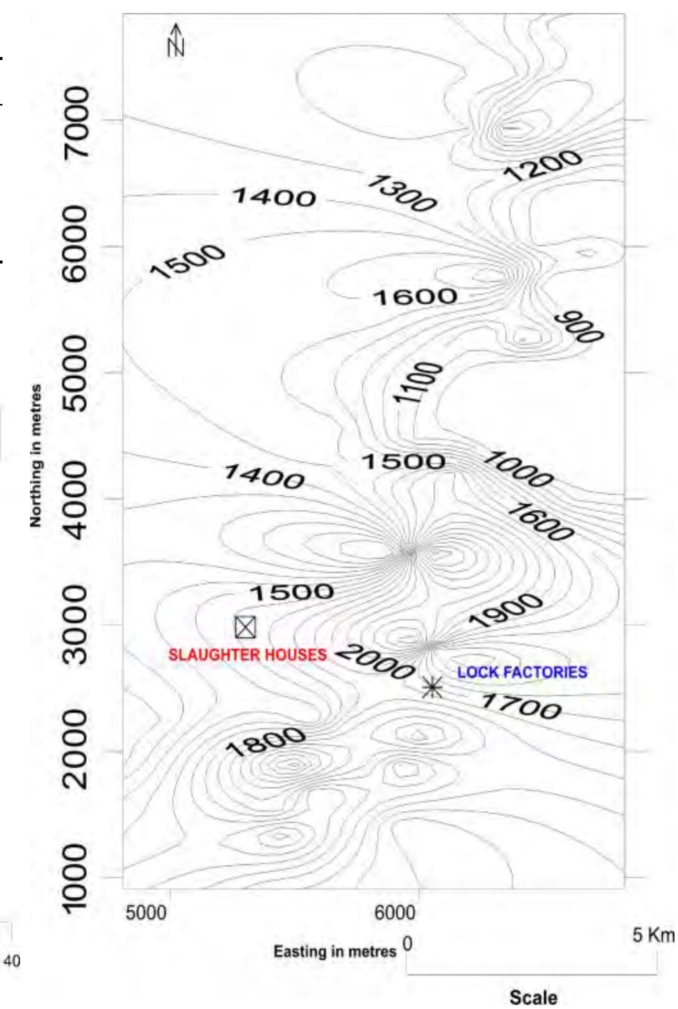

Fig. 7. Distribution of TDS in the Study Area

The TDS distribution map of the study area is shown in Fig. 7. From this map it is clear that very high TDS values can be observed in the areas falling in the vicinity of slaughter houses and lock factories. The TDS values above 1500 mg/l in south west of the study area make the involvement of anthropogenic activities certain.

7. Conclusions

Groundwater is immensely important for water supply in both the urban and rural areas of developing nations. The groundwater in the study area is slightly alkaline in nature. Based on total dissolved solids, about 72% of the groundwater samples are within the desirable limit and 23% are within the permissible limits of drinking water, but 5% are unsuitable for drinking as well as for irrigation. Primarily, groundwater in the area exhibits rock water dominance, but the unique characteristics can be well attributed to the combined effect of rock water interaction and anthropogenic activities. The classification of cation and anion facies in the triangular field of Piper diagram shows that majority of the groundwater samples fall into Magnesium and Sodium or Potassium type in cation facies and where as bicarbonate type seems to be the dominant anion facies with some samples falling in no dominant field. The trilinear plot in the piper diagram suggests that alkaline earths exceed alkalies, weak acids exceed strong acids. In the groundwater chemistry, the order of cation abundance is Na > Mg > K > Ca except in few samples where Mg replaces Cl and in anionic chemistry the order is $SO_4 > HCO_3 > CO_3 > Cl$.

The suitability of water for irrigation is evaluated based on %Na, SAR, P.I, K.R, Gibbs diagram, C.R, R.S.C and Salinity hazards. Gibb's diagram shows that the composition of water is rock dominance and some of the samples are evaporation crystallization dominance. On the basis of electrical conductivity values, sample no. 9 is not suitable for drinking as well as for irrigation activity, because excess salinity reduces the osmotic activity of plants. The Wilcox diagram reveals that majority of the samples fall in good to excellent and good to permissible categories except for some of the samples that belong to permissible to doubtful category. These generally give low crop yield due to presence of excess sodium salts which reduces the intake of soil nutrients. As per the SAR classification, all groundwater samples fall under safe category and are excellent for irrigation purpose. But as per RSC classification, 35% of the samples are unsuitable for irrigation purposes. The crop yields are low due to the continued usage of high residual sodium carbonate water for irrigation. Hence these soils require gypsum treatment to improve permeability of soils and better crop yield. The factors responsible for the declining quality of groundwater in Aligarh district are (1) dumping of large amount of wastes (acid) through boring by illegal lock factories, and (2) another most important pollutant source is the slaughterhouse (Kattigarh) where at least 2500 buffaloes are slaughtered daily, and because of percolation of blood, aquifer system is getting contaminated.

8. Acknowledgements

This work was carried out under M.Sc. project under kind supervision of Dr. Shadab Khurshid. One of the authors (SMW) gratefully acknowledges to the Chairman Dr. L A K Rao, Department of Geology, Aligarh Muslim University, for the facility provided to carry out this research work. Thanks are also due to Dr. Abu Talib and Dr. A H M Ahmad, Department of Geology, Aligarh Muslim University, (U.P.), for their encouragement while preparing this paper.

Reference

Adegbola, Adedayo Ayodele1, Adewoye and Abosede Olufunmilayo (2012) On investigating pollution of groundwater from Atenda Abattoir Wastes, Ogbomoso, Nigeria, *Interna Joun Engi Tech* **2(9)** 1569-1585

AL-Mutairi N Z (2006) Coagulant toxicity and effectiveness in a slaughterhouse wastewater treatment plant *Ecotoxic Environ Safe* **65** 74-83

APHA (1989, 1995) Standard methods for the examination of water and wastewater, 17th & 20th American Public Health

Association/American Water Works Association/Water Environment Federation, Washington DC, USA

Ayer R S and Bronson R L (1972) Guidelines for interpretation of water quality for Agriculture, University of California, Extension Monograph, 13

Back W (1966) Hydrochemical facies and groundwater flow patterns in the northern part of the Atlantic Coastal Plain. USGS Prof. Paper 498-A

Balasubamanian A (1986) Hydrogeological Investigation in the Tambrapani River basin, Tamilnadu, unpublished PhD thesis, University of Mysore 345

Benka-Coker M and Ojioro O (1995) Effect of slaughterhouse wastes on the water quality of Ikpoba River, Nigeria. *Bioresource Technol* **52** 5-12

Caixeta C E T, Cammarota M C and Xavier A M F (2002) Slaughterhouse wastewater treatment: valuation of a new three-phase separation system in an UASB reactor *Biores Technol* **81** 61-69

Datta P S and Tyagi S K (1996) Major ion chemistry of groundwater Delhi area: Chemical weathering processes and groundwater flow regime *Jour Geol Soc India* **47(2)** 179-188

Davis S N and Dewiest R J M (1966) Hydrogeology. Wiley, New York

Director of Census Operations (2001) District Census Handling of Uttar Pradesh, Census of India

Doneen L D (1962) The influence of crop and soil on percolating water proc. 1961 Biennial conference on Groundwater Recharge, 156-163

Drever J I (1982) The geochemistry of natural waters. Prentice-Hall, Englewood Cliffs, NJ. edn. and 19^{th} edn. American Public Health Association, Washington, DC

Faure G (1998) Principles and applications of geochemistry, 2nd edn. Prentice Hall, Englewood Cliffs, New Jersey

Fetter C W (1990) Applied Hydrogeology. 2^{nd} edn. Prentice Hall, Englewood Cliffs, New Jersey

Gibbs R J (1970) Mechanical controlling world's water chemistry Science **170** 10-1910

ISI (1991) Indian standard specification for Drinking Water. IS: 10500

Karanth K R (1987, 1989) Ground water assessment, development and management. Tata McGraw Hill, New Delhi, 720

Kelley W P (1951) Alkali soils - their formation properties and reclamation. Reinold Publ. Corp., New York

Kobya M, Senturk E and Bayramoglu M (2005) Treatment of poultry slaughterhouse wastewater by eletrocoagulation, *Jour Hazar Mater* **133** 172-176

Koech H K, Ogendi G M and Kipkemboi J (2012) Status of Treated Slaughter-House Efluent and its Effects on the Physico-Chemical Characteristics of Surface Water in Kavuthi Stream, Dagoretti-Kenya, *Rese Jour Enviro Ear Scie* **4(8)** 789-796

Piper A M (1953) A graphic procedure I the geo-chemical interpretation of water analysis, USGS Groundwater Note no, 12

Raju N J, Ram P and Dey S (2007) Hydrogeochemical parameters for assessment of groundwater quality in the upper Gunjanaeru River basin, Cuddapah district, Andhra Pradesh, south India. *Environ Geol* **52** 1067-1074

Ramakrishna (1998) Groundwater, Handbook, India, 556

Richards L A (1954) Diagnosis and improvement of saline and alkali soils. US Department of Agriculture Handbook 60

Saleh A, Al-Ruwaih F and Shehata M (1999) Hydrogeochemical processes operating within the main aquifers of Kuwait. *Jour Arid Environ* **42** 195-209

Sayed S K I, van der Zanden J, Wijffels R and Lettinga G (1988) Anaerobic degradation of the various fractions of slaughterhouse wastewater. *Biol Wastes* **23** 117-142

Umar R (1990) Aquifer system and groundwater resource potential of Ganga Kali Sub-basin in part of Aligarh, Etah Districts, U.P. (PhD Thesis) Aligarh Muslim Unievrsity, Aligarh, India

Umar R and Absar A (2003) Chemical characteristics of groundwater in parts of the Gambhir River basin, Bharatpur district, Rajasthan, India. *Environ Geol* **44** 535-544

Umar R and Ahmad M S (2000) Groundwater quality in parts of Central Ganga Basin, India. *Environ Geol* **39(6)** 673-678

Umar R and Ahmed I (2007) Hydrochemical characteristics of groundwater in parts of Krishni-Yamuna Basin, Muzaffarnagar district, UP. *Jour Geol Soc India* **69** 989-995

USEPA (2002a) Environmental assessment of proposed effluent limitations guidelines and standards for the meat and poultry products industry point source, EPA-821-B-01008, Office of Water, US Environmental Protection Agency, Washington, DC

USSL (1954) Diagnosis and Improvement of Saline and Alkali Soils. USDA Agr. Handbook No. 60, Washington, D.C.

Wilcox L V (1948) The quality of water for irrigation uses. US Department of Agriculture, Tech. Bull., 1962. Washington DC, 19

World Health Organization (1993) Guidelines for drinking Water quality, 2nd edition **1** 188.