International Journal of Research in Advent Technology, Vol.5, No.6, June 2017
E-ISSN: 2321-9637
Available online at www.ijrat.org

Hydrochemical Characterization and Assessment of Groundwater Quality in the Parts of Yamuna River Basin, Uttar Pradesh, India

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Abstract- A hydrogeochemical study has been carried out to assess the groundwater quality in parts of Yamuna river basin in and around Aligarh, Mathura and Agra districts. A total no. of 150 water samples were collected in which 144 from hand pumps and 6 from the bank of Yamuna river in post-monsoon 2015 and pre-monsoon 2016 respectively and analysed for pH, EC, TDS, Total Hardness, anions (Cl, HCO_3, CO_3, SO_4, F & NO_3) and cations (Ca, Mg, Na & K). In the post-monsoon period the order of major dominance of cations in groundwater are Na>Mg>K>Ca and the anions is Cl>HCO_3>SO_4>NO_3>CO_3>F and in the pre-monsoon period the order of major dominance of cations in groundwater are Na>Mg>K>Ca & the anions is Cl>SO_4>HCO_3>CO_3>NO_3>F. Important constituents that influence the water quality for irrigation are estimated using established methods like Electrical Conductivity (EC), Total Dissolved Solids (TDS), Sodium Percentage (Na%), Sodium Adsorption Ratio (SAR), Kelly Ratio (KR), Magnesium Adsorption Ratio (MAR), Permeability Index (PI), Chloroalkaline Indices (CAI), Bicarbonate Hazards (BH) and Residual Sodium Carbonate (RSC) .Most of the samples have exceeded the critical levels of irrigation water indices. Nitrate concentration in the Post-monsoon is high as compare to the pre-monsoon period. High concentration of nitrate indicating the anthropogenic influences. Present investigation has revealed that the groundwater of the study area is potable, hard, alkaline, and moderately mineralized and alkali chloride type. Saline nature of the groundwater in study area is attributed to evaporation from water table, irrigation return flow and anthropogenic activities. Anthropogenic contributions from agricultural and domestic sources and weathering of rock forming minerals control the hydrochemistry of the area.

Keywords: Hydrogeochemistry, Groundwater Quality, Irrigation, Yamuna River Basin, Uttar Pradesh

1. INTRODUCTION

Groundwater is the prime natural resource and precious national asset. It is major source of water for drinking, irrigation, and industrial uses in many arid and semiarid regions of the world. Groundwater quality has become an important water resource issue due to rapid increase of population, industrialization and urbanization, flow of pollution from upland to low land, and excessive use of fertilizers and pesticides in agriculture [16]. Water quality is influenced by natural and anthropogenic effects including local climate, geology and irrigation practices. Once undesirable constituents enter the ground, it is difficult to control their dissolution. The chemical characteristics of groundwater play an important role in classifying and assessing water quality. Many naturally occurring major, minor and trace elements in drinking water can have a significant effect on human health either through deficiency or excessive intake [13]. Hence understanding of the process that control the water quality is needed towards the aim of water quality control and improvement [15] [41]. Adverse quality conditions increase the investment in irrigation and health, as well as decrease agricultural production. Access to safe drinking water remains an urgent necessity, as 30% of urban and 90% of the rural Indian population still depend completely on untreated surface or groundwater resources [26]. While access to drinking water in India has increased over the past decades, the tremendous adverse impact of unsafe water on health continues. It is estimated that about 21% of the communicable diseases in India are water borne [6]. Scarcity of clean and potable water has emerged in recent years as one of the most serious development

issues in many parts of West Bengal, Jharkhand, Orissa, Western Uttar Pradesh, Andhra Pradesh, Rajasthan and Punjab [42]. India is gifted by nature with a large number of major rivers. There is an extreme disparity in the distribution of water resources spatially and temporally in these river basins due to unequal precipitation. The Indo-gangetic plain is the largest alluvial plain of the world, which has been formed by deposition of terrigenous clastic sediments through the streams of Indus, Ganga and Brahmaputra river system [40]. The Ganga plain makes the central part of this alluvial plain. The Yamuna river sub-basin makes the western part of the Ganga basin which forms an important groundwater province of India. 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 [45]. Several studies have been carried out on groundwater pollution, groundwater resource potential and chemical quality of water in Yamuna basin [23] [24] [25] [22] [28] [46] [47] [21]. In the present study, an attempt has been made to decipher the chemical variations in groundwater under various natural and anthropogenic influences and to assess its suitability for agricultural and domestic use. Aim of the study to identify various hydrochemical processes that regulate the quality of groundwater. Conventional graphical representation were applied to assess the groundwater quality and to classify the groundwater of the area into distinct groups.

2. STUDY AREA

The study area is in the drainage basin of Yamuna River in and around Aligarh, Mathura and Agra districts, UP, India. It covers an area of 2808 Km^2 (Fig.1) and lies between latitudes 27˚5′ 0" N to 27˚45′ 0" N and longitudes 77˚40′ 0" E to 78˚0′ 0" E and falls in Survey of India toposheet no. 54E/10, 11, 12 and 14, 15, 16 on 1:50,000 scale. In the study area two Ganga canal is found in which one is found on NE side and second is flowing from north to south in middle of the area and Agra canal is also found which is flowing NW to SE. These canals also feed the groundwater of the study area. Yamuna river traverses through the Geophysical control of the district in the direction from north to south and divides it into two physical units – the eastern or trans Yamuna and the western or cis- Yamuna tract except few scattered low hills, occurring near the Bharatpur border, the entire area is fairly flat, generally sloping towards south. The average annual rainfall is 620 mm. The climate is sub-tropical humid and it is characterised by a hot dry summer and a pleasant cold season. About 88% of rainfall takes place from June to September. During the monsoon surplus water is available for deep percolation to ground water. January is the coldest month. With the mean daily minimum temperature at about 7^0C and May is the hottest month with mean daily maximum temperature 42^0C and mean daily minimum temperature at 26^0C with the onset of the monsoon, day temperature dropdown appreciably. The soils of the study area which forms a part of the Indo-Gangetic alluvium (consisting of sand, clay, kankar and reh) have remarkable diversities in different parts. Mainly three types of soils, namely Silty soil, Sandy soil and Loamy soil are found in the area. The clay, kankar (calcareous concretion) and Reh (saline efflorescence) are also predominating. The Rabi, Kharif and Jayed are the main cropping seasons of the area. The Wheat, Barley, Gram, Pea are the main Rabi crops, whereas the Paddy, Jwar, Bajra, Corn & Groundnut are the main Kharif crops. Some Jayed crops are Urad, Moong, Sawan and Corn. Other important crops of the area are Sugarcane, Arhar, Sun Flower and Soyabeen. These crops are cultivated mainly by using the natural rain water and available surface and groundwater.

3. GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The study area occupies a part of Indo-Gangetic plain and its major part is underlain by alluvial sediments of Quaternary age comprising mainly a sequence of clay, silt, sand of different grades, gravels and kankar in varying proportions. The alluvium was deposited over the slopes of the basement of Vindhyan rocks e.g. sand stone, shale, silt stone etc. The study area is mostly covered by a thick pile of Quaternary sediments with restricted patches of outcrops of Vindhyan Supergroup. Vindhyan Supergroup consists of rocks of Bhander group, which includes white to purple quartz arenite, medium to fine grained purplish to reddish spotted and laminated sandstone with inter mittent partings of shales, shale pebble conglomerate, siltstone and greenish sandstone. This Vindhyan Supergroup belongs to Proterozoic-III age (Table.1), [7].

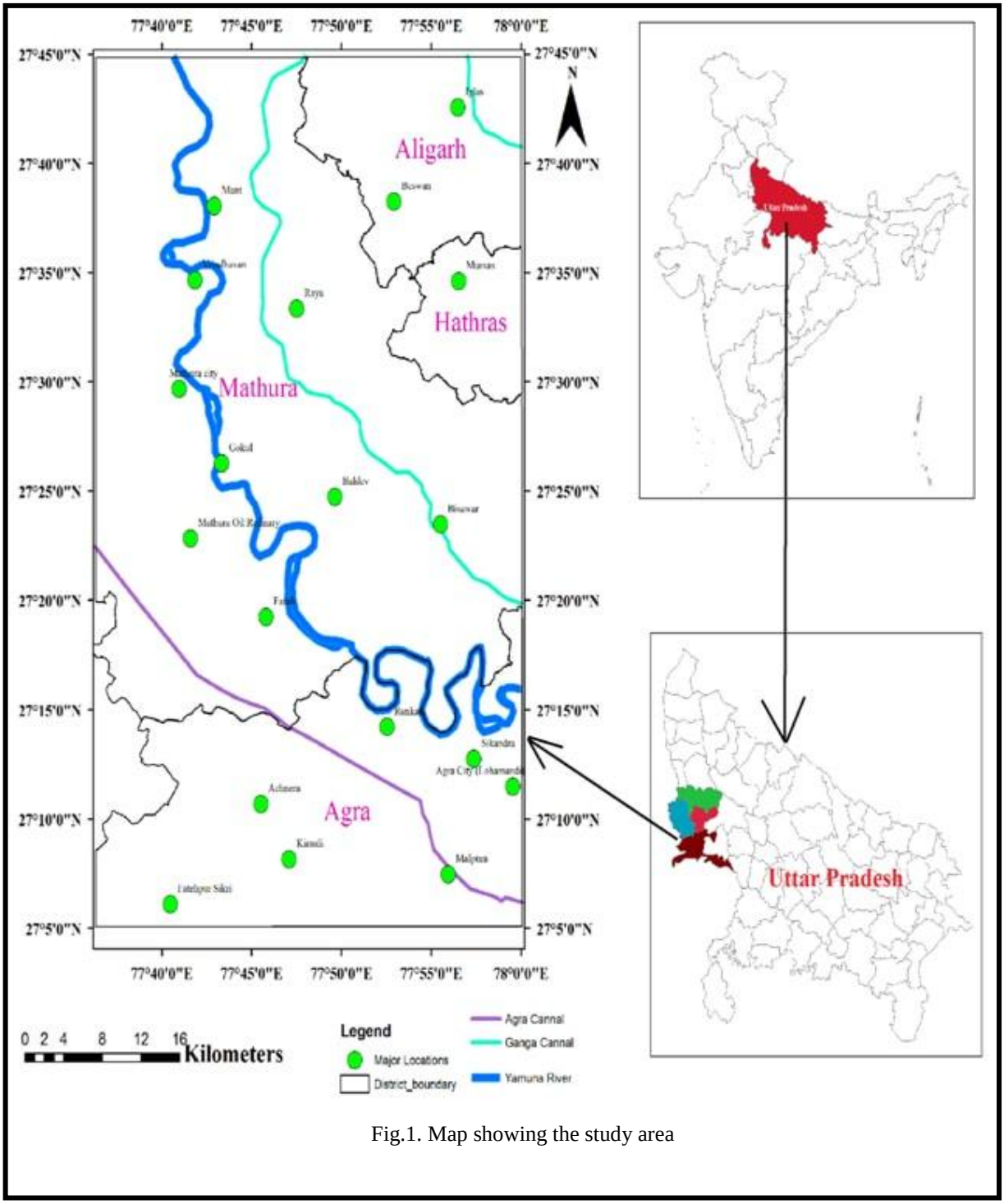


Fig.1. Map showing the study area

Table.1 The generalized geological succession of the study area

Group	Age	Formation	Lithology
Quaternary	Holocene	Newer Alluvium	Fine to medium grained micaceous sand with sub-ordinate silt & clay
	Middle to Late Pleistocene	Older Alluvium (Varansi Alluvium)	Oxidised, Khaki to brownish yellow silt, clay with kankar disseminations, and grey to brown fine to medium grained sand
----------Unconformity----------			
Proterozoic-III	Vindhyan Supergroup		Upper Bhander sandstone with shale, siltstone, shale pebble conglomerate.

The shallow aquifer group occurs down to depth of 50.0 mbgl where as deep aquifers group exist between the depth ranges of 135 - 185 mbgl. The aquifer material is generally composed of fine to medium grained sand. Kankars are invariably associated with sand and clay in older alluvium plain. Ground water occurs under unconfined to semi-confined conditions in the shallow aquifer group and semiconfined to confined condition in the deep aquifer group. The phreatic or water table aquifers are mainly recharged by rainfall, and seepage from surface water bodies viz. canals, lakes and ponds etc. The withdrawal of ground water from these aquifers is mainly made through the shallow tubewells of cavity/strainer type, borings, hand pumps and dug wells etc. The base flow of the perennial rivers/tributaries and the water requirements of the deep-rooted phreatophitic plants are also met by this upper most phreatic aquifer system. The unconfined aquifers are comparatively more sensitive to the seasonal and environmental changes [8].

4. METHODOLOGY

A total number of 150 water samples were collected from the study area (Fig. 2) for physico-chemical analysis in two successive post and pre-monsoon seasons corresponding to November 2015 and May 2016 to understand the chemical variations of the groundwater. Prior to sampling the wells were pumped for about three to five minutes. Polyethylene bottles of one litre capacity were used for collecting the water samples. The samples were analysed as per the standard methods of APHA [1]. EC and pH were measured by precalibrated portable conductivity and pH meters. TDS values were calculated from EC by conversion factor. Total hardness and Ca^{+2} were calculated by EDTA titrimetric method. Mg^{+2} is calculated by the difference of hardness and calcium. Values of CO_3^- and HCO_3^- were also determined by titration. Chloride was determined by titration with $AgNO_3$ solution. SO_4^{-2} values were determined by gravimetric method, Na^+ & K^+ by Flame Emission Photometry and NO_3^- by colorimetric method. SPADNS method was used to determine F^- concentration in water samples. The results of chemical analyses of groundwater of study area are given in (Table 2, Table 3).

5. RESULT AND DISCUSSION

In water resource management, water quality is as significant as the quantity of water. Ranges of chemical parameters in groundwater of study area and their comparison with BIS [4] and WHO [49] standards are presented in Table 4.

5.1 Classification of Groundwater

Groundwater classification is done for the characterization of chemical composition of groundwater. Composition of groundwater depends on the type of rocks and soil present in the area. Rainwater percolation through the soil zones and unsaturated rock material chemically reacts with the gases, minerals and water present in the aquifer. The characteristics and composition evolve as it flows through different types of soil and gas phases. The hydrochemical investigation of the groundwater provides information about the source and extent of groundwater pollution and determines its utility for various purposes [48]. Various classification schemes have been proposed for surface and groundwater. In the present study, the groundwater of the area is classified on the basis of Piper's trilinear and Gibb's diagram.

5.1.1 Piper's Trilinear Diagram

Hydrochemical facies were classified on the basis of dominant ions using the Piper's trilinear diagrams [32] and to plots to determine the water type of the study area.

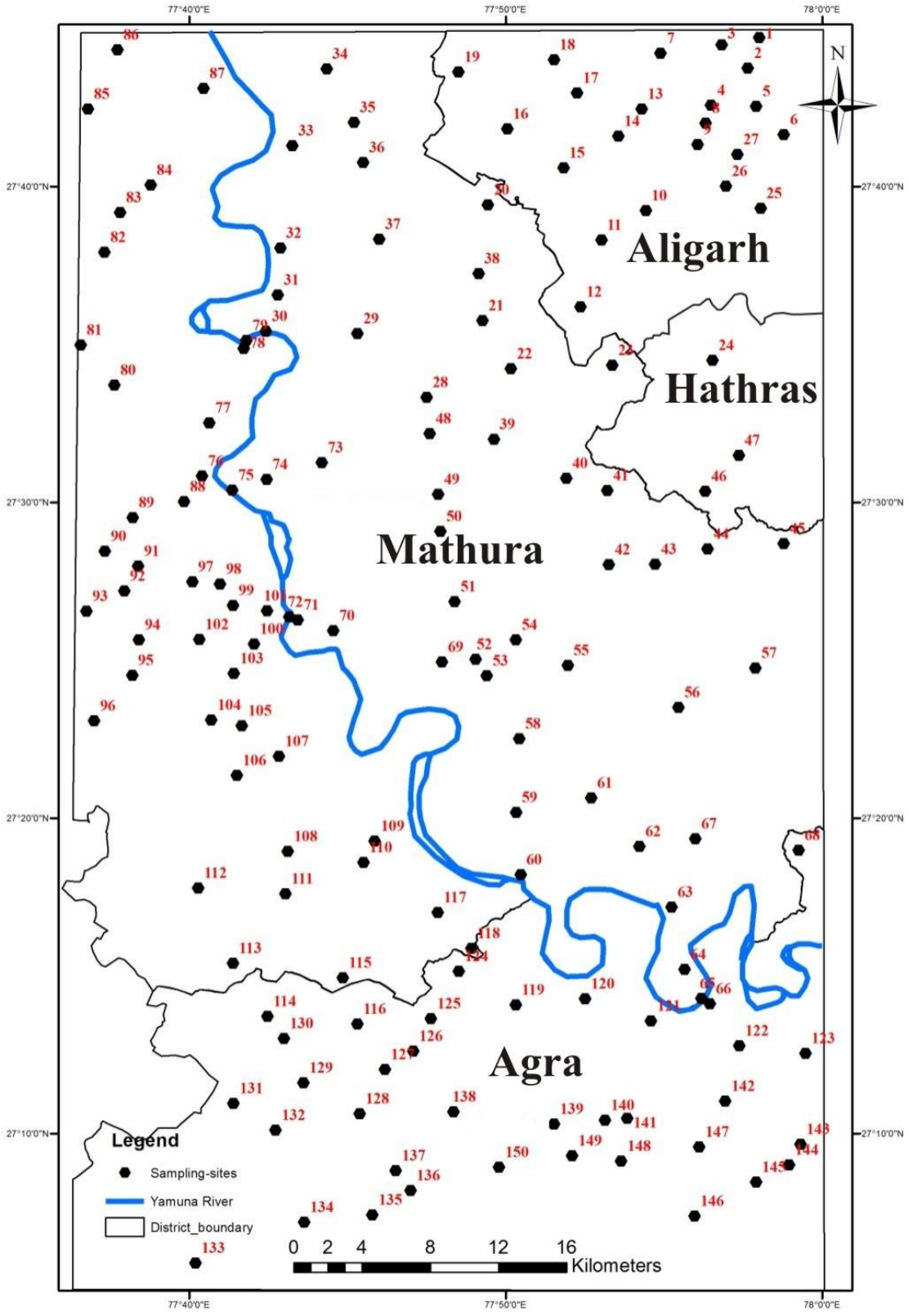


Fig.2. Map showing the sampling locations of the study area

Table. 2 Geochemical analysis of water samples of the study area, Post-monsoon 2015

S.No.	Locations	Source	Ph	Ec	TDS	TH	Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	Cl^{-}	SO_4^{-2}	CO_3^{-2}	HCO_3^{-}	F^{-}	NO_3^{-}
1	Sahara Kalan	(HP)	9.1	400	260	172	212	40	25.7	26.3	14.2	297	0	325	1.04	46.2
2	Tehra	(HP)	9.2	300	195	180	84	35	43.3	17.5	17.0	275	52	208	0.77	22.6
3	Gindauli	(DHP)	9.3	500	325	260	212	40	35.3	41.9	14.2	344	0	455	0.38	26.2
4	Iglas Chauraha	(HP)	9.3	600	390	264	240	42	28.9	46.8	34.1	329	0	481	1.01	33.0
5	Byauhara	(HP)	9.1	500	325	312	184	38	33.7	55.6	14.2	299	52	390	0.71	37.0
6	Khedia Gurdev	(HP)	9.3	400	260	224	168	37	32.1	35.1	14.2	216	52	273	1.32	41.1
7	Kamalpur	(HP)	9.3	700	455	312	268	40	20.8	63.4	65.3	230	0	507	0.85	30.2
8	Lalpur	(DHP)	9.4	700	455	172	272	43	11.2	35.1	68.2	280	78	273	0.74	34.0
9	Nagla Heera	(DHP)	8.9	2000	1300	480	380	57	19.2	105	375	729	0	572	1.20	45.0
10	Mohkampur	(HP)	9.2	1600	1040	336	368	49	16.0	72.1	256	430	0	663	1.52	32.7
11	Beswan	(HP)	8.7	700	455	268	252	62	70.5	22.4	114	408	0	390	0.29	21.6
12	Sathini	(HP)	8.9	2100	1365	656	380	51	65.7	120	432	581	0	520	0.68	37.5
13	Matroi	(HP)	9.3	600	390	188	256	40	30.5	27.3	19.9	314	0	429	1.26	27.8
14	Harautha	(DHP)	9.3	1300	845	236	352	52	28.9	40.0	119	390	52	559	1.46	34.7
15	Tamutiya	(DHP)	8.7	1900	1235	780	348	70	57.7	155	381	482	0	546	0.75	42.0
16	Gorai	(HP)	8.7	5100	3315	960	760	800	27.3	217	1037	1155	0	819	1.04	113
17	Jatwar	(DHP)	9.2	2800	1820	672	600	81	86.6	111	452	678	26	832	1.43	72.6
18	Khirsaulit	(HP)	9.1	1300	845	344	340	50	16.0	74.1	159	330	52	520	1.49	28.9
19	Jamau	(DHP)	9.2	4200	2730	788	1080	67	20.8	179	897	1187	52	702	0.98	27.4
20	Nimgaon	(HP)	8.4	4800	3120	1504	760	70	164	267	1346	1507	0	221	0.62	23.5
21	Aithakhera	(HP)	9.2	1000	650	200	332	42	54.5	15.6	85.2	235	39	572	1.69	47.7
22	Birhana	(DHP)	9.3	500	325	184	59	34	28.9	27.3	17.0	141	26	182	1.10	24.2
23	Sonai	(HP)	9.0	1400	910	456	320	65	35.3	89.7	216	222	33.8	603	1.30	38.3
24	Mursan	(HP)	8.7	3100	2015	688	380	59	32.1	148	625	488	0	624	0.73	159
25	Karas	(HP)	9.3	1000	650	324	292	45	68.9	37.0	99.4	208	0	572	0.65	48.2
26	Sikura	(HP)	9.1	500	325	240	200	41	44.9	31.2	42.6	80.5	0	312	0.42	26.5
27	Kajrauth	(HP)	9.3	700	455	184	268	48	25.7	29.2	45.4	199	0	481	0.84	48.4
28	Raya	(HP)	8.3	4100	2665	1300	324	664	46.5	289	702	890	0	689	0.82	164
29	Piprauli	(HP)	9.2	1200	780	236	312	51	44.9	30.2	128	356	0	637	1.30	38.1
30	Keshi ghat	(YR)	9.0	1600	1040	356	316	68	78.6	39.0	293	308	0	377	0.59	64.8

31	Dangauli	(HP)	9.1	1300	845	320	300	98	52.9	45.8	179	498	0	351	0.51	27.2
32	Mant	(HP)	8.6	2600	1690	820	608	96	111	133	517	692	0	611	0.52	124
33	Bhadravan	(HP)	8.1	5600	3640	2160	972	68	244	378	1832	736	0	468	1.41	21.6
34	Taintigaon	(HP)	8.3	6500	4225	1976	1360	300	97.8	422	1318	2447	0	507	1.12	161
35	Harnol	(DHP)	9.4	700	455	132	212	100	20.8	19.5	31.2	219	26	299	1.01	36.6
36	Naseethi	(HP)	9.5	700	455	204	264	40	20.8	37.0	17.0	308	65	390	1.52	23.5
37	Jabra	(DHP)	8.9	900	585	404	228	42	16.0	88.7	148	274	0	429	0.84	21.6
38	Andua	(HP)	9.1	600	390	228	212	75	16.0	45.8	39.8	204	39	429	0.68	33.4
39	Madem	(HP)	8.6	1400	910	288	256	90	33.7	49.7	301	329	0	260	0.28	20.5
40	Nunera	(HP)	8.3	5200	3380	1220	1296	71	36.9	275	1420	1252	0	754	0.75	34.5
41	Anora	(DHP)	9.1	900	585	256	260	38	25.7	46.8	96.6	316	0	403	1.13	21.4
42	Jugsana	(DHP)	9.3	1900	1235	388	324	316	22.4	80.9	230	488	104	559	1.25	35.7
43	Baltigarhi	(HP)	8.0	7200	4680	2500	760	260	86.6	557	2414	2169	0	611	0.68	25.7
44	Unchagaon	(HP)	8.2	3700	2405	1152	372	368	125	205	676	878	0	494	0.62	178
45	Kajrauti	(HP)	8.4	5200	3380	1480	792	100	89.8	306	1397	1279	0	585	0.95	131
46	Khutipuri	(HP)	9.1	500	325	332	64	40	64.1	41.9	39.8	177	52	338	0.61	36.2
47	Siyamal	(HP)	8.5	4200	2730	1052	768	170	96.2	198	1040	284	0	455	0.39	38.7
48	Siyara	(DHP)	9.5	1400	910	256	344	42	16.0	52.6	142	351	130	585	1.62	34.9
49	Dharampura	(HP)	9.5	1000	650	116	312	41	12.8	20.5	68.2	178	78	507	1.41	23.5
50	Karab	(HP)	9.4	2900	1885	540	380	384	46.5	103	625	496	104	689	1.40	25.7
51	Bandi	(HP)	9.3	6300	4095	504	1520	65	38.5	99.4	1903	1082	130	689	1.66	27.2
52	Baldev Chauraha	(HP)	9.0	400	260	224	45	37	46.5	26.3	31.3	261	0	273	0.74	20.1
53	Dauji Mandir Baldev	(HP)	9.3	1000	650	180	304	50	32.1	24.4	85.2	406	0	572	0.83	31.3
54	Awerni	(HP)	8.3	8400	5460	2624	1520	284	233	498	3221	201	0	520	1.04	39.0
55	Artauni	(DHP)	9.5	4100	2665	512	1008	320	25.7	109	568	149	78	923	0.79	45.0
56	Bisawar	(HP)	9.3	1500	975	368	320	49	38.5	66.3	244	229	0	572	0.65	25.0
57	Nagla tikait	(HP)	8.7	3000	1950	808	680	59	22.4	183	625	182	52	832	0.55	107
58	Angai	(HP)	9.1	2800	1820	148	260	45	25.7	20.5	99.4	199	0	481	0.89	26.0
59	Madhura	(HP)	8.9	900	585	136	780	168	25.7	17.5	710	282	0	416	0.93	6.8
60	Kanjaulighat	(YR)	9.2	1100	715	496	288	55	17.6	110	880	213	0	676	1.01	4.1
61	Barauli	(HP)	8.9	2300	1495	100	320	93	22.4	10.7	111	257	0	364	1.21	20.0
62	Sarai salbhan	(HP)	9.3	1100	715	644	592	82	93.0	100	216	141	0	741	0.72	17.4

63	Badam garhi	(HP)	8.5	1000	650	444	544	65	85.0	56.5	142	237	0	546	0.92	16.9
64	Sehat	(DHP)	8.8	500	325	224	260	37	27.3	38.0	284	78.3	0	247	1.37	11.3
65	Kailash mandir (near sikandra)	(YR)	8.6	1600	1040	490	306	56	56.2	101	536	75.3	0	454	1.91	26.3
66	Kailash mandir (near sikandra)	(HP)	8.4	1800	1170	220	356	42	25.2	70.5	411	114	0	308	0.56	47.2
67	Midhawali	(HP)	9.0	3900	2535	820	260	70	36.9	177	71.0	199	0	312	0.81	25.5
68	Sorai	(HP)	8.8	3100	2015	1052	312	85	46.5	228	134	209	0	377	1.02	21.1
69	Hataura	(HP)	9.5	2600	1690	192	720	52	17.6	36.1	284	198	104	1235	1.64	4.6
70	Mahaban	(HP)	8.5	3000	1950	232	396	57	52.9	24.4	1065	273	0	494	0.83	6.7
71	Gokul	(DHP)	8.9	1700	1105	584	304	85	93.0	85.8	440	171	0	676	0.68	34.3
72	Gokul	(YR)	9.1	1700	1105	540	300	67	68.9	89.7	335	213	0	390	0.55	67.2
73	Gausna	(DHP)	8.2	5700	3705	1860	736	82	83.4	403	1926	1093	0	468	1.12	30.0
74	Laxminagar	(HP)	8.8	3000	1950	780	368	53	17.6	179	693	725	104	312	0.59	70.6
75	Vishram Ghat	(YR)	9.1	1700	1105	420	304	68	78.6	54.6	426	308	0	377	1.28	40.6
76	Masani	(HP)	9.1	1900	1235	404	340	50	30.5	79.9	483	612	0	377	0.65	41.0
77	Ahilyaganj	(HP)	8.8	3400	2210	948	400	52	14.4	222	1008	732	0	494	1.31	42.8
78	Cheerharan Ghat Vrindhaban	(HP)	8.7	1100	715	300	260	60	14.4	64.3	312	325	0	429	0.52	9.7
79	Cheerharan Ghat Vrindhaban	(YR)	9.0	1600	1040	428	272	68	72.1	60.4	440	402	0	754	1.04	42.5
80	Chattikara	(HP)	8.8	4100	2665	1084	972	57	17.6	253	1406	480	0	754	0.90	35.7
81	Jait	(HP)	8.5	3000	1950	1480	380	70	104	297	1065	283	0	845	1.21	16.9
82	Parkham	(DHP)	8.9	2100	1365	820	340	48	46.5	172	625	486	0	403	1.15	36.6
83	Nagla mauji	(DHP)	7.8	2800	1820	2075	392	41	105	383	1209	1605	0	432	1.42	12.8
84	Sei	(HP)	8.5	4800	3120	1428	1020	70	36.9	326	1647	1206	0	559	1.12	36.2
85	Naugaon	(HP)	9.0	1000	650	440	268	47	16.0	97.5	213	382	26	429	0.71	8.2
86	Agraila	(HP)	9.5	1700	1105	296	624	48	20.8	59.5	284	391	52	832	1.67	2.4
87	Gangrauli	(HP)	8.7	2000	1300	400	406	34	25.0	104	892	431	0	542	1.61	15.8
88	Krishna Nagar Chauraha	(HP)	8.8	2200	1430	624	348	75	19.2	140	554	653	0	650	1.27	31.7
89	Girdharpur	(HP)	8.8	1800	1170	892	292	62	38.5	194	497	484	0	325	1.15	62.3
90	Naugawan	(HP)	8.2	5300	3445	1872	936	324	112	388	1917	702	0	572	1.20	84.8
91	Salempur	(HP)	8.7	3900	2535	1224	960	64	27.3	282	1434	913	0	585	1.27	17.8
92	Mukandpur	(HP)	8.6	2900	1885	896	852	56	19.2	207	880	810	0	663	0.81	2.5
93	Usphar	(HP)	8.5	2900	1885	1216	372	248	22.4	283	880	807	0	663	1.14	4.0
94	Tarsi	(HP)	8.4	6400	4160	1460	984	784	135	274	2229	1530	0	793	1.10	45.2

95	Mudhesi	(HP)	7.9	9500	6175	3792	2280	91	77.0	877	4658	924	0	884	1.62	45.0
96	Kosi khurd	(DHP)	8.1	9500	6175	2900	2112	672	101	645	4260	865	0	689	1.59	16.5
97	Narauli	(HP)	9.0	2300	1495	424	396	52	22.4	89.7	639	558	52	377	1.24	7.2
98	Birjapur	(HP)	8.5	2100	1365	532	344	55	22.4	116	753	65.2	0	455	0.78	2.4
99	Nawada	(HP)	9.3	800	520	152	336	43	20.8	24.4	142	105	104	377	1.38	0.4
100	Ronchi banger	(DHP)	8.9	1900	1235	624	360	64	20.9	139	554	625	78	429	1.46	2.2
101	Aurangabad	(HP)	9.3	500	325	136	256	41	24.1	18.5	71.0	250	26	325	1.92	8.6
102	Aduki	(HP)	9.2	1300	845	124	296	32	38.5	6.8	1604	213	78	364	1.20	19.7
103	Bad	(HP)	8.8	7000	4550	456	336	38	44.9	83.8	369	877	52	351	1.45	9.0
104	Bhainsa	(DHP)	9.1	1600	1040	128	936	62	27.3	14.6	554	378	0	910	1.35	18.3
105	Mathura Refinary	(DHP)	9.5	2900	1885	176	1008	56	17.6	32.2	611	588	156	767	1.87	16.3
106	Dhana Shamsabad	(HP)	8.2	1500	975	892	1056	55	51.3	186	1647	344	0	546	1.10	6.7
107	Barari	(HP)	8.5	5100	3315	968	1140	63	33.7	215	1889	913	0	689	1.74	5.1
108	Sanaura	(HP)	8.6	2600	1690	1824	960	65	72.1	401	1974	294	0	364	1.30	13.4
109	Farah	(HP)	8.1	5500	3575	2092	1008	82	200	388	2599	625	0	260	0.83	17.4
110	Chandravan	(HP)	8.2	3700	2405	1672	760	95	168	305	2244	391	0	156	0.99	40.5
111	Jamalpur	(HP)	8.5	1600	1040	736	680	75	62.5	141	1491	274	0	156	0.81	15.3
112	Dhana jiwna	(HP)	8.9	3000	1950	820	360	83	25.7	184	994	382	0	494	0.96	8.9
113	Jurawai	(DHP)	8.3	6500	4225	1084	328	92	52.9	232	2371	141	0	598	1.20	2.6
114	Sandhan	(DHP)	8.7	2800	1820	916	300	75	123	148	2002	499	0	442	1.11	17.2
115	Baroda	(HP)	8.5	1600	1040	532	256	43	20.8	92.6	428	102	52	506	0.74	44.6
116	Aganpura	(HP)	8.8	2800	1820	876	924	52	81.6	208	1856	231	0	574	1.61	12.4
117	Shahzadpur	(HP)	8.7	2500	1625	1112	344	224	49.7	241	753	569	0	624	1.14	57.7
118	Rajpura Jat	(DHP)	9.0	3900	2535	748	1020	60	11.2	175	1392	545	0	780	1.20	4.0
119	Arsena	(DHP)	8.5	5000	3250	836	1152	64	38.5	180	1906	119	0	468	1.54	4.5
120	Runakta	(HP)	7.9	3500	2275	408	924	51	30.6	195	428	278	0	478	1.84	6.8
121	Atrauni	(HP)	9.0	1400	910	636	300	47	22.4	141	355	151	52	611	1.58	7.7
122	Sikandra	(HP)	9.2	1400	910	300	360	50	19.2	61.4	298	116	78	455	1.06	6.8
123	Transport Nagar	(HP)	8.6	2400	1560	784	816	58	35.3	170	738	156	0	624	1.07	8.7
124	Kitham	(DHP)	8.6	2400	1560	968	352	54	16.0	226	994	132	0	338	1.74	4.6
125	Mai	(HP)	9.3	1400	910	448	336	50	17.6	98.4	355	490	104	351	1.52	21.8
126	Nanau	(DHP)	9.2	3100	2015	540	1032	56	17.6	121	809	313	0	715	1.71	1.8

127	Kachora	(HP)	8.2	3700	2405	1108	352	260	136	187	1420	650	0	429	0.81	9.6
128	Achnera	(HP)	8.4	6600	4290	2408	1152	70	101	525	3067	467	0	520	1.57	3.0
129	Arua khas	(HP)	8.5	7700	5005	980	672	180	122	165	2045	527	0	429	0.85	8.4
130	Fatehpura	(HP)	9.0	900	585	804	384	86	107	131	1590	294	0	585	0.95	4.6
131	Turkio	(DHP)	8.9	2500	1625	1020	768	70	83.4	198	1661	494	0	351	0.99	13.1
132	Biara	(HP)	8.3	5600	3640	1800	984	62	86.6	386	2726	628	0	325	1.18	9.0
133	Fatehpur sikri	(HP)	8.1	7300	4745	2260	1944	95	162	452	2556	1189	0	546	1.30	109
134	Korai	(HP)	9.0	3400	2210	752	984	62	96.2	125	951	413	0	741	1.02	13.4
135	Bidyapur	(HP)	9.2	5000	3250	764	1032	80	56.1	152	1264	387	0	546	0.85	11.0
136	Kiraoli	(DHP)	9.3	4000	2600	800	1080	100	43.3	169	1306	364	78	611	0.79	10.6
137	Puramana	(DHP)	8.7	3600	2340	1472	1104	82	83.4	308	1264	343	0	585	1.28	6.8
138	Raiba	(HP)	9.1	3800	2470	924	1032	81	9.6	219	1207	641	52	871	1.78	25.7
139	Sahai	(HP)	9.6	2400	1560	500	924	56	4.8	119	412	150	104	975	1.32	7.4
140	Anguthi	(HP)	9.1	2300	1495	396	246	51	35.7	98.5	432	201	0	324	0.73	10.4
141	Bichpuri	(HP)	9.0	700	455	440	220	43	54.5	74.1	185	165	0	377	1.10	11.7
142	Amarpura	(HP)	8.1	3600	2340	1464	936	70	96.2	298	1250	89.2	0	832	1.11	72.0
143	Rasoolpur	(HP)	9.3	2100	1365	392	816	228	14.4	86.7	412	365	52	624	1.42	83.5
144	Naripura	(HP)	8.4	3100	2015	848	924	65	48.1	177	980	348	0	533	0.78	67.6
145	Dhanauli	(HP)	9.4	3100	2015	420	2016	59	22.4	88.7	667	276	52	923	1.75	6.5
146	Malpura	(HP)	9.4	1200	780	212	320	45	25.7	36.1	241	127	52	260	1.73	14.5
147	Pathauli	(HP)	8.5	3200	2080	1336	300	100	33.7	305	838	229	78	624	1.15	82.8
148	Sahara	(HP)	9.4	5100	3315	388	1080	66	14.4	85.8	1448	390	104	767	1.78	2.2
149	Midhakur	(HP)	9.5	6100	3965	616	2160	65	41.7	125	1392	124	182	1313	1.64	2.1
150	Mahuar	(HP)	9.2	4200	2730	608	1104	62	12.8	140	1292	119	78	936	1.50	21.3

Table. 3 Geochemical analysis of water samples of the study area, Pre-monsoon 2016

S.No.	Locations	Source	Ph	Ec	TDS	TH	Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	Cl^{-}	SO_4^{-2}	CO_3^{-2}	HCO_3^{-}	F^{-}	$NO3^{-}$
1	Sahara Kalan	(HP)	8.5	400	260	160	212	33	25.7	23.4	85.2	90.6	52	195	1.49	13.4
2	Tehra	(HP)	8.3	300	195	128	188	28	28.9	13.6	56.8	168	26	208	1.67	0.7
3	Gindauli	(DHP)	7.7	1200	780	216	288	90	16.0	42.9	156	134	52	377	0.88	0.7
4	Iglas Chauraha	(HP)	8.1	700	455	144	268	36	8.0	30.2	71.0	93.7	104	338	1.34	11.4
5	Byauhara	(HP)	8.3	400	260	168	172	30	27.3	24.4	85.2	94.0	26	208	1.52	7.2
6	Khedia Gurdev	(HP)	8.2	700	455	168	212	35	8.0	36.1	85.2	97.3	104	273	1.68	7.8
7	Kamalpur	(HP)	8.0	3200	2080	416	664	53	12.8	93.6	554	1146	52	507	1.35	7.6
8	Lalpur	(DHP)	7.8	800	520	144	268	33	14.4	26.3	114	99.1	104	273	1.1	14.0
9	Nagla Heera	(DHP)	7.6	2400	1560	352	308	49	16.0	76.0	454	584	52	364	1.31	13.3
10	Mohkampur	(HP)	8.0	1400	910	236	344	40	52.9	25.3	241	371	52	403	1.26	8.3
11	Beswan	(HP)	7.9	2100	1365	220	592	47	12.8	45.8	341	363	78	494	1.85	2.1
12	Sathini	(HP)	8.6	400	260	212	180	41	27.3	35.1	71.0	120	78	169	1.67	1.1
13	Matroi	(HP)	8.0	2300	1495	424	320	49	16.0	93.6	426	818	78	182	1.32	16.1
14	Harautha	(DHP)	8.0	2500	1625	392	356	94	6.4	91.6	369	668	156	507	1.55	61.9
15	Tamutiya	(DHP)	7.5	6000	3900	2304	1440	156	62.5	523	1789	2405	0	169	0.88	45.5
16	Gorai	(HP)	8.2	1400	910	248	332	73	14.4	51.7	227	367	52	260	1.02	11.7
17	Jatwar	(DHP)	8.2	2400	1560	408	360	47	11.2	92.6	383	616	104	546	2.12	25.9
18	Khirsaulit	(HP)	8.3	1200	780	156	284	40	11.2	31.2	185	192	130	312	2.11	19.7
19	Jamau	(DHP)	7.8	5000	3250	648	768	75	17.6	147	852	2090	78	585	1.65	30.3
20	Nimgaon	(HP)	8.2	1800	1170	408	364	53	8.0	94.5	270	530	78	403	1.56	9.4
21	Aithakhera	(HP)	7.8	1200	780	184	308	43	16.0	35.1	170	170	78	312	0.85	9.1
22	Birhana	(DHP)	8.0	2100	1365	256	356	38	9.6	56.5	383	240	156	572	0.96	5.9
23	Sonai	(HP)	7.5	3100	2015	660	732	86	14.4	152	682	698	130	273	0.77	34.2
24	Mursan	(HP)	7.6	2900	1885	432	648	47	12.8	97.5	582	730	78	364	1.75	8.0
25	Karas	(HP)	7.5	1100	715	296	260	33	12.8	64.3	99.4	130	78	286	0.72	29.6
26	Sikura	(HP)	7.9	1700	1105	248	364	41	8.0	55.6	241	237	130	468	0.71	6.6
27	Kajrauth	(HP)	7.9	600	390	164	240	35	16.0	30.2	114	94.4	26	208	0.5	5.1
28	Raya	(HP)	7.8	2100	1365	604	324	65	9.6	141	483	215	104	403	0.11	10.6
29	Piprauli	(HP)	8.5	200	130	140	172	26	25.7	18.5	56.8	106	26	143	0.92	0.2
30	Keshi ghat	(YR)	7.5	1600	1040	400	352	63	77.0	50.7	383	109	78	338	0.94	30.3

31	Dangauli	(HP)	8.1	1500	975	212	320	38	16.0	41.9	284	233	52	338	2.1	0.0
32	Mant	(HP)	7.9	2100	1365	416	356	65	22.4	87.7	412	514	52	286	1.75	15.3
33	Bhadravan	(HP)	7.6	2300	1495	612	280	46	68.9	107	611	523	0	169	0.6	12.7
34	Taintigaon	(HP)	7.8	6400	4160	1804	1520	178	49.7	409	1392	2805	0	429	1.36	146
35	Harnol	(DHP)	7.8	1500	975	272	260	162	20.8	53.6	213	312	78	247	1.38	38.5
36	Naseethi	(HP)	7.9	2100	1365	560	324	67	36.9	114	412	652	0	247	1.26	58.6
37	Jabra	(DHP)	7.9	1800	1170	620	300	43	19.2	139	440	189	78	364	1.72	2.2
38	Andua	(HP)	7.6	4700	3055	916	1216	55	36.9	201	1420	1095	0	260	0.82	5.9
39	Madem	(HP)	7.8	2500	1625	484	344	59	11.2	111	497	509	52	377	1.25	8.2
40	Nunera	(HP)	7.4	5600	3640	1620	688	69	46.5	366	1647	1532	0	247	0.74	25.1
41	Anora	(DHP)	7.3	2900	1885	436	344	177	17.6	95.5	738	175	0	351	0.56	0.2
42	Jugsana	(DHP)	7.9	3800	2470	448	640	356	14.4	100	653	1074	78	637	1.59	22.4
43	Baltigarhi	(HP)	7.5	7100	4615	2360	1092	146	27.3	558	2343	2088	0	234	1.27	8.1
44	Unchagaon	(HP)	7.6	3600	2340	820	316	240	19.2	188	639	691	0	260	0	140
45	Kajrauti	(HP)	7.4	4500	2925	1180	648	100	40.1	263	1335	910	0	286	0.75	6.1
46	Khutipuri	(HP)	8.2	600	390	320	184	30	9.6	72.1	114	112	78	312	0	19.2
47	Siyamal	(HP)	8.3	900	585	316	212	54	9.6	71.2	99.4	131	78	338	0.95	11.4
48	Siyara	(DHP)	8.1	700	455	244	212	30	16.0	49.7	114	159	78	221	0.89	2.3
49	Dharampura	(HP)	8.1	1300	845	308	284	35	11.2	68.2	241	283	78	299	0.73	0.1
50	Karab	(HP)	7.9	2700	1755	692	340	75	38.5	145	710	437	0	377	0.67	3.7
51	Bandi	(HP)	8.2	5100	3315	488	1080	53	25.7	103	1477	961	130	572	1.86	5.2
52	Baldev Chauraha	(HP)	8.4	400	260	188	172	31	24.1	31.2	71.0	90.3	0	234	0.98	0.0
53	Dauji Mandir Baldev	(HP)	7.9	1100	715	120	296	35	6.4	25.3	71.0	261	78	377	1.23	0.1
54	Awerni	(HP)	8.7	1100	715	168	316	33	11.2	34.1	99.4	101	182	507	1.69	4.9
55	Artauni	(DHP)	8.4	1900	1235	104	380	40	11.2	18.5	142	93.3	208	884	2.36	2.2
56	Bisawar	(HP)	7.8	3100	2015	352	1232	47	12.8	78.0	852	162	52	559	1.58	0.0
57	Nagla tikait	(HP)	8.3	400	260	216	180	30	30.5	34.1	71.0	26.7	52	182	1.67	1.5
58	Angai	(HP)	7.9	3100	2015	460	1200	41	14.4	103	724	178	0	728	1.25	0.0
59	Madhura	(HP)	8.7	1100	715	92	384	40	14.4	13.6	85.2	48.8	104	598	1.23	0.0
60	Kanjaulighat	(YR)	8.5	1000	650	104	332	31	9.6	19.5	56.8	22.9	156	364	1.89	0.0
61	Barauli	(HP)	7.6	2500	1625	428	1072	40	14.4	95.5	611	115	52	247	1.28	0.0
62	Sarai salbhan	(HP)	8.2	1500	975	276	324	35	20.8	54.6	383	37.5	52	169	0.39	8.1

63	Badam garhi	(HP)	7.7	1400	910	248	308	43	27.3	43.9	270	111	52	182	0.45	12.5
64	Sehat	(DHP)	8.1	300	195	176	172	26	27.3	26.3	71.0	25.3	52	143	1.45	3.3
65	Kailash mandir (near sikandra)	(YR)	7.8	1700	1105	420	336	64	32.1	82.8	426	54.5	78	364	1.8	9.4
66	Kailash mandir (near sikandra)	(HP)	7.8	1800	1170	240	348	38	16.0	48.7	369	94.6	52	260	0.37	25.2
67	Midhawali	(HP)	7.7	4100	2665	644	1344	51	16.0	147	1051	295	52	299	1.14	0.0
68	Sorai	(HP)	7.9	3400	2210	804	1200	49	25.7	180	923	244	78	143	0.66	12.9
69	Hataura	(HP)	7.8	2600	1690	256	1152	40	19.2	50.7	554	182	78	455	1.93	1.3
70	Mahaban	(HP)	7.9	2400	1560	584	376	43	11.2	136	625	184	0	286	1.02	0.0
71	Gokul	(DHP)	8.0	1100	715	272	264	35	17.6	55.6	256	38.1	0	273	0.43	0.0
72	Gokul	(YR)	7.3	1600	1040	404	336	67	46.5	70.2	398	59.7	52	390	1.45	11.2
73	Gausna	(DHP)	7.6	6500	4225	1108	1032	178	80.2	221	1874	1216	0	754	0.99	4.7
74	Laxminagar	(HP)	8.0	3000	1950	252	664	41	17.6	50.7	639	493	78	481	1.34	15.4
75	Vishram Ghat	(YR)	7.6	1800	1170	412	304	62	57.7	65.3	440	160	78	377	0.86	15.4
76	Masani	(HP)	7.4	2500	1625	416	352	43	36.9	78.9	497	392	0	286	0	58.3
77	Ahilyaganj	(HP)	7.7	3700	2405	696	640	45	4.8	167	880	558	104	546	1.98	32.4
78	Cheerharan Ghat Vrindhaban	(HP)	7.8	1300	845	320	248	74	8.0	73.1	312	172	78	338	0.11	0.1
79	Cheerharan Ghat Vrindhaban	(YR)	7.4	1700	1105	400	316	64	49.7	67.3	398	233	52	364	0.96	15.2
80	Chattikara	(HP)	8.1	1600	1040	216	304	38	11.2	45.8	327	262	52	429	0.97	2.6
81	Jait	(HP)	7.7	700	455	248	200	30	27.3	43.9	142	116	52	221	0.39	1.0
82	Parkham	(DHP)	7.3	3300	2145	836	304	64	24.1	189	767	910	0	572	0.3	23.5
83	Nagla mauji	(DHP)	7.3	4400	2860	1936	344	53	77.0	425	1377	1500	0	299	1.1	3.5
84	Sei	(HP)	7.5	4600	2990	1240	372	344	48.1	273	1150	1460	0	247	0.34	33.6
85	Naugaon	(HP)	8.2	1100	715	376	240	50	12.8	84	213	141	78	364	1.2	4.5
86	Agraila	(HP)	7.8	1800	1170	292	332	38	14.4	62	270	197	104	702	1.49	1.8
87	Gangrauli	(HP)	8.0	2500	1625	388	364	41	14.4	86	753	231	0	416	1.35	1.7
88	Krishna Nagar Chauraha	(HP)	7.3	3300	2145	800	344	47	27.3	178	866	356	0	325	0.65	35.4
89	Girdharpur	(HP)	8.0	1800	1170	600	256	67	30.5	128	298	351	0	208	0.99	57.7
90	Naugawan	(HP)	7.7	3000	1950	948	320	69	28.9	213	980	413	0	234	0.55	0.2
91	Salempur	(HP)	7.9	3900	2535	768	376	49	11.2	180	682	1691	156	481	1.61	0.0
92	Mukandpur	(HP)	8.3	1700	1105	168	308	38	54.5	7.8	241	367	78	611	1.62	1.7
93	Usphar	(HP)	7.3	4800	3120	1500	376	144	68.9	324	1321	1118	0	442	1.31	22.7
94	Tarsi	(HP)	7.5	6400	4160	2040	948	184	444	227	2116	1538	0	481	1.49	23.2

95	Mudhesi	(HP)	7.6	2900	1885	660	320	178	22.4	147	611	677	52	338	0.64	0.0
96	Kosi khurd	(DHP)	8.0	1800	1170	484	256	134	20.8	105	383	217	52	338	2.1	6.9
97	Narauli	(HP)	7.3	3300	2145	896	316	47	96.2	160	1079	364	0	195	0.28	1.2
98	Birjapur	(HP)	7.9	1100	715	224	236	33	19.2	42.9	213	56.3	52	221	1.6	8.7
99	Nawada	(HP)	8.2	600	390	260	180	30	11.2	56.5	114	44.8	52	182	0	4.4
100	Ronchi banger	(DHP)	7.7	2100	1365	532	276	47	19.2	118	497	341	52	364	1.7	0.0
101	Aurangabad	(HP)	7.9	800	520	248	196	28	19.2	48.7	170	100	0	221	0.34	2.7
102	Aduki	(HP)	8.1	1900	1235	376	340	33	12.8	83.8	341	368	104	390	1.74	3.5
103	Bad	(HP)	7.4	6900	4485	2668	744	88	119	578	2528	1442	0	325	1.41	98.9
104	Bhainsa	(DHP)	7.3	1900	1235	492	288	32	11.2	113	426	340	0	312	1.74	0.1
105	Mathura Refinary	(DHP)	8.3	2000	1300	140	344	36	9.6	28.3	426	290	78	520	1.81	0.0
106	Dhana Shamsabad	(HP)	7.9	1000	650	212	256	40	22.4	38.0	227	83.3	52	195	0.76	2.7
107	Barari	(HP)	7.9	5400	3510	608	1280	46	14.4	139	1576	718	107	520	1.3	1.5
108	Sanaura	(HP)	7.4	3100	2015	728	300	255	24.1	163	966	250	0	273	0.64	0.0
109	Farah	(HP)	7.4	5300	3445	1928	1232	65	489	173	2187	124	0	169	0.62	5.9
110	Chandravan	(HP)	7.9	4000	2600	488	1344	43	14.4	110	1051	245	52	416	0.78	2.3
111	Jamalpur	(HP)	8.1	2000	1300	344	348	35	19.2	72.1	469	92.3	78	208	1.62	1.1
112	Dhana jiwna	(HP)	7.9	3400	2210	488	1216	43	14.4	110	923	139	78	364	2.2	0.0
113	Jurawai	(DHP)	7.5	7300	4745	2720	1408	69	20.8	650	3451	54.4	0	221	1.69	0.0
114	Sandhan	(DHP)	7.7	3200	2080	624	1152	40	16.0	142	866	183	52	169	1.37	21.8
115	Baroda	(HP)	8.0	1500	975	352	304	54	6.4	81.9	284	68.6	78	377	0.59	23.8
116	Aganpura	(HP)	8.0	4600	2990	768	1424	46	16.0	177	1732	132	52	416	1.98	0.0
117	Shahzadpur	(HP)	8.5	1800	1170	180	1072	35	68.9	2.0	341	144	130	481	2.52	0.5
118	Rajpura Jat	(DHP)	7.8	6500	4225	852	1600	72	17.6	197	2059	372	104	351	1.65	0.0
119	Arsena	(DHP)	7.2	5400	3510	1596	1360	54	9.6	383	1846	319	52	338	1.55	0.0
120	Runakta	(HP)	8.2	2400	1560	392	1152	40	14.4	86.7	341	253	130	429	1.93	12.1
121	Atrauni	(HP)	8.3	1700	1105	396	324	35	11.2	89.7	256	196	52	312	2.32	1.4
122	Sikandra	(HP)	8.1	1600	1040	200	344	40	6.4	44.8	312	86.3	104	364	1.33	1.2
123	Transport Nagar	(HP)	7.9	2500	1625	512	332	268	20.8	112	554	178	52	351	1.03	17.0
124	Kitham	(DHP)	7.8	2500	1625	876	316	40	35.3	192	866	70.6	52	169	1.95	0.5
125	Mai	(HP)	8.1	2600	1690	588	380	59	14.4	135	625	166	104	260	2.17	69.0
126	Nanau	(DHP)	7.9	3100	2015	468	1216	44	6.4	110	682	202	52	559	2.33	0.0

127	Kachora	(HP)	7.4	9200	5980	4944	1552	376	266	1043	5226	406	0	286	0.89	0.0
128	Achnera	(HP)	7.7	6700	4355	2428	1456	57	112	523	2883	255	0	325	1.64	6.4
129	Arua khas	(HP)	7.4	10000	6500	784	2976	264	104	128	4303	742	52	273	2.4	26.0
130	Fatehpura	(HP)	8.2	1000	650	356	220	31	17.6	76.0	412	26.9	52	143	0.71	36.6
131	Turkio	(DHP)	7.9	2000	1300	396	320	81	12.8	88.7	497	123	104	234	1.01	3.7
132	Biara	(HP)	7.4	6400	4160	1784	1440	86	36.9	412	2442	265	0	130	1.29	0.0
133	Fatehpur sikri	(HP)	8.2	5500	3575	1752	2624	168	133	346	2130	590	52	312	1.76	70.4
134	Korai	(HP)	7.9	2900	1885	692	380	40	30.5	150	696	333	78	338	1.47	0.0
135	Bidyapur	(HP)	7.9	6100	3965	304	880	50	22.4	60.4	1193	544	78	1053	1.51	68.9
136	Kiraoli	(DHP)	7.7	4200	2730	684	2528	384	35.3	145	1022	203	52	650	1.94	9.1
137	Puramana	(DHP)	7.7	4000	2600	640	1120	51	20.8	143	1051	277	52	507	1	0.0
138	Raiba	(HP)	7.8	4500	2925	860	1344	49	14.4	201	1221	349	104	221	1.73	6.0
139	Sahai	(HP)	8.6	800	520	144	284	32	38.5	11.7	128	27.1	104	299	1.96	0.0
140	Anguthi	(HP)	8.1	1500	975	300	316	38	12.8	65.3	341	90.9	78	299	0.82	3.9
141	Bichpuri	(HP)	8.4	1000	650	276	264	30	17.6	56.5	199	44.8	52	286	2.1	7.6
142	Amarpura	(HP)	8.0	2200	1430	248	2432	40	30.5	41.9	270	292	78	351	1.81	1.5
143	Rasoolpur	(HP)	8.1	4800	3120	1248	1344	52	27.3	288	1420	418	26	195	1.59	14.0
144	Naripura	(HP)	7.7	3200	2080	800	380	49	30.5	176	852	217	52	273	0.19	22.5
145	Dhanauli	(HP)	7.5	2000	1300	620	268	41	81.8	101	682	61.8	0	156	0.69	3.7
146	Malpura	(HP)	8.7	900	585	200	284	35	17.6	38.0	128	46.4	78	221	2.25	5.4
147	Pathauli	(HP)	7.6	3600	2340	1048	848	90	41.7	230	696	338	0	338	1.04	89.9
148	Sahara	(HP)	7.8	6100	3965	592	1120	54	9.6	138	1363	452	208	1235	1.75	0.0
149	Midhakur	(HP)	8.6	900	585	160	300	34	9.6	33.1	99.4	32.0	208	325	0.43	3.0
150	Mahuar	(HP)	8.2	2300	1495	320	1296	42	9.6	72.1	454	93.0	130	572	2.5	1.6

Table.4 Range of chemical parameters in groundwater of the study area

Water quality parameters	BIS (2012)		WHO (2006)	Concentration in the study area					
	Highest desirable limit (mg/l)	Max. Permissible limit (mg/l)	Highest desirable limit (mg/l)	Post-monsoon 2015			Pre-monsoon 2016		
				Min.	Max.	Average	Min.	Max.	Average
pH	6.5-8.5	No Relaxation	7.0-8.5	7.8	9.6	8.9	7.2	8.7	7.9
Ec (µS/cm)	-	-	750	300	9500	2769.3	200	10000	2719.3
TDS	500	2000	500	195	6175	1800.1	130	6500	1767.6
TH	200	600	500	100	3792	755.6	92	4944	616.4
Ca	75	200	75	4.8	243.7	51.8	4.8	489	33.8
Mg	30	100	30	6.8	877.1	153.7	2	1042.8	129.6
Na	-	200	200	45	2280	594.8	172	2976	607.6
K	-	-	-	32	800	98.9	26	384	70.4
CO_3	-	-	-	0	182	22.2	0	208	59.8
HCO_3	200	600	200	156	1313	533.3	130	1235	354.6
Cl	250	1000	250	14.2	4657.6	842.5	56.8	5225.6	723.7
SO_4	200	400	200	65.2	2447	462.5	22.9	2805.3	400
F	1	1.5	0.6-1.5	0.3	1.9	1.1	0	2.5	1.3
NO_3	45	No Relaxation	50	0.4	177.6	32.5	0	145.9	14

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 [3]. From the cationic and anionic triangular field of the Piper diagram, it is observed that 61.3% samples fall in the alkali field showing abundance of alkalies over alkaline earths (Ca^{+2}, Mg^{+2}) in post-monsoon (Fig. 3a), 23.3% show abundance in magnesium type and 15.3% fall in no dominant type. In anionic facies, 59.3% samples fall in chloride type, 29.3% fall in "no dominant type" field lacking any dominant anion, 8.7% fall in bicarbonate type and 2.7% show abundance in sulphate type. As far as the ionic facies are concerned in diamond shaped field of the piper trilinear diagram, there are two major facies, viz. Na-K-Cl-SO_4 and Ca-Mg-Cl-SO_4.

During the pre-monsoon season (Fig. 3b), 82% samples fall in the alkali type, 13.3% show abundance in magnesium type and 4.7% fall in no dominant type. In anionic facies, 61.3% samples fall in chloride type, 26.7% fall in no dominant type and 12% show abundance in bicarbonate type. As far as the ionic facies are concerned in diamond shaped field of the piper trilinear diagram, there are two major facies, viz. Na-K-Cl-SO_4 and Ca-Mg-Cl-SO_4. The groundwater of the study area is, therefore, alkali-chloride type.

5.1.2 Gibb's diagram

The source of the dissolved ions in the groundwater can be understood by Gibb's diagram [14]. It is a plot of $(Na^+)/(Na^+ + Ca^{+2})$ 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 in (Fig. 4a and 4b). The plots of the present study indicate rock dominance over the chemistry of groundwater in the study 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 few samples fall in evaporation dominance so they are not suitable for irrigation purpose.

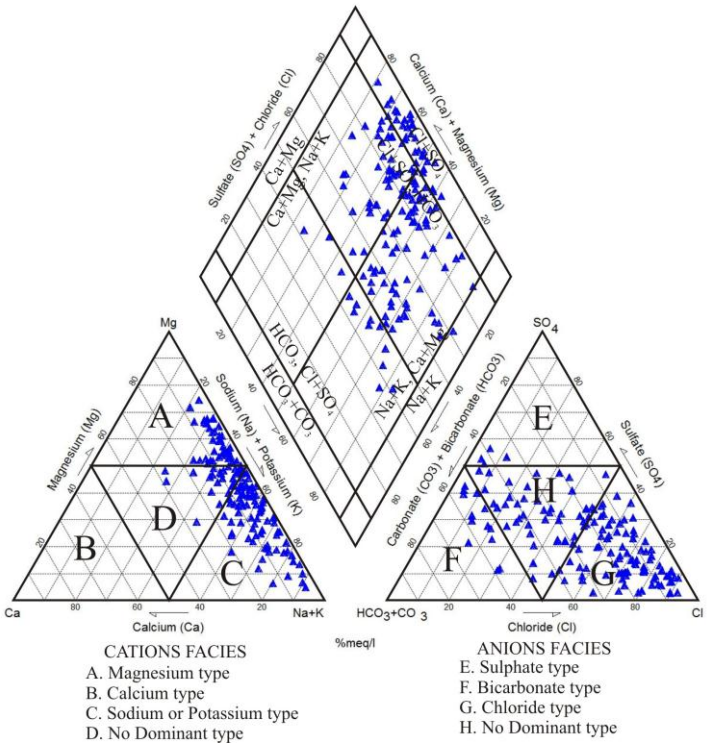
5.2 Evaluation of water quality for drinking purposes

Understanding the quality of groundwater is important as is the main factor determining its suitability for domestic, drinking, agricultural and industrial purposes. The water used for drinking purposes should be colorless and free from turbidity and microorganisms [19]. Chemically the water should be soft with less dissolved solids and free from poisonous constituents.

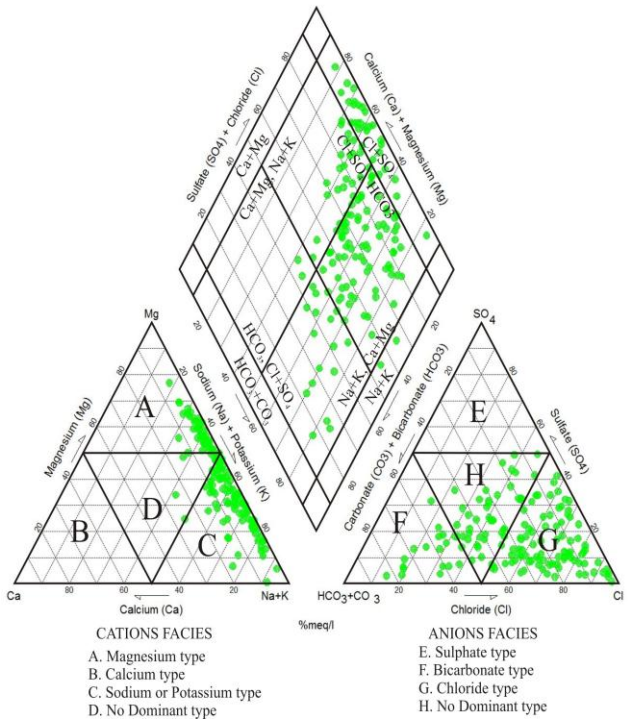
5.2.1 pH: It is measure the acidity and alkalinity of water, also an indicator of quality of water. The pH value of water is controlled by the amount of dissolved carbon dioxide, carbonates and bicarbonates. In the study area pH value of groundwater ranges from 7.8 to 9.6 with an average value of 8.9 in post-monsoon 2015 and in pre-monsoon 2016, pH value of groundwater ranges from 7.2 to 8.7 with an average value of 7.9. This shows that groundwater of the study area is mainly alkaline in nature. In post-monsoon period 26.7% of water samples are found below the highest desirable limit and 73.3% of water samples are found above the highest desirable limit. In pre-monsoon period 93.3% of water samples are found below the highest desirable limit and 6.7% of water samples are found above the highest desirable limit as per BIS [4], WHO [49].

5.2.2 EC: Electrical conductivity gives an idea about the extent of mineralization and is indicative of salinity of water. In the study area EC value of groundwater ranges from 300 to 9500 µS/cm with an average value of 2769.3 in post-monsoon and in pre-monsoon, EC value of groundwater ranges from 200 to 10000 µS/cm with an average value of 2719.3 µS/cm. In post-monsoon period 13.3% of water samples are found below the highest desirable limit and 86.7% of water samples are found above the highest desirable limit. In pre-monsoon period 9.3% of water samples are found below the highest desirable limit and 90.7% of water samples are found above the highest desirable limit as per WHO [49].

5.2.3 TDS: Total dissolved solids further indicate the saline behavior of groundwater. High value of TDS influences the taste, hardness and corrosive property of water. The alkaline nature of the water samples with high EC and high TDS values in groundwater can be attributed to high reactivity of soil and anthropogenic contamination. In the study area TDS value of groundwater ranges from 195 to 6175 mg/l



(a)



(b)

Fig.3 Piper-Trilinear diagram for (a) Post-monsoon 2015 (b) Pre-monsoon 2016

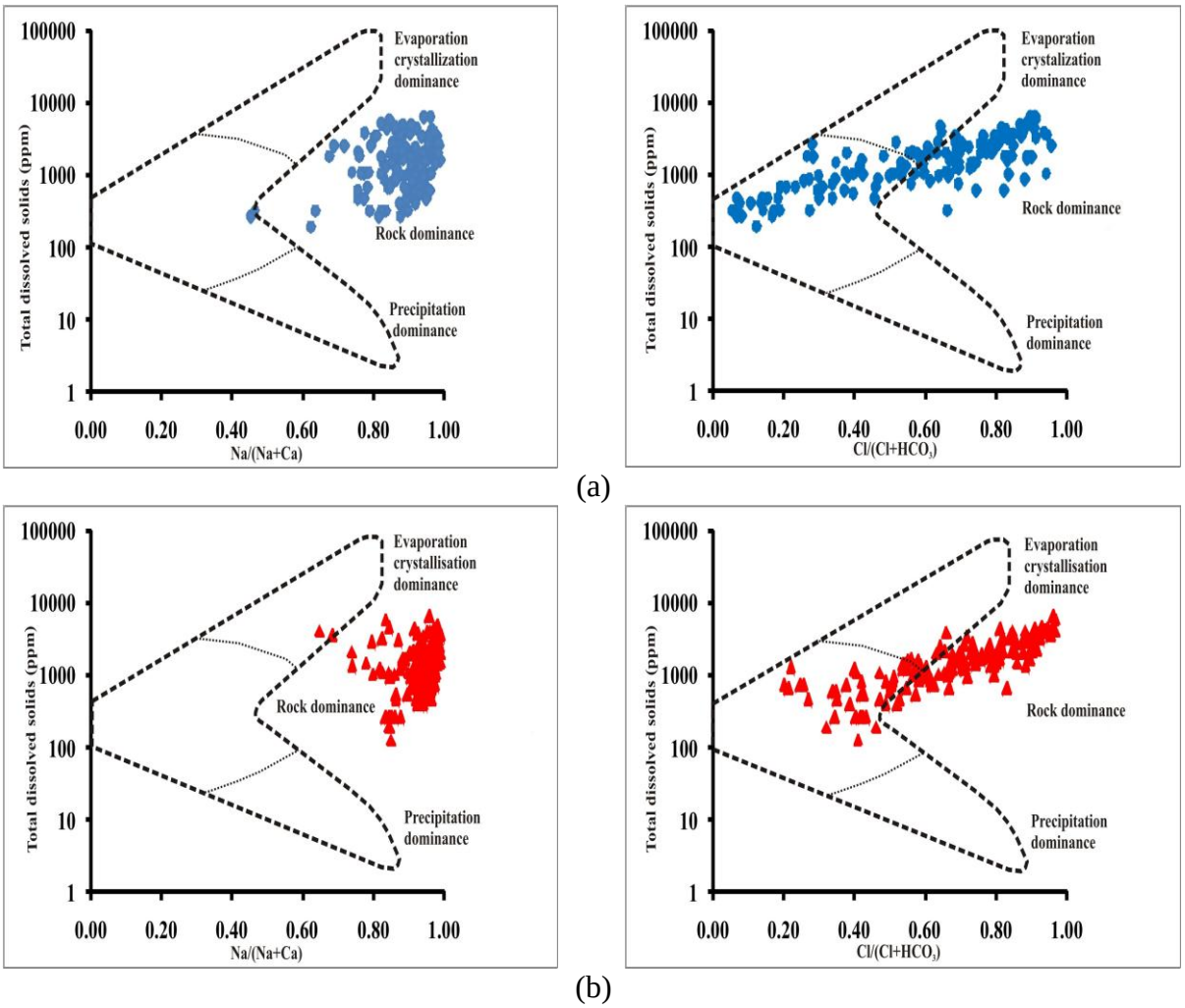


Fig.4 Chemical data for groundwater plotted in accordance with the scheme of Gibbs (1970), (a) Post-monsoon 2015, (b) Pre-monsoon 2016

with an average value of 1800.1 mg/l in post-monsoon and in pre-monsoon, TDS value of groundwater ranges from 130 to 6500 mg/l with an average value of 1767.6 mg/l. In post-monsoon period 14% of water samples are found below the highest desirable limit, 51.3% of water samples are found above the highest desirable limit and in pre-monsoon period 10% of water samples are found below the highest desirable limit and 56% of water samples are found above the highest desirable limit as per BIS [4], WHO [49]. In post-monsoon period 34.7% of water samples are found above the maximum permissible limit and in pre-monsoon period 34% of water samples are found above the maximum permissible limit as per BIS [4].

5.2.4 Hardness: In the study area hardness value of groundwater ranges from 100 to 3792 mg/l with an average value of 755.6 mg/l in post-monsoon and in pre-monsoon, hardness value of groundwater ranges from 92 to 4944 mg/l with an average value of 616.4 mg/l. In post-monsoon period 45.3% of water samples are found below the highest desirable limit and 54.7% of water samples are found above the highest desirable limit. In pre-monsoon period 62% of water samples are found below the highest desirable limit and 38% of water samples are found above the highest desirable limit as per WHO [49].

According to Sewyer and McCarty [37], the hardness of water classified in four category i.e., <75 mg/l is soft water, 75-150 mg/l is moderately hard, 150-300

mg/l is hard and >300 mg/l is very hard. In both season no sample is found under soft water category. In moderately hard category 5.3% of the water samples are found in post-monsoon period and in pre-monsoon period 6.7% of the water samples is found. In hard category 20% of the water samples are found in post-monsoon period and in pre-monsoon period 28% of the water samples is found. In very hard category 74.7% of the water samples are found in post-monsoon period and in pre-monsoon period 65.3% of the water samples is found. This shows that groundwater of the study area is hard to very hard.

5.2.5 Sodium: In the study area sodium value of groundwater ranges from 45 to 2280 mg/l with an average value of 594.8 mg/l in post-monsoon and in pre-monsoon, sodium value of groundwater ranges from 172 to 2976 mg/l with an average value of 607.6 mg/l. In post-monsoon period 4% of water samples are found below the max. permissible limit and 96% of water samples are found above the max. permissible limit. In pre-monsoon period 6.7% of water samples are found below the max. permissible limit and 93.3% of water samples are found above the max. permissible limit as per BIS [4].

5.2.6 Potassium: In the study area potassium value of groundwater ranges from 32 to 800 mg/l with an average value of 98.9 mg/l in post-monsoon and in pre-monsoon, potassium value of groundwater ranges from 26 to 384 mg/l with an average value of 70.4 mg/l.

5.2.7 Calcium: In the study area calcium value of groundwater ranges from 4.8 to 243.7 mg/l with an average value of 51.8 mg/l in post-monsoon and in pre-monsoon, calcium value of groundwater ranges from 4.8 to 489 mg/l with an average value of 33.8 mg/l. In post-monsoon period 78.7% of water samples are found below the highest desirable limit, 19.3% of water samples are found above the highest desirable limit and in pre-monsoon period 92.7% of water samples are found below the highest desirable limit and 5.3% of water samples are found above the highest desirable limit as per BIS [4], WHO [49]. In post-monsoon period 2% of water samples are found above the maximum permissible limit and in pre-monsoon period 2% of water samples are found above the maximum permissible limit as per BIS [4].

5.2.8 Magnesium: In the study area magnesium value of groundwater ranges from 6.8 to 877.1 mg/l with an average value of 153.7 mg/l in post-monsoon and in pre-monsoon, magnesium value of groundwater ranges from 2 to 1042.8 mg/l with an average value of 129.6 mg/l. In post-monsoon period 12.7% of water samples are found below the highest desirable limit and 32.7% of water samples are found above the highest desirable limit. In pre-monsoon period 10% of water samples are found below the highest desirable limit and 46% of water samples are found above the highest desirable limit as per BIS [4], WHO [49]. In post-monsoon period 54.6% of water samples are found above the maximum permissible limit and in pre-monsoon period 44% of water samples are found above the maximum permissible limit as per BIS [4]. Excess content of calcium and magnesium impart the hardness in water and is not good for drinking purposes. The principal sources of magnesium in natural waters are various kinds of rocks and sewage.

5.2.9 Carbonate: In the study area carbonate value of groundwater ranges from 0 to 182 mg/l with an average value of 22.2 mg/l in post-monsoon and in pre-monsoon, carbonate value of groundwater ranges from 0 to 208 mg/l with an average value of 59.8 mg/l.

5.2.10 Bicarbonate: In the study area bicarbonate value of groundwater ranges from 156 to 1313 mg/l with an average value of 533.3 mg/l in post-monsoon and in pre-monsoon, bicarbonate value of groundwater ranges from 130 to 1235 mg/l with an average value of 354.6 mg/l. In post-monsoon period 2% of water samples are found below the highest desirable limit and 66% of water samples are found above the highest desirable limit. In pre-monsoon period 13.3% of water samples are found below the highest desirable limit and 80.7% of water samples are found above the highest desirable limit as per BIS [4], WHO [49]. In post-monsoon period 32% of water samples are found above the maximum permissible limit and in pre-monsoon period 6% of water samples are found above the maximum permissible limit as per BIS [4].

5.2.11 Chloride: In the study area chloride value of groundwater ranges from 14.2 to 4657.6 mg/l with an average value of 842.5 mg/l in post-monsoon and in pre-monsoon, chloride value of groundwater ranges from 56.8 to 5225.6 mg/l with an average value of 723.7 mg/l. In post-monsoon period 29.3% of water samples are found below the highest desirable limit

and 38% of water samples are found above the highest desirable limit. In pre-monsoon period 26.7% of water samples are found below the highest desirable limit and 51.3% of water samples are found above the highest desirable limit as per BIS [4], WHO [49]. In post-monsoon period 32.7% of water samples are found above the maximum permissible limit and in pre-monsoon period 22% of water samples are found above the maximum permissible limit as per BIS [4]. Chloride content is derived mainly from the domestic waste waters, septic tanks, and irrigation return flow and chemical fertilizers [43] [15].

5.2.12 Sulphate: In the study area sulphate value of groundwater ranges from 65.2 to 2447 mg/l with an average value of 462.5 mg/l in post-monsoon and in pre-monsoon, sulphate value of groundwater ranges from 22.9 to 2805.3 mg/l with an average value of 400 mg/l. In post-monsoon period 20% of water samples are found below the highest desirable limit and 40% of water samples are found above the highest desirable limit. In pre-monsoon period 45.3% of water samples are found below the highest desirable limit and 27.3% of water samples are found above the highest desirable limit as per BIS [4], WHO [49]. In post-monsoon period 40% of water samples are found above the maximum permissible limit and in pre-monsoon period 27.3% of water samples are found above the maximum permissible limit as per BIS [4]. In general, sulphate values have increased in post-mosoon season as compare with pre-monsoon season due to industrial effluents. Sulphate content in groundwater is made possible through oxidation, precipitation, solution and concentration, as the water travers through rocks [19].

5.2.13 Fluoride: In the study area fluoride value of groundwater ranges from 0.3 to 1.9 mg/l with an average value of 1.1 mg/l in post-monsoon and in pre-monsoon, fluoride value of groundwater ranges from 0 to 2.5 mg/l with an average value of 1.3 mg/l. In post-monsoon period 40.7% of water samples are found below the highest desirable limit and 40.7% of water samples are found above the highest desirable limit. In pre-monsoon period 36% of water samples are found below the highest desirable limit and 26% of water samples are found above the highest desirable limit as per BIS [4] , WHO [49]. In post-monsoon period 18.6% of water samples are found above the maximum permissible limit and in pre-monsoon period 38% of water samples are found above the maximum permissible limit as per BIS [4]. The host rocks which contain the minerals such as apatite, biotite, hornblende, fluorite, clay and chemical fertilizers are responsible for higher content of fluoride in groundwater [35]. Fluoride may be an essential element in drinking water. Low intake dose (<0.5 mg/l) leads to dental carries [12] and higher intake of fluoride may change the metabolic activities of soft tissues like thyroid, reproductive organs, brain, liver and kidney [33]. Hence, it is essential to have a safe limit of fluoride concentration between 0.6 to 1.5 mg/l in drinking water WHO [49].

5.2.14 Nitrate: In the study area nitrate value of groundwater ranges from 0.4 to 177.6 mg/l with an average value of 32.5 mg/l in post-monsoon and in pre-monsoon, nitrate value of groundwater ranges from 0 to 145.9 mg/l with an average value of 14 mg/l. In post-monsoon period 81.3% of water samples are found below the highest desirable limit and 18.7% of water samples are found above the highest desirable limit. In pre-monsoon period 92% of water samples are found below the highest desirable limit and 8% of water samples are found above the highest desirable limit as per BIS [4]. The concentration of nitrate is attributed to the poor sanitary conditions, decaying organic matter, sewage and fertilizer from agricultural runoff [19]. Nitrogen in groundwater is mainly derived from organic industrial effluents, fertilizers or nitrogen fixing bacteria, leaching of animal dung, sewage and septic tanks through soil and water matrix to groundwater. Higher concentration of nitrate can cause blue baby syndrome called methemoglobinemia, gastric cancer, goiter, birth malformation and hypertension [5]. In the study area nitrate derived from organic sources is probably the cause for most of such occurrences, which can be assigned fairly definitely to drainage of water through soil containing domestic wastes, vegetable and animal matter.

5.3 Evaluation of water quality for irrigation purposes

Water quality, soil types and cropping practices play an important role for a suitable irrigation practices. Excessive amount of dissolved ions in irrigation water affects plants and agricultural soil, both physically and chemically, thus reduce the productivity. The physical effects of these ions are to lower the osmotic

pressure in the plant structural cells, thus preventing water from reaching the branches and leaves [31].

The important hydrochemical parameters for rating the water quality for irrigation purposes are Electrical conductivity (EC), Total dissolved solids (TDS), Sodium percentage (Na%), Sodium Adsorption Ratio (SAR), Kelly Ratio (KR), Magnesium Adsorption Ratio (MAR), Permeability Index (PI), Chloroalkaline Indices (CAI), Bicarbonate Hazards (BH) and Residual Sodium Carbonate (RSC) are given in (Table.5, Table.6) and discussed as follows.

5.3.1 Electrical Conductivity: Electrical conductance of water is an important factor to check the suitability of water for irrigation purposes. It gives salinity hazard to water which in turn reduces the soil permeability and plant growth. The larger variation in EC is generally attributed to bedrock formation, saline soil, agricultural activities, storage of animal waste and local contamination of domestic sewage [34].

As per Richard's [36] classification, In post-monsoon 2015, zero % samples are found in excellent type, 13.3% in good type, 32% in permissible type, 20% in doubtful type, 34.7% in unsuitable type and in pre-monsoon 2016, 0.7 % samples are found in excellent type, 9.3% in good type, 35.3% in permissible type, 20.7% in doubtful type, 34% in unsuitable type (Table.7).

5.3.2 Wilcox Plot: Wilcox [50] plot based on analytical data relating sodium percentage and electrical conductivity indicates that in post-monsoon 6.7% of water samples are found in excellent to good category, 2% are found in good to permissible category, 35.3% are found in permissible to doubtful category, 21.3% are found in doubtful to unsuitable, 34.7% are found in unsuitable category and in pre-monsoon monsoon 6.7% of water samples are found in excellent to good category, zero % are found in good to permissible category, 39.3% are found in permissible to doubtful category, 21.3% are found in doubtful to unsuitable, 32.7% are found in unsuitable category (Fig. 5a, 5b). Majority of samples fall in the permissible to doubtful category to unsuitable category and may not be suitable for irrigation purposes.

5.3.3 Total Dissolved Solids: TDS gives an idea about the various kinds of minerals present in water. In natural water the dissolved solids are primarily composed of chloride, sulphates, carbonates, bicarbonates, phosphates, calcium, magnesium, sodium, potassium etc. Excess salts of calcium, magnesium, sodium, potassium present in the irrigation water may prove to be detrimental to plants. When present in excessive quantities, they reduce the osmotic activities of the plants and may prevent adequate aeration [30].

As per Davies and De Weist, [10] classification, In post-monsoon 14% of the water samples are found in category of desirable for drinking, 18.7% are found in category of permissible for drinking, 49.3% are found in category of useful for irrigation, 18% are found in category of unfit for both and in pre-monsoon 10% of the water samples are found in the category of desirable for drinking, 20% are found in category of permissible for drinking, 54% are found in category of useful for irrigation, 16% are found in category of unfit for both. Classification shows that majority of the water samples are useful for irrigation purpose except few samples.

5.3.4 Sodium Percentage (Na%): The sodium percent is an important factor for studying sodium hazard. Sodium by the process of Base Exchange replaces calcium in the soil, which in turn reduces the soil permeability [30]. Therefore, it is considered to be very important in classifying the water for its irrigation use. Using the high percentage sodium water for irrigation may exploit the plant growth, affects soil permeability and eventually results in soil with poor internal drainage [18]. The sodium percentage is calculated using the following formula:

$$Na\% = \frac{(Na^{+} + K^{+}) \times 100}{Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}}$$

As per Wilcox [50] classification, In post-monsoon, zero % samples are found in excellent to good type, 3.3% in good to permissible type, 32% in permissible to doubtful type, 50.7% in doubtful to unsuitable type, 14% in unsuitable type and in pre-monsoon, zero % samples are found in excellent to good type, 1.3% in good to permissible type, 23.3% in permissible to doubtful type, 51.3% in doubtful to unsuitable type, 24% in unsuitable type (Table.7). Majority of water samples are found in doubtful to unsuitable and unsuitable type water category. So this water is not use for irrigational purposes.

5.3.5 Sodium Adsorption Ratio (SAR): It is considered as a better measure of sodium (alkali) hazard in irrigation water as it is directly related to the adsorption of sodium on soil and is a valuable

Table.5 Different Irrigation water quality parameters of the study area, Post-monsoon 2015

S.No.	Locations	Source	Ec (µS/cm)	TDS (mg/l)	Na%	SAR	RSC	KR	MAR	PI	CAI-1	CIA-2	BH
1	Sahara Kalan	(HP)	400	260	74.67	6.99	1.85	2.65	63.09	90.81	-24.25	-1.42	5.33
2	Tehra	(HP)	300	195	55.65	2.71	1.52	1.01	40.31	75.55	-8.34	-0.52	3.41
3	Gindauli	(DHP)	500	325	66.09	5.69	2.20	1.75	66.45	82.56	-24.25	-1.30	7.46
4	Iglas Chauraha	(HP)	600	390	68.31	6.39	2.54	1.95	72.98	83.94	-10.82	-1.43	7.89
5	Byauhara	(HP)	500	325	58.71	4.50	1.81	1.27	73.33	73.56	-21.12	-1.00	6.39
6	Khedia Gurdev	(HP)	400	260	64.58	4.85	1.68	1.61	64.59	79.62	-19.34	-1.14	4.48
7	Kamalpur	(HP)	700	455	66.73	6.55	1.99	1.84	83.52	80.87	-5.79	-2.05	8.31
8	Lalpur	(DHP)	700	455	78.77	8.96	3.59	3.39	83.90	91.05	-5.64	-1.22	4.48
9	Nagla Heera	(DHP)	2000	1300	64.88	7.49	-0.36	1.70	90.12	74.59	-0.68	-0.46	9.38
10	Mohkampur	(HP)	1600	1040	71.70	8.67	4.06	2.35	88.23	84.59	-1.36	-1.05	10.87
11	Beswan	(HP)	700	455	69.93	6.67	1.00	2.03	34.62	82.47	-2.87	-1.05	6.39
12	Sathini	(HP)	2100	1365	57.32	6.41	-4.75	1.24	75.24	65.25	-0.45	-0.43	8.52
13	Matroi	(HP)	600	390	76.20	8.08	3.24	2.93	59.89	92.33	-20.38	-1.66	7.03
14	Harautha	(DHP)	1300	845	77.71	9.91	6.12	3.21	69.77	91.30	-3.88	-1.27	9.16
15	Tamutiya	(DHP)	1900	1235	51.72	5.38	-6.85	0.96	81.74	58.59	-0.56	-0.56	8.95
16	Gorai	(HP)	5100	3315	73.34	10.59	-6.04	1.70	93.00	69.90	-0.81	-0.93	13.43
17	Jatwar	(DHP)	2800	1820	67.46	10.01	0.92	1.92	68.14	75.06	-1.18	-0.94	13.64
18	Khirsaulit	(HP)	1300	845	69.73	7.92	3.28	2.12	88.51	81.37	-2.54	-1.27	8.52
19	Jamau	(DHP)	4200	2730	75.28	16.61	-2.74	2.94	93.48	79.99	-0.90	-0.86	11.51
20	Nimgaon	(HP)	4800	3120	53.38	8.47	-26.81	1.09	73.13	55.06	0.09	0.11	3.62
21	Aithakhera	(HP)	1000	650	79.40	10.17	6.65	3.59	32.29	94.78	-5.37	-1.88	9.38
22	Birhana	(DHP)	500	325	48.04	1.88	0.13	0.69	61.19	68.32	-6.06	-0.70	2.98
23	Sonai	(HP)	1400	910	62.78	6.47	1.78	1.51	80.90	73.69	-1.53	-1.48	9.89
24	Mursan	(HP)	3100	2015	56.39	6.26	-3.72	1.18	88.51	64.72	-0.01	-0.01	10.23
25	Karas	(HP)	1000	650	67.95	7.02	2.84	1.94	47.24	81.95	-3.88	-2.15	9.38
26	Sikura	(HP)	500	325	66.80	5.59	0.27	1.80	53.66	80.93	-7.01	-4.05	5.11
27	Kajrauth	(HP)	700	455	77.60	8.54	4.17	3.13	65.52	94.07	-8.92	-2.35	7.89
28	Raya	(HP)	4100	2665	54.13	3.88	-15.07	0.53	91.18	43.13	-0.55	-0.52	11.30
29	Piprauli	(HP)	1200	780	75.75	8.79	5.68	2.85	52.87	91.65	-3.07	-1.40	10.44

30	Keshi ghat	(YR)	1600	1040	68.32	7.25	-1.00	1.91	45.28	77.57	-0.85	-0.95	6.18
31	Dangauli	(HP)	1300	845	70.65	7.26	-0.71	2.02	59.06	79.17	-2.04	-0.97	5.75
32	Mant	(HP)	2600	1690	63.55	9.18	-6.56	1.60	66.63	68.83	-0.96	-0.86	10.02
33	Bhadravan	(HP)	5600	3640	50.18	9.04	-36.02	0.97	72.11	52.39	0.16	0.53	7.67
34	Taintigaon	(HP)	6500	4225	62.52	13.21	-31.74	1.48	87.79	62.52	-0.77	-0.54	8.31
35	Harnol	(DHP)	700	455	81.54	7.98	3.10	3.46	60.93	96.19	-12.20	-1.81	4.90
36	Naseethi	(HP)	700	455	75.18	7.99	4.43	2.78	74.76	89.75	-24.68	-1.34	6.39
37	Jabra	(DHP)	900	585	57.29	4.90	-1.16	1.21	90.22	69.40	-1.60	-1.12	7.03
38	Andua	(HP)	600	390	70.69	6.07	3.71	2.00	82.65	85.78	-8.80	-1.64	7.03
39	Madem	(HP)	1400	910	69.76	6.52	-1.56	1.91	71.10	77.82	-0.56	-0.67	4.26
40	Nunera	(HP)	5200	3380	70.16	16.02	-12.38	2.28	92.55	73.82	-0.43	-0.66	12.36
41	Anora	(DHP)	900	585	70.33	7.02	1.43	2.18	75.25	84.16	-3.45	-1.38	6.61
42	Jugsana	(DHP)	1900	1235	73.84	7.10	4.77	1.79	85.73	77.97	-2.38	-1.10	9.16
43	Baltigarhi	(HP)	7200	4680	43.92	6.56	-40.69	0.65	91.46	43.24	0.42	0.64	10.02
44	Unchagaon	(HP)	3700	2405	52.35	4.74	-15.21	0.69	73.17	48.17	-0.33	-0.30	8.10
45	Kajrauti	(HP)	5200	3380	55.23	8.89	-20.40	1.15	85.03	58.26	0.07	0.10	9.59
46	Khutipuri	(HP)	500	325	36.24	1.52	0.58	0.42	52.13	54.17	-2.35	-0.45	5.54
47	Siyamal	(HP)	4200	2730	63.94	10.23	-13.83	1.57	77.41	66.06	-0.27	-1.23	7.46
48	Siyara	(DHP)	1400	910	75.56	9.29	8.74	2.88	84.55	89.63	-2.95	-0.98	9.59
49	Dharampura	(HP)	1000	650	86.16	12.52	8.56	5.78	72.67	103.37	-6.50	-1.90	8.31
50	Karab	(HP)	2900	1885	70.69	7.07	3.83	1.51	78.74	72.42	-0.48	-0.60	11.30
51	Bandi	(HP)	6300	4095	86.91	29.25	5.42	6.47	81.15	91.03	-0.25	-0.49	11.30
52	Baldev Chauraha	(HP)	400	260	39.14	1.30	-0.04	0.43	48.54	62.90	-2.25	-0.35	4.48
53	Dauji Mandir Baldev	(HP)	1000	650	79.96	9.81	5.74	3.64	55.88	96.61	-4.96	-1.35	9.38
54	Awerni	(HP)	8400	5460	58.00	12.82	-44.60	1.24	78.12	57.88	0.20	3.87	8.52
55	Artauni	(DHP)	4100	2665	83.37	19.24	7.35	4.22	87.65	88.02	-2.21	-5.57	15.13
56	Bisawar	(HP)	1500	975	67.08	7.21	1.93	1.87	74.17	79.48	-1.17	-1.59	9.38
57	Nagla tikait	(HP)	3000	1950	65.47	10.33	-1.02	1.80	93.15	72.37	-0.74	-1.82	13.64
58	Angai	(HP)	2800	1820	80.65	9.25	4.90	3.78	57.08	98.74	-3.39	-2.11	7.89
59	Madhura	(HP)	900	585	93.30	28.95	4.08	12.36	53.26	99.64	-0.88	-3.00	6.82
60	Kanjaulighat	(YR)	1100	715	58.07	5.58	1.02	1.24	91.23	70.19	0.45	2.49	11.08
61	Barauli	(HP)	2300	1495	89.00	13.86	3.95	6.90	44.33	102.68	-4.15	-2.32	5.97

62	Sarai salbhan	(HP)	1100	715	68.14	10.09	-0.87	1.98	64.27	75.41	-3.52	-6.76	12.15
63	Badam garhi	(HP)	1000	650	73.86	11.17	-0.01	2.64	52.57	81.70	-5.24	-4.09	8.95
64	Sehat	(DHP)	500	325	73.01	7.51	-0.48	2.50	69.92	84.10	-0.51	-2.28	4.05
65	Kailash mandir (near sikandra)	(YR)	1600	1040	56.86	5.63	-3.74	1.19	74.88	65.47	0.04	0.29	7.44
66	Kailash mandir (near sikandra)	(HP)	1800	1170	69.88	8.19	-2.09	2.17	82.34	78.38	-0.41	-1.53	5.05
67	Midhawali	(HP)	3900	2535	44.07	3.92	-11.51	0.68	88.91	48.57	-5.46	-2.43	5.11
68	Sorai	(HP)	3100	2015	42.46	4.15	-15.15	0.64	89.10	45.99	-3.13	-2.55	6.18
69	Hataura	(HP)	2600	1690	89.35	22.45	19.82	8.05	77.33	101.73	-3.02	-3.20	20.25
70	Mahaban	(HP)	3000	1950	79.98	11.26	3.42	3.68	43.43	91.64	0.39	2.03	8.10
71	Gokul	(DHP)	1700	1105	56.62	5.44	-0.71	1.12	60.59	66.15	-0.22	-0.68	11.08
72	Gokul	(YR)	1700	1105	57.48	5.58	-4.52	1.19	68.43	64.99	-0.54	-0.94	6.39
73	Gausna	(DHP)	5700	3705	47.49	7.37	-30.04	0.85	88.95	49.88	0.38	0.90	7.67
74	Laxminagar	(HP)	3000	1950	52.31	5.69	-7.24	1.01	94.43	57.38	0.12	0.12	5.11
75	Vishram Ghat	(YR)	1700	1105	63.83	6.42	-2.30	1.56	53.66	72.39	-0.23	-0.39	6.18
76	Masani	(HP)	1900	1235	66.25	7.31	-2.00	1.81	81.39	75.19	-0.16	-0.17	6.18
77	Ahilyaganj	(HP)	3400	2210	49.32	5.61	-11.14	0.90	96.25	55.25	0.35	0.63	8.10
78	Cheerharan Ghat Vrindhaban	(HP)	1100	715	67.87	6.48	0.95	1.86	88.14	80.28	-0.44	-0.56	7.03
79	Cheerharan Ghat Vrindhaban	(YR)	1600	1040	61.09	5.69	3.72	1.37	58.26	74.96	-0.08	-0.11	12.36
80	Chattikara	(HP)	4100	2665	66.53	12.74	-9.64	1.92	95.99	71.24	-0.09	-0.34	12.36
81	Jait	(HP)	3000	1950	37.92	4.27	-16.13	0.55	82.62	43.53	0.40	1.96	13.85
82	Parkham	(DHP)	2100	1365	49.08	5.13	-10.01	0.89	86.01	55.27	0.10	0.17	6.61
83	Nagla mauji	(DHP)	2800	1820	32.76	3.95	-30.06	0.46	85.85	36.36	0.48	0.49	7.08
84	Sei	(HP)	4800	3120	61.43	11.65	-19.80	1.53	93.64	64.62	0.02	0.04	9.16
85	Naugaon	(HP)	1000	650	59.03	5.52	-1.02	1.31	91.02	69.52	-1.11	-0.76	7.03
86	Agraila	(HP)	1700	1105	82.55	15.67	9.38	4.52	82.62	93.05	-2.50	-2.04	13.64
87	Gangrauli	(HP)	2000	1300	65.09	7.92	-1.05	1.78	87.42	74.80	0.27	0.75	8.89
88	Krishna Nagar Chauraha	(HP)	2200	1430	57.41	6.02	-2.00	1.20	92.40	66.21	-0.08	-0.09	10.66
89	Girdharpur	(HP)	1800	1170	44.13	4.22	-12.76	0.70	89.36	48.74	-0.01	-0.01	5.33
90	Naugawan	(HP)	5300	3445	56.37	9.34	-28.56	1.07	85.21	55.65	0.11	0.36	9.38
91	Salempur	(HP)	3900	2535	63.59	11.84	-15.25	1.68	94.51	67.34	-0.06	-0.12	9.59
92	Mukandpur	(HP)	2900	1885	67.92	12.29	-7.31	2.04	94.71	73.05	-0.53	-0.79	10.87
93	Usphar	(HP)	2900	1885	47.73	4.60	-13.80	0.66	95.45	47.67	0.10	0.16	10.87

94	Tarsi	(HP)	6400	4160	68.03	11.13	-16.56	1.45	77.21	64.13	0.01	0.02	13.00
95	Mudhesi	(HP)	9500	6175	56.87	15.98	-62.45	1.29	95.00	58.46	0.24	1.58	14.49
96	Kosi khurd	(DHP)	9500	6175	64.96	16.93	-47.52	1.56	91.41	63.19	0.10	0.69	11.30
97	Narauli	(HP)	2300	1495	68.34	8.31	-0.68	2.00	86.94	76.34	-0.02	-0.02	6.18
98	Birjapur	(HP)	2100	1365	60.27	6.44	-3.33	1.39	89.60	68.70	0.24	3.68	7.46
99	Nawada	(HP)	800	520	83.65	11.79	6.57	4.76	66.08	96.69	-2.87	-2.06	6.18
100	Ronchi banger	(DHP)	1900	1235	57.73	6.22	-3.03	1.24	91.75	64.65	-0.09	-0.09	7.03
101	Aurangabad	(HP)	500	325	81.61	9.50	3.45	4.05	56.21	96.85	-5.01	-1.63	5.33
102	Aduki	(HP)	1300	845	84.60	11.53	6.07	5.16	22.80	99.68	0.70	4.38	5.97
103	Bad	(HP)	7000	4550	62.81	6.80	-1.74	1.58	75.68	71.35	-0.48	-0.25	5.75
104	Bhainsa	(DHP)	1600	1040	94.25	35.82	12.34	15.77	47.21	102.96	-1.67	-3.24	14.92
105	Mathura Refinary	(DHP)	2900	1885	92.70	32.84	14.21	12.30	75.24	99.97	-1.59	-1.57	12.57
106	Dhana Shamsabad	(HP)	1500	975	72.36	15.27	-9.12	2.54	85.81	76.43	-0.01	-0.04	8.95
107	Barari	(HP)	5100	3315	72.27	15.82	-8.34	2.52	91.43	76.48	0.05	0.15	11.30
108	Sanaura	(HP)	2600	1690	53.99	9.71	-31.02	1.13	90.25	56.12	0.23	2.05	5.97
109	Farah	(HP)	5500	3575	52.03	9.52	-38.08	1.03	76.34	53.26	0.38	2.13	4.26
110	Chandravan	(HP)	3700	2405	51.18	8.03	-31.28	0.98	75.13	51.79	0.45	3.26	2.56
111	Jamalpur	(HP)	1600	1040	67.88	10.83	-12.34	1.98	79.02	70.09	0.26	1.87	2.56
112	Dhana jiwna	(HP)	3000	1950	51.67	5.43	-8.53	0.94	92.29	57.30	0.37	1.31	8.10
113	Jurawai	(DHP)	6500	4225	43.06	4.30	-12.18	0.65	87.96	47.99	0.75	17.16	9.80
114	Sandhan	(DHP)	2800	1820	44.70	4.29	-11.27	0.70	66.66	49.86	0.74	3.96	7.25
115	Baroda	(HP)	1600	1040	58.28	5.32	1.27	1.27	88.12	70.45	0.00	0.00	8.30
116	Aganpura	(HP)	2800	1820	65.97	12.28	-12.00	1.88	80.95	70.21	0.22	2.30	9.41
117	Shahzadpur	(HP)	2500	1625	47.87	4.45	-12.31	0.66	88.98	48.41	0.04	0.06	10.23
118	Rajpura Jat	(DHP)	3900	2535	75.14	16.10	-2.39	2.92	96.30	80.51	-0.15	-0.54	12.79
119	Arsena	(DHP)	5000	3250	75.32	17.21	-9.28	2.96	88.65	78.85	0.05	1.07	7.67
120	Runakta	(HP)	3500	2275	69.96	13.46	-9.98	2.26	91.41	74.11	-2.39	-4.95	7.84
121	Atrauni	(HP)	1400	910	52.49	5.14	-1.15	1.01	91.30	62.48	-0.40	-0.82	10.02
122	Sikandra	(HP)	1400	910	73.59	8.98	3.98	2.57	84.17	84.60	-0.99	-1.64	7.46
123	Transport Nagar	(HP)	2400	1560	69.93	12.58	-5.67	2.23	88.91	75.28	-0.75	-4.70	10.23
124	Kitham	(DHP)	2400	1560	45.93	4.88	-14.10	0.78	95.92	50.53	0.41	4.16	5.54
125	Mai	(HP)	1400	910	63.63	6.85	0.14	1.61	90.29	71.78	-0.57	-0.41	5.75

126	Nanau	(DHP)	3100	2015	80.88	19.18	0.77	4.10	91.94	86.52	-1.00	-3.54	11.72
127	Kachora	(HP)	3700	2405	49.51	4.57	-15.37	0.68	69.59	47.62	0.46	1.36	7.03
128	Achnera	(HP)	6600	4290	51.52	10.14	-40.30	1.03	89.66	53.59	0.41	3.66	8.52
129	Arua khas	(HP)	7700	5005	63.06	9.28	-12.78	1.47	69.27	65.00	0.42	2.21	7.03
130	Fatehpura	(HP)	900	585	53.77	5.86	-6.66	1.03	66.96	60.07	0.58	4.28	9.59
131	Turkio	(DHP)	2500	1625	63.01	10.39	-14.90	1.62	79.82	66.23	0.26	1.17	5.75
132	Biara	(HP)	5600	3640	54.88	10.02	-31.16	1.17	88.14	56.88	0.43	2.53	5.33
133	Fatehpur sikri	(HP)	7300	4745	65.51	17.67	-36.83	1.85	82.32	67.16	-0.19	-0.52	8.95
134	Korai	(HP)	3400	2210	74.48	15.52	-3.05	2.81	68.36	79.79	-0.63	-1.95	12.15
135	Bidyapur	(HP)	5000	3250	75.20	16.13	-6.52	2.90	81.87	79.32	-0.30	-1.31	8.95
136	Kiraoli	(DHP)	4000	2600	75.33	16.49	-3.60	2.90	86.65	79.34	-0.33	-1.18	10.02
137	Puramana	(DHP)	3600	2340	62.68	12.43	-20.25	1.61	86.03	65.65	-0.39	-1.93	9.59
138	Raiba	(HP)	3800	2470	71.45	14.65	-2.74	2.39	97.44	76.46	-0.36	-0.80	14.28
139	Sahai	(HP)	2400	1560	80.38	17.83	9.29	3.96	97.63	87.76	-2.54	-4.45	15.98
140	Anguthi	(HP)	2300	1495	54.57	4.78	-4.68	1.07	82.14	62.84	0.03	0.08	5.31
141	Bichpuri	(HP)	700	455	54.52	4.53	-2.72	1.07	69.38	65.26	-1.02	-1.49	6.18
142	Amarpura	(HP)	3600	2340	58.89	10.57	-16.02	1.37	83.78	63.09	-0.19	-2.25	13.64
143	Rasoolpur	(HP)	2100	1365	83.87	17.80	4.01	4.46	90.92	89.06	-2.51	-2.77	10.23
144	Naripura	(HP)	3100	2015	70.88	13.70	-8.45	2.34	86.01	75.19	-0.49	-1.66	8.74
145	Dhanauli	(HP)	3100	2015	91.28	42.49	8.35	10.30	86.82	95.19	-3.68	-9.25	15.13
146	Malpura	(HP)	1200	780	77.85	9.50	1.71	3.25	70.09	87.79	-1.18	-1.77	4.26
147	Pathauli	(HP)	3200	2080	36.55	3.54	-14.27	0.48	93.79	40.46	0.35	0.96	10.23
148	Sahara	(HP)	5100	3315	86.08	23.67	8.17	5.97	90.83	92.12	-0.18	-0.62	12.57
149	Midhakur	(HP)	6100	3965	88.45	37.60	15.12	7.53	83.30	92.63	-1.40	-6.43	21.52
150	Mahuar	(HP)	4200	2730	80.08	19.33	5.61	3.89	94.80	86.05	-0.34	-2.33	15.34

Table. 6 Different Irrigation water quality parameters of the study area, Pre-monsoon 2016

S.No.	Locations	Source	Ec (µS/cm)	TDS (mg/l)	Na%	SAR	RSC	KR	MAR	PI	CAI-1	CIA-2	BH
1	Sahara Kalan	(HP)	400	260	75.69	7.25	1.70	2.85	60.31	88.40	-3.13	-1.99	3.20
2	Tehra	(HP)	300	195	77.51	7.20	1.70	3.17	44.06	93.18	-4.48	-1.66	3.41
3	Gindauli	(DHP)	1200	780	77.22	8.47	3.54	2.86	81.68	88.82	-2.32	-2.29	6.18
4	Iglas Chauraha	(HP)	700	455	81.16	9.65	6.09	3.99	86.26	96.13	-5.20	-1.88	5.54
5	Byauhara	(HP)	400	260	70.85	5.74	0.88	2.20	59.84	85.78	-2.39	-1.98	3.41
6	Khedia Gurdev	(HP)	700	455	74.81	7.06	4.54	2.71	88.22	89.78	-3.16	-1.37	4.48
7	Kamalpur	(HP)	3200	2080	78.18	14.06	1.61	3.42	92.40	85.11	-0.91	-0.56	8.31
8	Lalpur	(DHP)	800	520	81.09	9.65	5.03	4.00	75.24	94.52	-2.85	-1.61	4.48
9	Nagla Heera	(DHP)	2400	1560	67.24	7.09	0.56	1.88	88.77	77.13	-0.13	-0.12	5.97
10	Mohkampur	(HP)	1400	910	77.06	9.70	3.58	3.14	44.39	88.91	-1.32	-0.95	6.61
11	Beswan	(HP)	2100	1365	85.80	17.24	6.24	5.77	85.61	94.66	-1.77	-1.69	8.10
12	Sathini	(HP)	400	260	67.44	5.35	1.08	1.83	68.22	78.35	-3.38	-1.34	2.77
13	Matroi	(HP)	2300	1495	63.82	6.71	-3.01	1.62	90.68	69.48	-0.25	-0.15	2.98
14	Harautha	(DHP)	2500	1625	69.22	7.76	5.56	1.95	95.97	78.36	-0.70	-0.36	8.31
15	Tamutiya	(DHP)	6000	3900	58.76	12.95	-43.97	1.34	93.31	58.78	-0.30	-0.30	2.77
16	Gorai	(HP)	1400	910	76.44	9.11	0.97	2.87	85.64	84.78	-1.51	-1.03	4.26
17	Jatwar	(DHP)	2400	1560	67.07	7.69	4.14	1.89	93.22	77.91	-0.54	-0.35	8.95
18	Khirsaulit	(HP)	1200	780	80.89	9.82	6.29	3.91	82.25	94.21	-1.54	-0.94	5.11
19	Jamau	(DHP)	5000	3250	72.87	13.02	-0.96	2.54	93.29	78.40	-0.45	-0.24	9.59
20	Nimgaon	(HP)	1800	1170	67.49	7.78	0.93	1.91	95.16	76.32	-1.23	-0.69	6.61
21	Aithakhera	(HP)	1200	780	79.55	9.81	3.99	3.59	78.49	91.45	-1.98	-1.53	5.11
22	Birhana	(DHP)	2100	1365	76.01	9.61	9.39	2.98	90.74	89.70	-0.50	-0.53	9.38
23	Sonai	(HP)	3100	2015	71.75	12.30	-4.59	2.38	94.61	75.05	-0.75	-0.75	4.48
24	Mursan	(HP)	2900	1885	77.03	13.46	-0.20	3.22	92.68	82.89	-0.77	-0.71	5.97
25	Karas	(HP)	1100	715	66.94	6.53	1.29	1.88	89.31	77.83	-3.28	-1.61	4.69
26	Sikura	(HP)	1700	1105	77.04	9.98	6.98	3.15	92.03	89.16	-1.45	-1.06	7.67
27	Kajrauth	(HP)	600	390	77.35	8.10	0.96	3.14	75.85	89.29	-2.49	-2.77	3.41
28	Raya	(HP)	2100	1365	56.24	5.69	-2.18	1.15	96.08	63.23	-0.14	-0.24	6.61
29	Piprauli	(HP)	200	130	74.24	6.29	0.39	2.65	54.62	87.43	-4.02	-2.12	2.34

30	Keshi ghat	(YR)	1600	1040	67.70	7.62	0.07	1.90	52.33	75.54	-0.54	-1.11	5.54
31	Dangauli	(HP)	1500	975	77.61	9.50	2.98	3.24	81.33	89.34	-0.83	-1.03	5.54
32	Mant	(HP)	2100	1365	67.03	7.54	-2.01	1.84	86.69	73.79	-0.46	-0.42	4.69
33	Bhadravan	(HP)	2300	1495	51.89	4.89	-9.61	0.98	72.16	56.36	0.23	0.37	2.77
34	Taintigaon	(HP)	6400	4160	65.88	15.45	-29.56	1.81	93.21	66.94	-0.78	-0.51	7.03
35	Harnol	(DHP)	1500	975	73.73	6.81	1.14	2.05	81.08	79.20	-1.54	-0.96	4.05
36	Naseethi	(HP)	2100	1365	58.22	5.92	-7.29	1.24	83.75	63.31	-0.34	-0.28	4.05
37	Jabra	(DHP)	1800	1170	52.93	5.20	-4.01	1.04	92.35	60.44	-0.12	-0.24	5.97
38	Andua	(HP)	4700	3055	74.50	17.35	-14.31	2.85	90.08	76.89	-0.34	-0.60	4.26
39	Madem	(HP)	2500	1625	62.65	6.75	-1.91	1.52	94.29	70.40	-0.16	-0.18	6.18
40	Nunera	(HP)	5600	3640	49.09	7.38	-28.81	0.91	92.93	50.86	0.33	0.48	4.05
41	Anora	(DHP)	2900	1885	68.80	7.11	-3.09	1.69	90.02	72.93	0.08	0.44	5.75
42	Jugsana	(DHP)	3800	2470	80.26	13.05	3.95	3.06	92.06	84.13	-0.98	-0.72	10.44
43	Baltigarhi	(HP)	7100	4615	51.68	9.70	-44.06	0.99	97.16	51.83	0.23	0.36	3.84
44	Unchagaon	(HP)	3600	2340	54.46	4.76	-12.37	0.83	94.22	52.03	-0.09	-0.10	4.26
45	Kajrauti	(HP)	4500	2925	56.23	8.15	-19.24	1.18	91.63	58.23	0.19	0.39	4.69
46	Khutipuri	(HP)	600	390	57.46	4.44	1.22	1.23	92.59	70.81	-1.70	-1.06	5.11
47	Siyamal	(HP)	900	585	62.32	5.15	1.73	1.44	92.50	74.04	-2.73	-1.41	5.54
48	Siyara	(DHP)	700	455	66.89	5.86	1.28	1.86	83.79	78.53	-2.08	-1.13	3.62
49	Dharampura	(HP)	1300	845	67.95	6.99	1.26	1.98	91.02	78.32	-0.92	-0.75	4.90
50	Karab	(HP)	2700	1755	54.36	5.58	-7.84	1.05	86.28	59.95	0.18	0.39	6.18
51	Bandi	(HP)	5100	3315	83.01	21.12	3.82	4.75	87.03	87.99	-0.15	-0.25	9.38
52	Baldev Chauraha	(HP)	400	260	68.52	5.42	0.03	1.97	68.37	83.66	-3.08	-3.32	3.84
53	Dauji Mandir Baldev	(HP)	1100	715	84.99	11.67	6.35	5.29	86.82	100.35	-5.79	-1.46	6.18
54	Awerni	(HP)	1100	715	81.08	10.53	10.97	4.04	83.52	96.96	-4.14	-1.42	8.31
55	Artauni	(DHP)	1900	1235	89.29	16.11	19.32	7.85	73.32	109.14	-3.33	-1.51	14.49
56	Bisawar	(HP)	3100	2015	88.47	28.35	3.76	7.50	91.01	93.23	-1.25	-5.96	9.16
57	Nagla tikait	(HP)	400	260	66.32	5.30	0.35	1.79	65.11	78.36	-3.24	-2.84	2.98
58	Angai	(HP)	3100	2015	85.09	24.16	2.60	5.59	92.27	90.45	-1.57	-8.78	11.93
59	Madhura	(HP)	1100	715	90.51	17.32	11.41	8.99	61.19	106.86	-6.28	-3.41	9.80
60	Kanjaulighat	(YR)	1000	650	87.86	14.07	9.06	6.86	77.15	102.04	-8.38	-2.40	5.97
61	Barauli	(HP)	2500	1625	84.59	22.37	-2.90	5.37	91.69	87.94	-1.73	-7.33	4.05

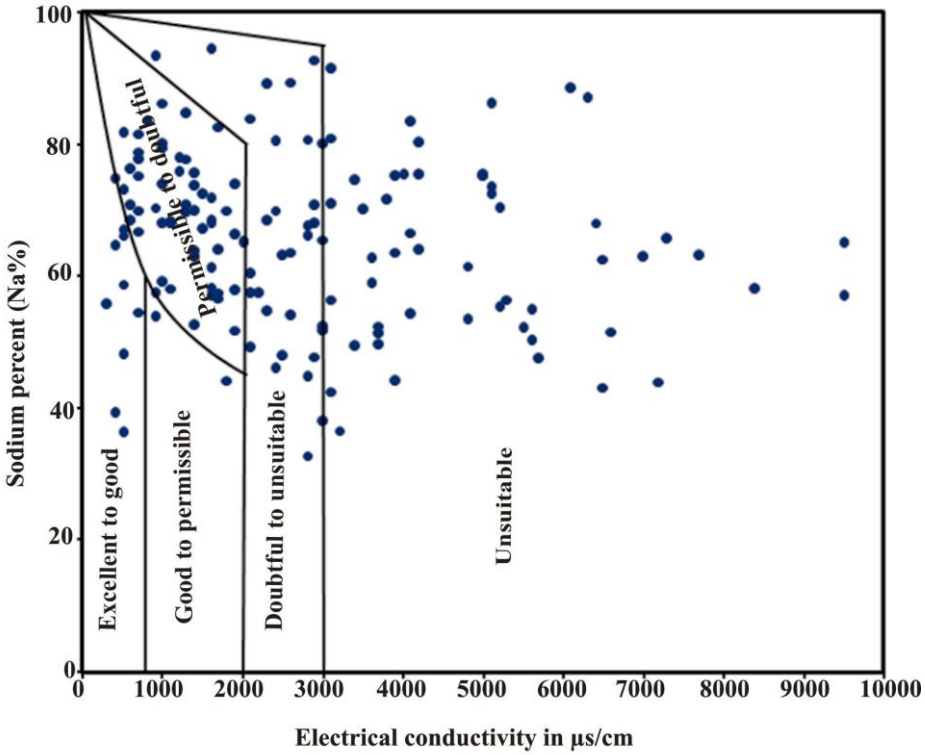
62	Sarai salbhan	(HP)	1500	975	72.83	8.43	-1.09	2.52	81.36	80.05	-0.37	-1.52	2.77
63	Badam garhi	(HP)	1400	910	74.28	8.45	-0.30	2.67	72.85	82.13	-0.88	-1.60	2.98
64	Sehat	(DHP)	300	195	69.62	5.61	0.52	2.10	61.67	81.66	-3.02	-2.64	2.34
65	Kailash mandir (near sikandra)	(YR)	1700	1105	65.64	7.08	0.06	1.72	81.16	73.77	-0.34	-1.05	5.97
66	Kailash mandir (near sikandra)	(HP)	1800	1170	76.81	9.70	1.13	3.11	83.51	86.01	-0.53	-1.35	4.26
67	Midhawali	(HP)	4100	2665	82.06	22.87	-6.42	4.47	93.86	84.83	-0.99	-3.77	4.90
68	Sorai	(HP)	3400	2210	76.63	18.28	-11.35	3.20	92.13	78.43	-1.03	-3.43	2.34
69	Hataura	(HP)	2600	1690	90.79	31.11	4.87	9.66	81.45	95.56	-2.23	-5.50	7.46
70	Mahaban	(HP)	2400	1560	59.55	6.72	-7.16	1.38	95.27	65.65	0.02	0.10	4.69
71	Gokul	(DHP)	1100	715	69.19	6.91	-1.04	2.08	84.00	80.01	-0.69	-6.39	4.48
72	Gokul	(YR)	1600	1040	66.64	7.23	-0.05	1.79	71.56	75.23	-0.44	-1.57	6.39
73	Gausna	(DHP)	6500	4225	68.78	13.39	-10.08	2.00	82.14	71.88	0.08	0.16	12.36
74	Laxminagar	(HP)	3000	1950	85.43	18.07	5.38	5.66	82.72	93.24	-0.64	-0.89	7.89
75	Vishram Ghat	(YR)	1800	1170	64.01	6.48	0.45	1.59	65.35	72.89	-0.18	-0.36	6.18
76	Masani	(HP)	2500	1625	66.08	7.46	-3.73	1.82	78.11	73.63	-0.16	-0.24	4.69
77	Ahilyaganj	(HP)	3700	2405	67.22	10.47	-1.71	1.97	98.30	73.45	-0.15	-0.25	8.95
78	Cheerharan Ghat Vrindhaban	(HP)	1300	845	66.14	5.98	1.65	1.66	93.82	76.04	-0.42	-0.61	5.54
79	Cheerharan Ghat Vrindhaban	(YR)	1700	1105	65.53	6.83	-0.39	1.70	69.28	74.13	-0.35	-0.59	5.97
80	Chattikara	(HP)	1600	1040	76.42	8.93	4.39	3.02	87.19	90.19	-0.52	-0.67	7.03
81	Jait	(HP)	700	455	65.35	5.49	0.34	1.73	72.85	77.29	-1.33	-1.30	3.62
82	Parkham	(DHP)	3300	2145	46.70	4.54	-7.58	0.78	92.91	53.94	0.32	0.36	9.38
83	Nagla mauji	(DHP)	4400	2860	29.36	3.38	-34.35	0.38	90.20	31.67	0.59	0.74	4.90
84	Sei	(HP)	4600	2990	49.85	4.56	-21.10	0.64	90.44	44.01	0.24	0.25	4.05
85	Naugaon	(HP)	1100	715	60.58	5.34	0.94	1.37	91.59	71.30	-0.93	-1.00	5.97
86	Agraila	(HP)	1800	1170	72.25	8.39	9.06	2.44	87.81	87.59	-1.00	-1.01	11.51
87	Gangrauli	(HP)	2500	1625	68.21	7.98	-1.05	2.01	90.84	77.82	0.22	0.95	6.82
88	Krishna Nagar Chauraha	(HP)	3300	2145	49.91	5.25	-10.89	0.92	91.60	55.38	0.35	1.08	5.33
89	Girdharpur	(HP)	1800	1170	51.37	4.51	-8.75	0.91	87.48	55.71	-0.51	-0.53	3.41
90	Naugawan	(HP)	3000	1950	44.92	4.49	-15.39	0.72	92.49	47.89	0.44	1.43	3.84
91	Salempur	(HP)	3900	2535	53.04	5.86	-2.50	1.05	96.40	59.99	0.10	0.05	7.89
92	Mukandpur	(HP)	1700	1105	80.98	10.31	9.24	3.97	19.24	98.75	-1.08	-0.73	10.02
93	Usphar	(HP)	4800	3120	39.72	4.19	-23.17	0.54	88.67	40.72	0.47	0.75	7.25

94	Tarsi	(HP)	6400	4160	52.76	9.09	-33.24	1.00	46.01	53.46	0.24	0.45	7.89
95	Mudhesi	(HP)	2900	1885	57.98	5.38	-6.11	1.04	91.62	59.58	-0.06	-0.07	5.54
96	Kosi khurd	(DHP)	1800	1170	59.74	5.02	-2.54	1.13	89.39	64.37	-0.33	-0.57	5.54
97	Narauli	(HP)	3300	2145	45.19	4.56	-14.93	0.76	73.46	48.73	0.52	2.09	3.20
98	Birjapur	(HP)	1100	715	71.01	6.81	0.82	2.26	78.79	82.21	-0.83	-1.65	3.62
99	Nawada	(HP)	600	390	61.99	4.82	-0.55	1.48	89.36	72.94	-1.65	-1.95	2.98
100	Ronchi banger	(DHP)	2100	1365	55.04	5.17	-3.09	1.11	91.08	63.38	0.07	0.11	5.97
101	Aurangabad	(HP)	800	520	64.79	5.38	-1.40	1.70	80.85	76.98	-0.90	-2.05	3.62
102	Aduki	(HP)	1900	1235	67.21	7.57	2.23	1.94	91.59	77.25	-0.61	-0.53	6.39
103	Bad	(HP)	6900	4485	39.02	6.22	-48.76	0.60	89.03	40.09	0.52	1.19	5.33
104	Bhainsa	(DHP)	1900	1235	57.19	5.60	-4.87	1.25	94.38	65.68	-0.10	-0.17	5.11
105	Mathura Refinary	(DHP)	2000	1300	84.85	12.56	8.29	5.27	83.04	100.47	-0.30	-0.43	8.52
106	Dhana Shamsabad	(HP)	1000	650	73.92	7.60	0.64	2.60	73.84	83.78	-0.87	-1.61	3.20
107	Barari	(HP)	5400	3510	82.16	22.41	-0.25	4.51	94.15	86.15	-0.26	-0.64	8.52
108	Sanaura	(HP)	3100	2015	57.01	4.80	-10.29	0.88	91.86	54.50	0.29	1.54	4.48
109	Farah	(HP)	5300	3445	58.72	12.16	-36.05	1.38	37.03	59.78	0.12	2.71	2.77
110	Chandravan	(HP)	4000	2600	85.75	26.27	-1.34	5.90	92.71	89.34	-0.98	-4.30	6.82
111	Jamalpur	(HP)	2000	1300	69.69	8.10	-0.96	2.17	86.20	76.81	-0.20	-0.58	3.41
112	Dhana jiwna	(HP)	3400	2210	84.50	23.77	-1.33	5.34	92.71	88.12	-1.05	-5.02	5.97
113	Jurawai	(DHP)	7300	4745	53.29	11.65	-51.59	1.11	98.11	54.21	0.36	31.41	3.62
114	Sandhan	(DHP)	3200	2080	80.15	19.91	-8.16	3.96	93.67	82.48	-1.07	-4.47	2.77
115	Baroda	(HP)	1500	975	67.15	6.99	1.64	1.85	95.51	77.13	-0.80	-1.47	6.18
116	Aganpura	(HP)	4600	2990	80.19	22.18	-7.03	3.97	94.86	83.26	-0.27	-3.03	6.82
117	Shahzadpur	(HP)	1800	1170	92.94	34.69	8.61	12.91	4.50	98.40	-3.88	-5.14	7.89
118	Rajpura Jat	(DHP)	6500	4225	80.51	23.66	-8.07	4.02	94.90	82.85	-0.21	-1.12	5.75
119	Arsena	(DHP)	5400	3510	65.13	14.69	-25.12	1.83	98.52	67.18	-0.15	-0.93	5.54
120	Runakta	(HP)	2400	1560	86.54	25.12	3.42	6.30	90.92	90.87	-4.25	-4.22	7.03
121	Atrauni	(HP)	1700	1105	65.10	7.03	-1.18	1.75	93.02	73.91	-1.05	-1.32	5.11
122	Sikandra	(HP)	1600	1040	79.76	10.50	5.38	3.69	92.10	91.51	-0.79	-1.34	5.97
123	Transport Nagar	(HP)	2500	1625	67.23	6.34	-2.90	1.39	89.97	67.83	-0.35	-0.96	5.75
124	Kitham	(DHP)	2500	1625	45.40	4.61	-13.25	0.77	90.07	48.91	0.40	3.11	2.77
125	Mai	(HP)	2600	1690	60.19	6.76	-4.20	1.38	93.95	65.33	-0.01	-0.02	4.26

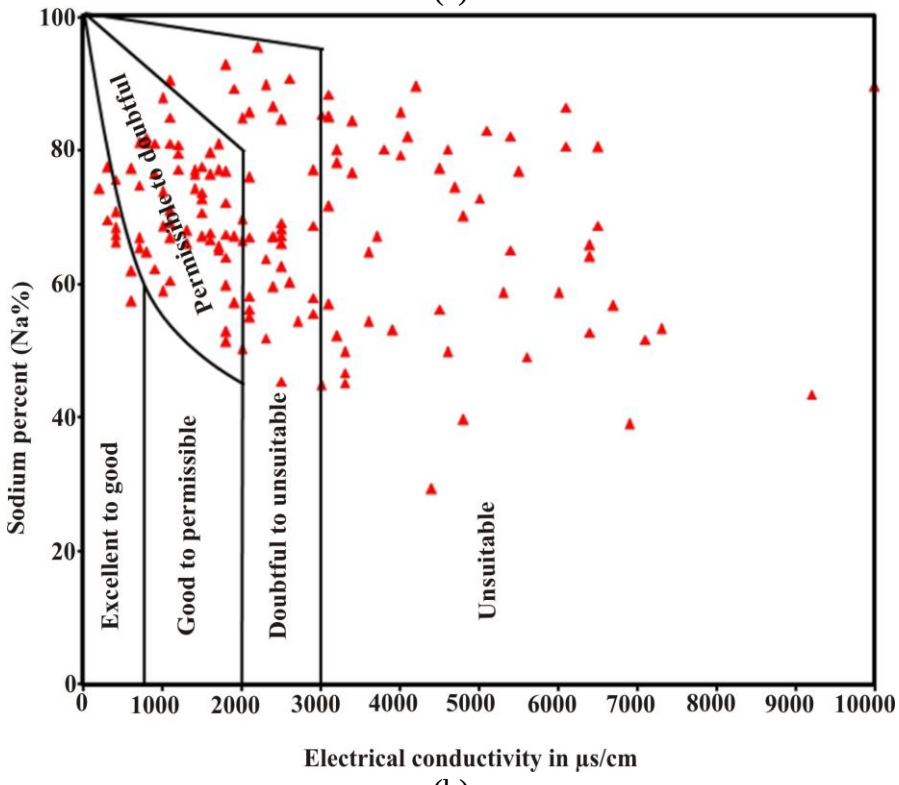
126	Nanau	(DHP)	3100	2015	85.04	24.26	1.40	5.57	96.62	89.63	-1.77	-5.80	9.16
127	Kachora	(HP)	9200	5980	43.49	9.53	-95.52	0.67	86.72	41.53	0.48	8.54	4.69
128	Achnera	(HP)	6700	4355	56.82	12.76	-43.90	1.29	88.60	58.31	0.21	3.24	5.33
129	Arua khas	(HP)	10000	6500	89.57	45.96	-9.64	8.16	67.13	90.54	-0.11	-0.75	4.48
130	Fatehpura	(HP)	1000	650	58.94	5.04	-3.14	1.33	87.78	66.12	0.12	0.49	2.34
131	Turkio	(DHP)	2000	1300	66.56	6.94	-0.73	1.73	92.01	72.32	-0.13	-0.29	3.84
132	Biara	(HP)	6400	4160	64.16	14.72	-34.07	1.73	94.91	64.84	0.07	0.90	2.13
133	Fatehpur sikri	(HP)	5500	3575	76.94	27.09	-28.63	3.22	81.24	77.79	-0.95	-3.80	5.11
134	Korai	(HP)	2900	1885	55.57	6.24	-5.89	1.18	89.15	61.78	0.12	0.24	5.54
135	Bidyapur	(HP)	6100	3965	86.53	21.81	13.71	6.21	81.78	95.49	-0.16	-0.36	17.26
136	Kiraoli	(DHP)	4200	2730	89.62	41.75	-1.47	7.93	87.28	91.44	-3.10	-14.82	10.66
137	Puramana	(DHP)	4000	2600	79.40	19.12	-2.93	3.75	91.97	83.64	-0.67	-2.66	8.31
138	Raiba	(HP)	4500	2925	77.37	19.78	-10.36	3.35	95.87	79.51	-0.71	-2.29	3.62
139	Sahai	(HP)	800	520	81.96	10.26	5.47	4.26	33.63	95.51	-2.61	-2.36	4.90
140	Anguthi	(HP)	1500	975	70.75	7.88	1.42	2.26	89.45	80.48	-0.51	-1.09	4.90
141	Bichpuri	(HP)	1000	650	68.65	6.86	0.83	2.05	84.23	79.92	-1.16	-2.35	4.69
142	Amarpura	(HP)	2200	1430	95.51	66.77	3.34	21.08	69.63	97.64	-12.85	-11.37	5.75
143	Rasoolpur	(HP)	4800	3120	70.24	16.42	-21.26	2.31	94.62	71.90	-0.47	-1.96	3.20
144	Naripura	(HP)	3200	2080	52.29	5.80	-10.01	1.02	90.61	56.92	0.27	0.99	4.48
145	Dhanauli	(HP)	2000	1300	50.33	4.65	-9.98	0.93	67.40	54.78	0.35	5.03	2.56
146	Malpura	(HP)	900	585	76.59	8.68	2.17	3.05	78.22	86.91	-2.63	-2.63	3.62
147	Pathauli	(HP)	3600	2340	64.83	11.31	-15.71	1.73	90.19	67.49	-0.97	-2.27	5.54
148	Sahara	(HP)	6100	3965	80.65	19.87	15.16	4.05	96.00	87.62	-0.29	-0.68	20.25
149	Midhakur	(HP)	900	585	81.10	10.24	9.02	4.02	85.18	94.27	-3.90	-1.45	5.33
150	Mahuar	(HP)	2300	1495	89.85	31.28	7.22	8.68	92.59	94.54	-3.42	-7.06	9.38

Table.7 Classification of Groundwater on the basis of Irrigation indices

Parameters	Range	Water classification	Post-monsoon 2015		Pre-monsoon 2016	
			Total no. of samples	%	Total no. of samples	%
Ec (µS/cm) (Richards, 1954)	<250	Excellent	0	0	1	0.70
	250-750	Good	20	13.3	14	9.3
	750-2000	Permissible	48	32.0	53	35.3
	2000-3000	Doubtful	30	20.0	31	20.7
	>3000	Unsuitable	52	34.7	51	34
SAR (meq/l) (Richards, 1954)	<10	Excellent	94	62.7	96	64.0
	10-18	Good	45	30.0	28	18.7
	18-26	Fair/Medium	5	3.3	17	11.3
	>26	Poor	6	4.0	9	6.0
Na% (meq/l) (Wilcox, 1955)	<20	Excellent to good	0	0	0	0
	20-40	Good to permissible	5	3.3	2	1.3
	40-60	Permissible to doubtful	48	32	35	23.3
	60-80	Doubtful to unsuitable	76	50.7	77	51.3
	>80	Unsuitable	21	14	36	24
TDS (mg/l) (Davis and Dewiest, 1966)	<500	Desirable for drinking	21	14	15	10
	500-1000	Permissible for drinking	28	18.7	30	20
	1000-3000	Useful for irrigation	74	49.3	81	54
	>3000	Unfit for both	27	18	24	16
RSC (meq/l) (Richards, 1954)	<1.25	Good	100	66.7	100	66.7
	1.25-2.5	Doubtful	11	7.3	13	8.7
	>2.5	Unsuitable	39	26	37	24.6
KR (meq/l) (Kelly, 1946)	<1	Suitable	25	16.7	19	12.7
	>1	Unsuitable	125	83.3	131	87.3
MAR (meq/l) (Ayers and Westcot, 1985)	<50	Suitable	10	6.7	7	4.7
	>50	Unsuitable	140	93.3	143	95.3
PI (meq/l) (Doneen, 1964)	>75	Safe (Class-I)	71	47.35	93	62
	25-75	Marginally safe (Class-II)	79	2.70	57	38
	<25	Unsafe (Class-III)	0		0	0
BH (meq/l) (Mandel and Shiftan, 1981)	<1.5	No problem	0	0	0	0
	1.5-8.5	Increasing problem	75	50	129	86
	>8.5	Severe problem	75	50	21	14



(a)



(b)

Fig.5. Wilcox diagram for (a) Post-monsoon 2015 (b) Pre-monsoon 2016

criterion for determining the suitability of the water for irrigation. Excessive sodium contents relative to the calcium and magnesium reduces the soil permeability and thus inhibits the supply of water needed for the crops. The SAR measures the relative proportion of sodium ions in a water sample to those of calcium and magnesium. SAR is calculated using the following formula:

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

As per Richard's [36] classification, In post-monsoon, 62.7% of the water samples are found in the excellent category, 30% in good category, 3.3% in medium category, 4% are found in poor category and in pre-monsoon, 64% of the water samples are found in the excellent category, 18.7% in good category, 11.3% in medium category, 6% are found in poor category (Table.7).

5.3.6 US Salinity Diagram: This diagram is used for rating the irrigation waters, in which EC is taken as an index of salinity hazard and SAR as an index of sodium hazard. The analytical data plotted on the US Salinity diagram (Fig. 6a, 6b) illustrates that, In post-monsoon, 11.3% of water samples are found in good quality water type, 45.3% in moderate quality water type, 20.7% in bad quality water type, 22.7% in very bad quality type and in pre-monsoon, 11.3% of water samples are found in good quality water type, 52% in moderate quality water type, 7.3% in bad quality water type, 29.3% in very bad quality type. Majority of the water samples are found in the moderate quality water type to very bad quality water type. This type of water is not use for irrigation purposes if this water used in irrigation on most soils with strong danger of developing harmful levels of exchangeable sodium [36].

5.3.7 Kelly's Ratio (KR): The level of sodium measured against calcium and magnesium is known as Kelly's ratio. Excess of sodium in water produces undesirable effects of changing soil properties and reducing soil permeability [20]. Therefore, it is taken as an indication of alkali hazard in water. KR is calculated using the following formula:

$$KR = \frac{Na^{+}}{Ca^{+2} + Mg^{+2}}$$

As per Kelly [20] classification, In post-monsoon, 16.7% of the water samples are found in suitable water type, 83.3% in unsuitable water type and in pre-monsoon 12.7% of water samples are found in suitable water type, 87.3% in unsuitable water type (Table.7). Majority of water samples are found in unsuitable type water so this is not use for irrigation.

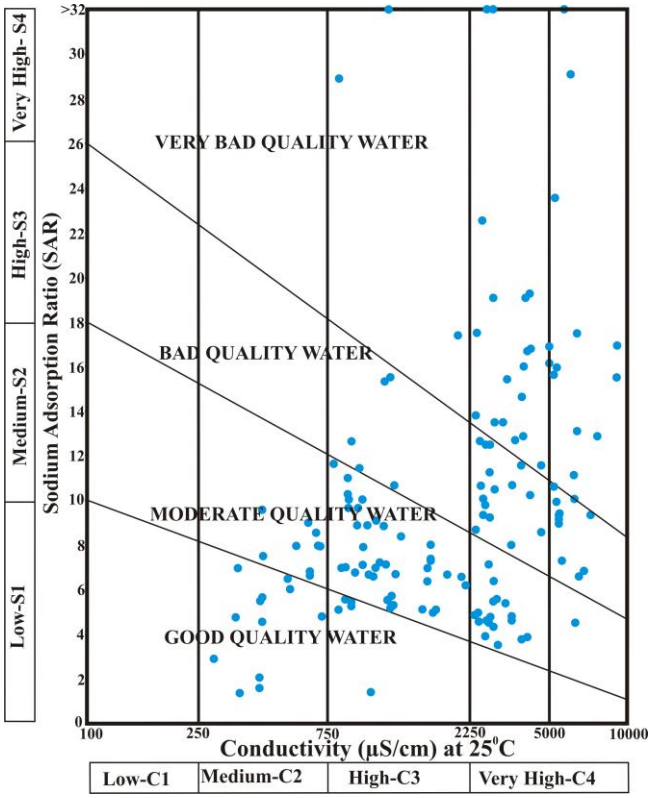
5.3.8 Magnesium Adsorption Ratio (MAR): It is the excess amount of magnesium over calcium. Normally the level of calcium and magnesium remains in a state of equilibrium [9]. The major source of magnesium in the groundwater is due to ion exchange of minerals in rocks and soils by water [29]. More magnesium in water enhances soil salinity and could adversely affect the crop yields [18]. MAR is calculated using the following formula:

$$MAR = \frac{(Mg^{+2} \times 100)}{Ca^{+2} + Mg^{+2}}$$

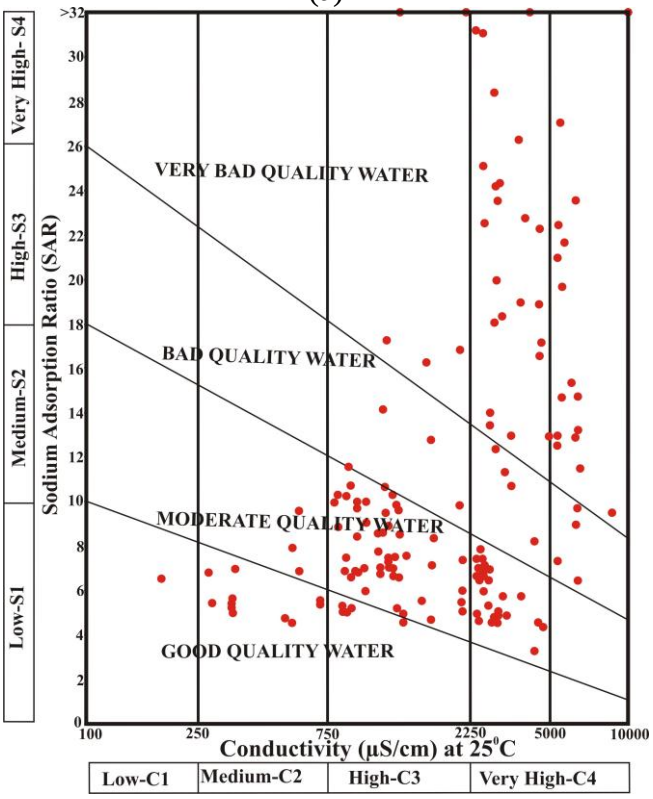
As per Ayers and Wescot [44] classification, In post-monsoon, 6.7% of the water samples are found in suitable water type, 93.3% in unsuitable water type and in pre-monsoon 4.7% of water samples are found in suitable water type, 95.3.3% in unsuitable water type (Table.7). Majority of water samples are found in unsuitable type water so this is not use for irrigation.

5.3.9 Permeability Index (PI): The soil permeability is affected by long term use of irrigated water. It is influenced by sodium, calcium, magnesium, and bicarbonate contents of the soil [30]. The high permeability index, in association with subsurface may facilitate widespread contamination of groundwater [44]. PI is calculated using the following formula:

$$PI = \frac{(Na^{+} + \sqrt{HCO3^{-}}) \times 100}{Ca^{+2} + Mg^{+2} + Na^{+}}$$



(a)



(b)

Fig.6. US Salinity diagram for (a) Post-monsoon 2015, (b) Pre-monsoon 2016

As per Doneen [11] classification, In post-monsoon, 47.3% of the water samples are found in safe category, 52.7% in marginally safe category, zero % in unsafe category and in pre-monsoon, 62% of the water samples are found in safe category, 38% in marginally safe category, zero % in unsafe category (Table.7). Majority of the water samples are found in safe and in marginally safe category, no samples are found in unsafe category. This type of water use for irrigation purposes.

5.3.10 Chloroalkaline Indices (CAI): Control on the dissolution of undesirable constituents in water is impossible during the surface runoff, but it is essential to know various changes in chemical composition undergone by groundwater during their travel in the subsurface [17]. The chloro-alkaline indices CAI-I and CAI-II are suggested by Schoeller [39] [38] which indicates ion exchange between the groundwater and its host environment during residence or travel. If there are Na^{+} and K^{+} ions in water which are exchanged with Mg^{+2} and Ca^{+2} ions, the indices are positive, indicating direct Base Exchange reaction or chloro-alkaline equiblirium. In contrast, if the exchange is in the reverse order, then the exchange is indirect and the indices are found negative, indicating chloro-alkaline disequilibrium. These reactions are known as cation-anion exchange reactions reactions viz., ion exchange between the groundwater and its host environment during residence or travel in subsurface. The chloro-alkaline indices calculated by following formula:

$$CAI - I = [Cl - (Na + K)]/Cl$$

$$CAI - II = [Cl - (Na + K)]/(SO_4 + CO_3 + NO_3)$$

In the study area majority of water samples show the negative CAI, indicating chloro-alkaline disequilibrium.

5.3.11 Bicarbonate Hazard (BH): Concentration of bicarbonates in water is considered as one of the important parameters for assessing the quality of irrigation water. As per Mandel and Shiftan [27] classification, In post-monsoon, zero% of the water samples are found in the no problem category, 50% in the increasing problem category, 50% in the severe problem category and in pre-monsoon, zero% of the water samples are found in the no problem category, 86% in the increasing problem category, 14% in the severe problem category (Table.7). Majority of the water samples are found in increasing problem category and in severe problem category to soil permeability. BH is calculated using the following formula:

$$BH = \frac{HCO3^{-} mg/l}{61}$$

5.3.12 Residual Sodium Carbonate (RSC): In addition to the SAR and Na%, the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the suitability of groundwater for irrigation. Because, in waters having high concentration of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. An excess quantity of sodium bicarbonate and carbonate is considered to be detrimental to the physical properties of soils as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. As a result, the relative proportion of sodium in water is increased in the form of sodium carbonate and this excess is denoted by RSC and it is calculated using the following formula.

$$RSC = (CO3^{-} + HCO3^{-}) - (Ca^{+2} + Mg^{+2})$$

As per Richard's [36] classification, In post-monsoon, 66.7% of the water samples found in the good water type, 7.3% in doubtful water type, 26% in unsuitable water type and in pre-monsoon, 66.7% of the water samples found in the good water type, 8.7% in doubtful water type, 24.6% in unsuitable water type (Table.7). Majority of the water samples show the good water type followed by unsuitable water type. Good water type samples are used in irrigation purposes but unsuitable water type samples are not used for irrigation.

6. CONCLUSION

The hydrochemical data shows that the quality of the groundwater of Yamuna river basin is deteriorated at some places and proper groundwater management strategies and necessary to protect sustainability of this valuable resource. It was found that groundwater of the study area is generally hard and alkaline. The dominant hydrochemical facies among the cations are Sodium or Potassium type while the majority of the samples show the chloride type facies among the anions. Irrigation water quality parameters like Electrical conductivity (EC), Total dissolved solids (TDS), Sodium percentage (Na%), Sodium Adsorption Ratio (SAR), Kelly Ratio (KR), Magnesium Adsorption Ratio (MAR), Permeability Index (PI), Chloroalkaline Indices (CAI), Bicarbonate Hazards (BH) and Residual Sodium Carbonate (RSC) indicate that the groundwater represented by all samples is not suitable for irrigation except few. The values of EC and SAR of groundwater samples have been plotted in U.S. Salinity diagram. The plots indicate that majority of samples indicating the moderate quality water (C3-S2) to very bad quality water (C4-S4). On the basis of Wilcox diagram it is seen that majority of samples fall in the permissible to doubtful category and unsuitable category.

7. *ACKNOWLEDGEMENT*

The authors are thankful to Chairman, Department of Geology, Aligarh Muslim University, Aligarh for providing necessary facilities to carry out the research work. The financial assistance received by first author in the form of Senior Research Fellowship (BSR) from University Grant Commission, New Delhi is acknowledged. The authors are also grateful to Dr. Seraj Khan (Scientist D, CGWB Lucknow) for fruitful discussion during the preparation of this manuscript.

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