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A Comprehensive Evaluation of Groundwater Quality for Irrigation in Tehsil Bah, Agra, India

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ABSTRACT: A higher agricultural yield depends on the quality of the water used. A significant source for irrigation is groundwater. 84 separate study locations had groundwater samples that were collected and analysed using the procedures outlined in the 2017 American Public Health Association, 23rd Edition (APHA). Tehsil Bah in the Agra district of Uttar Pradesh had its groundwater quality evaluated for irrigation purposes. Sodium adsorption ratio (SAR), sodium percentage (Na%), Residual Sodium Carbonate (RSC), Permeability Index (PI), Magnesium Ratio (MR), Electrical Conductivity (EC), Kelley's Index (KI), base exchange index, and meteoric genesis index were used to assess the suitability of groundwater quality for irrigation. 96.4 percent of groundwater samples were deemed inappropriate for irrigation according to the Wilcox diagram, with 3.6 percent of samples falling into the questionable to unsuitable category. All the samples fall into the C3-S1 and C3-S2 water classes, which denote water with a high salinity hazard and a moderate to medium sodium hazard, according to SAR and electrical conductivity values plotted in the US salinity diagram. The amount of dissolved substances in groundwater determined its suitability for irrigation. According to the classification, all of the reported values of Na percent fall into the good and medium category. RSC values range from -3.61 to 4.24, with 7.1 percent of samples falling into the bad and very bad category and not suitable for irrigation use, while the remaining 92.9 percent of samples fall into the excellent, good, and medium category.

KEYWORDS: Groundwater, Electrical conductivity, Irrigation water, Permeability.

INTRODUCTION

Water quantity and quality are just two of the many variables that affect the provision of water for irrigation. In general, quality considerations are subordinated to water quantity considerations. The primary cations and anions, as well as the dissolved salts, can be utilised to describe the quality of irrigation water. Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, and HCO_3^{-} are the primary cations and anions, respectively. A soil with an excessive concentration of these ions may experience salinity, sodicity, and permeability problems, all of which are harmful to plant growth and agricultural output. The three main issues with water quality around the world are rising salinity, decreasing permeability, and dangerous amounts of certain ions.[1] In India, agriculture is a crucial industry that produces the majority of the jobs in rural areas and accounts for roughly 16 percent of the GDP. One of the key factors that directly affect the health of people and other living things on the planet is the quality of the water.[2] More than two-thirds of the freshwater resources in the world are used for irrigation.[3]. Hydro-chemical indices including SAR, Na percent, KI, PI, and irrigation water coefficient have been employed by a lot of researchers.[4,5,6,7]

The rural population of India relies heavily on groundwater for residential uses including drinking. Around 65 percent of the world's agricultural land is irrigated with groundwater, making it the largest abstractor and primary user of groundwater resources.[8,9] Chloride, which is present in water, diffuses into the soil's water and builds up in plants' leaves. When the quantity of chloride surpasses the level at which crops can tolerate it, chloride toxicity results. However, it accumulates in the leaves and other plant parts similarly to chloride at larger amounts, which results in toxicity. Excess concentrations of cations and anions in water affect the productivity of crops, physicochemical properties of soil, decreasing fertility and damaging structure of soil.[10,11]

Plants and animals can be severely harmed by even small excesses of some metal species, which are necessary in trace amounts for their development and survival.[12,13]

Irrigation water quality standards were established on the basis of the total concentration of dissolved salts, in the form of cations and anions, which affects crops through the process of osmosis; the concentration of particular species, like chromium, which may be toxic to plants or have undesirable effects on crop quality, the concentrations of cations such as sodium that destroy the soil structure and decrease its permeability. These three factors were taken into consideration when developing the standards.[14]

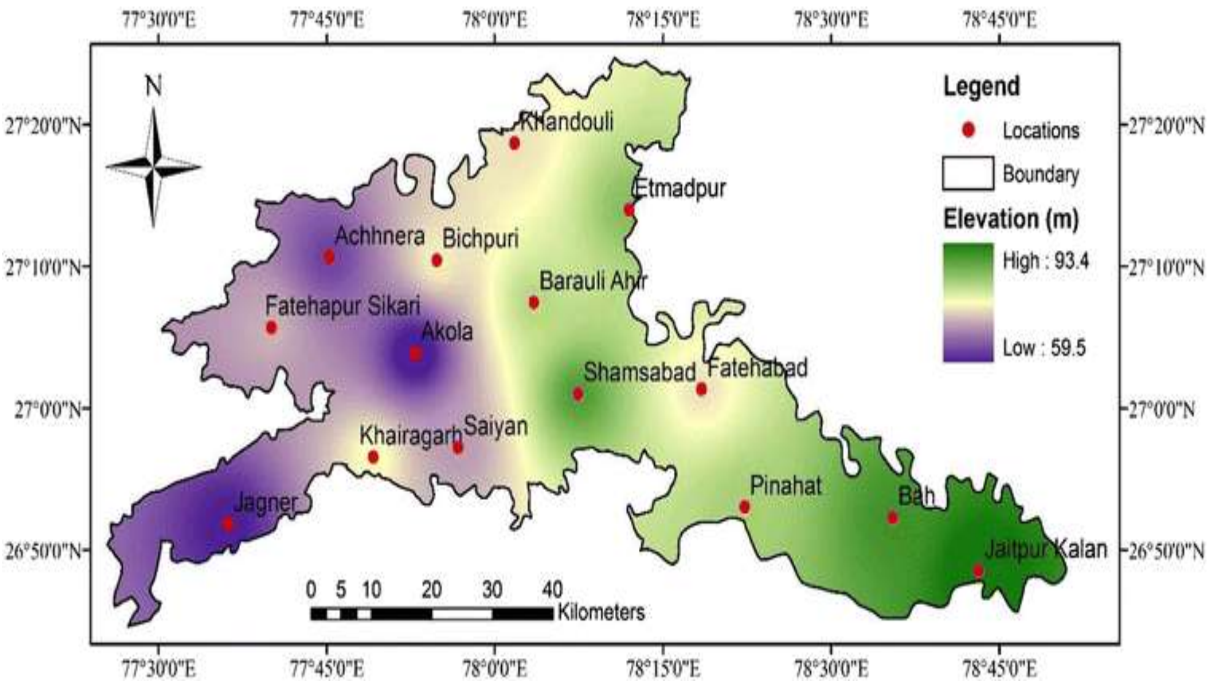
Irrigation accounts for 85% of India's total water use, which is followed by home usage (6%), the development of energy (3%), and industrial use (6%).[15]

In India 70% population lives in villages in which around 85% of rural population depends on the groundwater for drinking, domestic purposes.[16] Leaching of industrial waste and municipal solid waste (MSW), Use of chemical fertilizer and use of pesticide are one of the leading emerging sources of contamination for ground water quality, Groundwater may have many varieties of substances in the different concentrations in the form of solution or suspension.[17]The exponentially increasing rate of population, urbanization and industrialization is directly affecting to the availability and the quality of groundwater.[18] In the present research area, there is no data for the quality of groundwater used for agriculture irrigation. The goal of the research study is to create a database on the quality of groundwater and its suitability to use for agriculture irrigation. Electrical conductivity, sodium percentage, sodium absorption ratio, residual sodium carbonate, chloro-alkaline index, base exchange index, meteoric genesis index, permeability index, magnesium hazard and Kelly index were used to determine the suitability of groundwater for irrigation. The groundwater samples were also classified for irrigation using, the US salinity, Wilcox diagram and Gibbs plot, Therefore the current study was conducted for the assessment of groundwater quality for irrigation in Agra district of Uttar Pradesh.

Study Area:

The Agra district comes under the western part of the Uttar Pradesh. Yamuna and Chambal rivers flow in the region, the city of Agra situated in the bank of theYamuna River. The boundaries of district are shared with the two states, in west, Rajasthan state and Madhya Pradesh state is situated in the south.Districts surrounded to the Agra district are Mathura, Etah, Firozabad, Mainpuri and Etawah. Agra District encompasses an area of 4027 Sq. Km, and lies between latitude 26º44'10" to 27º24'30" North and longitude 77º 30'15" to 78º 51'30".The Agra district is a historical city and world famous for the Taj Mahal.

The Agra district is divided into six tehsils namely Bah, Fatehabad, Agra, Kiraoli, Etmadpur, Khairagarh. Study area comes under Tehsil Bah of Agra district and divided in to three blocks namely Bah, Jaitpur and Pinahat. Both Rabi and kharif crops are grown in the region and Major crops of the district are wheat, bajra, mustard and potato.Agra city is surrounded by many leather small scale industries and their effluents are discharged into the Yamuna River, Effluents discharged without complete treatment are causing impacts on the quality of the river water as well as underground water. About 80% population in Agra district of Uttar Pradesh depends on the groundwater for drinking and other purposes.



Map 1: Map of Agra district showing various Tehsil

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MATERIAL AND METHODS

Groundwater samples were collected from 84 locations of the tehsil Bah, Agra District and priority was given to the villages. The samples were collected from the different sources of groundwater as tube- wells, bore-wells and hand-pumps. The pH and electrical conductivity were measured immediately after collection of the sample in the field. Groundwater samples were collected in polyethylene bottles of 1 L capacity [19], before collecting the samples bottles were washed 2-3 times with the water to be sampled to avoid any type of cross contamination. Each sampling bottles were placed in an icebox to maintain the environmental condition and carried to the laboratory for further measurements. The quality of groundwater was analysed by adopting standard test methods and techniques given in the American public health association, 23rd Edition(APHA 2017)[20].Groundwater samples were analysed for physico-chemical characteristics such as pH, electrical conductivity (EC), total dissolved solids (TDS), anions (bicarbonate, HCO_3^-; carbonate, CO_3^{2-}; chloride, Cl^-; nitrate, NO_3^{2-}; sulphate,SO_4^{2-}; fluoride, F^-) and cations (calcium, Ca^{2+}; magnesium, Mg^{2+}; sodium, Na^+; potassium, K^+), followed by the laboratory analysis described in the American Public Health Association (APHA, 23rd Edition, 2017). Each sample was analysed twice, and the mean value was reported as final result.

The correctness of chemical analysis was examined using the ion–balancing [22] as given in Eq. 1.

$$e = \frac{(r_c - r_a)}{(r_c + r_a)} \times 100$$

Where rc is sum of the major cations and rais the sum of the major anions, values are expressed in milliequivalents per liter and e is the error percent. The ionic balance for all the analyses was within a limit of less than ±10%).

Based on the CPCB and CGWB (2000)[21]manual, four parameters, namely electrical conductivity, sodium absorption ratio, sodium percentage and residual sodium carbonate are considered for the evaluation of the water quality for irrigation uses. For all four parameters, a categorization criterion is used to assess the water quality of irrigation water by further dividing into five classes. These classes are excellent, good, medium, bad, and very bad. The classification criteria are presented in Table 1.

Table 1- Classification of water quality for agriculture irrigation (CGWB and CPCB 2000).

Water class	Na (%)	EC (µS/cm)	SAR	RSC (meq/l)
Excellent	< 20	< 250	< 10	< 1.25
Good	20–40	250–750	10–18	1.25–2.0
Medium	40–60	750–2250	18–26	2.0–2.5
Bad	60–80	2250–4000	> 26	2.5–3.0
Very bad	> 80	> 4000	> 26	> 3.0

RESULT AND DISCUSSION

Groundwater samples were collected from eighty-four location in the Tehsil Bah, Agra District, India. All the collected samples were analysed for sodium absorption ratio, sodium%, residual sodium carbonate, magnesium hazard, kelley's index, electrical conductivity, permeability index, results of the samples are given in Table-2.

Table 2- Summary of groundwater quality parameters for agriculture irrigation

Sample Location	Base Exchange Index	Meteoric Genesis Index	CAI	Na%	SAR	RSC	PI	MH	KI
Arnota-1	-0.13	-0.10	0.07	48.64	3.78	1.30	67.11	45.99	1.44
Arnota-2	0.13	0.18	-0.16	48.90	3.98	3.08	66.59	36.24	1.40
Arnota-3	0.33	0.37	-0.33	55.16	4.66	4.23	73.33	41.29	1.84
Basai Arela-1	0.18	0.23	-0.14	57.29	6.75	-2.02	70.97	39.92	2.00

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Sample Location	Base Exchange Index	Meteoric Genesis Index	CAI	Na%	SAR	RSC	PI	MH	KI
Basai Arela-2	0.13	0.23	-0.12	58.40	6.95	-3.35	72.14	41.38	2.14
Basai Arela-3	0.11	0.16	-0.10	58.08	6.46	-1.22	72.04	39.29	2.06
Nagala Bhari-1	-0.45	-0.40	0.30	32.58	1.90	1.25	52.45	36.60	0.70
Nagala Bhari-2	-0.55	-0.52	0.34	25.76	1.31	-1.34	44.39	37.46	0.50
Nagala Bhari-3	-0.22	-0.16	0.06	57.89	7.00	-3.61	70.15	33.04	1.97
Manik Pura-1	-0.61	-0.58	0.32	36.56	2.64	2.72	54.21	33.77	0.82
Manik pura-2	-1.01	-0.93	0.43	32.85	2.21	3.54	51.63	33.28	0.70
Manik pura-3	-0.77	-0.71	0.43	25.89	1.47	-0.13	44.79	38.24	0.51
Gurja Flu	-0.57	-0.54	0.40	26.17	1.44	1.18	46.18	37.98	0.52
Bhadrauli-1	-0.11	-0.04	0.02	51.85	4.41	1.18	67.86	33.63	1.55
Bhadrauli-2	-0.04	0.04	-0.02	44.84	3.52	-0.09	61.60	36.99	1.18
Bhadrauli-3	-0.50	-0.43	0.25	40.45	2.73	1.90	59.23	34.40	0.98
Pharaira-1	0.88	0.95	-1.47	49.09	3.31	4.24	69.00	30.48	1.37
Pharaira-2	0.40	0.51	-0.43	46.24	3.03	3.88	67.35	35.09	1.27
Bah-1	0.09	0.17	-0.10	38.30	2.79	-0.99	55.89	41.19	0.92
Bah-2	-0.06	0.01	0.00	52.83	5.05	-0.81	68.64	43.35	1.70
Bah-3	0.19	0.27	-0.12	44.12	3.43	-0.81	61.66	44.11	1.19
Jarar	-0.02	0.05	-0.03	29.58	1.79	0.44	48.92	41.05	0.62
Pinahat-1	0.21	0.32	-0.10	54.21	5.46	-1.73	68.51	36.89	1.73
Pinahat-2	0.42	0.51	-0.20	50.72	4.52	-0.56	66.18	36.37	1.50
Syahipura-1	-0.20	-0.07	0.03	48.55	4.55	-0.27	64.50	38.66	1.40
Syahipura-2	-0.17	-0.09	0.04	49.12	4.38	0.64	65.77	40.43	1.44
Chandrapur	0.41	0.48	-0.47	33.89	1.78	-0.55	52.68	30.76	0.72
Roop Pura	0.25	0.82	-1.11	25.67	1.38	0.66	49.22	37.79	0.56
Pahadpura	0.41	0.48	-0.47	33.89	1.78	-0.55	52.68	30.76	0.72
Natauli	0.25	0.31	-0.41	27.88	1.38	0.66	49.22	37.79	0.56
Holipura	0.20	0.30	-0.23	26.79	1.42	-0.91	46.34	40.78	0.54
Bateshwar	-0.32	-0.20	0.15	22.38	1.17	-0.78	41.58	39.38	0.43
Vipraoli	-0.87	-0.75	0.26	29.96	1.82	-0.84	49.04	43.54	0.64
Narhauli	-0.51	-0.39	0.16	30.68	2.03	-0.97	49.10	43.63	0.67
Gungawali	-1.21	-1.09	0.33	42.26	3.02	-0.04	58.98	30.37	1.04

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Harlalpura	-1.44	-1.34	0.42	43.69	3.17	0.26	60.19	28.57	1.09
Rani ka bagh	-1.05	-0.98	0.37	37.19	2.44	-0.39	53.92	28.99	0.83
Chousingi	-0.49	-0.37	0.13	49.28	4.64	-2.25	63.77	32.95	1.40
Chousingi-1	0.27	0.40	-0.17	51.79	4.66	-0.36	66.40	28.38	1.52
Changauli	-0.50	-0.36	0.13	45.24	3.70	-1.27	61.17	34.42	1.20
Sunsar	-1.09	-0.93	0.27	41.81	2.94	-1.39	58.73	34.38	1.05
Bichoula	-1.61	-1.43	0.39	33.52	2.07	-1.88	50.57	32.82	0.73
Gonsili	-1.13	-0.89	0.22	42.63	3.12	-2.38	58.92	34.59	1.09
Chamraua	-1.38	-1.14	0.27	43.60	3.28	-0.83	60.06	31.16	1.12
Hajarpura	-0.56	-0.24	0.05	52.70	4.90	-0.24	68.00	31.25	1.63
Vijoli	-0.33	-0.14	0.04	48.74	4.18	-2.12	63.60	31.54	1.37
Vijoli-1	-0.29	-0.03	0.01	53.04	4.97	-1.17	67.46	30.20	1.62
Kenjra	0.24	0.47	-0.12	49.01	4.06	-0.25	64.43	29.29	1.36
Bhagwanpura	-1.14	-0.94	0.22	48.87	4.04	-0.07	64.19	27.66	1.35
Basoni	-0.88	-0.71	0.15	53.38	4.71	-1.01	67.60	28.36	1.61
Kukthari	-0.79	-0.56	0.12	50.69	4.84	0.23	65.86	31.95	1.49
Sidhawali	-0.58	-0.37	0.08	52.00	5.01	-0.11	66.71	30.91	1.56
Pratap pura	-0.34	-0.10	0.03	50.93	4.78	-0.35	65.92	30.86	1.50
Rudmuli	-0.91	-0.71	0.18	46.22	3.76	-1.37	61.42	29.33	1.22
Abhaypura	-0.94	-0.74	0.19	45.28	3.58	-1.47	60.52	28.57	1.17
Lakhanpura	-1.14	-0.92	0.22	47.57	3.92	-0.90	63.24	30.77	1.31
Bamroli	-0.42	-0.19	0.06	52.23	5.17	-1.00	67.42	34.76	1.63
Vijkoli	-0.81	-0.58	0.15	52.31	5.24	-1.07	67.06	32.35	1.61
Mai	-0.54	-0.30	0.09	51.25	4.71	-1.02	66.28	30.46	1.53
Kwari	-0.50	-0.22	0.05	52.45	4.76	-1.48	66.99	28.37	1.59
Derak	-0.52	-0.33	0.11	52.18	5.18	0.51	67.31	30.95	1.60
Karkoli	-0.92	-0.66	0.16	54.88	5.58	0.02	69.32	28.03	1.76
Kherdanda	-0.57	-0.33	0.08	50.92	4.80	-0.71	65.99	32.10	1.51
Utsana	-0.50	-0.31	0.11	48.90	4.63	-0.74	64.28	33.14	1.41
Utsana-1	-0.36	-0.16	0.05	52.80	5.14	-0.44	67.29	28.57	1.61
Gajoura	-1.21	-1.00	0.25	53.45	5.44	-1.03	67.76	30.18	1.67
Paprinagar	-1.09	-0.85	0.24	55.13	5.75	-0.51	69.74	29.11	1.82
Paprinagar-1	-1.43	-1.20	0.29	53.08	5.28	-1.81	68.07	34.81	1.70
Pai	-1.52	-1.27	0.33	52.19	5.08	-0.25	68.05	33.77	1.65
Pai-1	-1.61	-1.35	0.33	48.37	4.60	-1.96	63.53	31.64	1.38
Badagaon	-1.76	-1.52	0.35	49.89	4.65	-0.63	65.22	30.25	1.46
Chitrahat	-2.00	-1.74	0.37	49.17	4.55	-0.49	63.97	25.60	1.38

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Richhapura	-1.91	-1.65	0.37	52.84	5.04	0.46	68.93	33.33	1.69
Kamtari	-1.06	-0.81	0.21	43.79	3.65	-1.20	59.64	31.74	1.13
Korath	-1.50	-1.28	0.26	47.81	4.02	-1.30	63.09	30.87	1.32
Khilawali	-1.40	-1.24	0.26	47.64	4.26	-1.15	62.57	31.98	1.30
Amahi	-1.61	-1.43	0.27	44.89	3.67	-1.24	59.98	29.63	1.15
KheraRathor	-1.45	-1.26	0.21	46.74	4.05	-2.42	61.80	35.15	1.27
Nawali	-0.81	-0.63	0.12	51.38	4.70	-1.06	65.61	29.30	1.49
Tasond	-1.65	-1.44	0.23	56.30	5.15	-0.60	70.77	30.89	1.85
Balai	-1.13	-0.92	0.17	47.94	4.16	-1.71	62.54	29.81	1.30
Kyori	-1.13	-0.84	0.14	50.24	4.72	-1.70	65.30	35.15	1.48
Sabora	-0.91	-0.67	0.14	48.23	4.28	-0.76	63.50	31.90	1.34
Pidhora	-0.75	-0.51	0.11	50.96	4.92	-1.39	65.66	32.35	1.51

All the values in the table are expressed inmeq/L except EC (in µS/cm) and Na%, PI, MH (in percentage).

Sodium adsorption ratio:

SAR is a measure of the amount of primary alkaline and earth alkaline cations in water that can be absorbed by plants. SAR values are important in determining water quality for agricultural irrigation because sodium replaces calcium and magnesium adsorption and damages soil structure by lowering the number of pores in the soil, making the soil structure more compact and impenetrable. Soil exchangeable sodium levels are more closely linked to this measurement, which can help determine whether or not irrigated water is suitable. An increase in soil permeability and structure may result from the use of high-sodium water for agriculture. When water has a high SAR value, soil treatment may be necessary to prevent long-term soil damage due to the displacement of Ca^{2+} and Mg^{2+} by salt in the water. Crop yields may be negatively affected as a result of reduced soil penetration and water permeability. All the values of samples tested are under excellent category as per the criterion of CPCB and CGWB. (2000). Maximum value of sodium absorption ratio is reported as 07 which is under <10, classified for the excellent category of water for agriculture purposes by the CPCB and CGWB. (2000).

The SAR is calculated using [22] with the ion concentrations expressed in milliequivalents/literas given in Eq. 2.

$$SAR = \left(\frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \right) \times 100$$

Sodium%:

The percentage of sodium (Na%), which is also known as soluble sodium percentage (SSP) is also used to assess the water quality for irrigation purpose. The sodium percentage in all kind of water is a commonly used parameter for the evaluation of suitability of water for agriculture irrigation. The sodium concentration in water induces the exchange of calcium and magnesium ions and deposited in to the clay particles, as a result Na% reduces soil permeability and cause for poor internal drainage. Sodium is as an important ion for classification of irrigation water, and it reduces permeability of soil by clogging of particles [23]. High level of sodium concentrations in irrigation water may result in absorption by clay particles, inducing the displacement of Mg^{2+} and Ca^{2+}, thus reduction in permeability of soil and weak interior drainage [24].The irrigation water's high concentration of Na^+ has a direct effect on plant development and the condition of the soil. Soil structure, infiltration, and aeration may be harmed if irrigation water contains a sodium concentration more than 60%, which might lead to a build-up of Na^+.

Na% values reported from 22.38 to 58.4 in which minimum reported value is 22.38 and maximum reported value is 58.4, all the reported values of Na% are come under the category of Good and medium as per the classification of CPCB and CGWB(2000). Values come under 20 are represent as excellent, 20-40 comes under good, 40-60 comes under medium, 60-80 is bad and > 80 is

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very bad quality of water for the agriculture irrigation.Na% is determined via calculation of all cations available in the relative proportion in water (Eq. 3), where all the concentrations are expressed in meq/l:

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

On the basis of SSP, irrigating water can be classified into:
% Na < 20% (Excellent), 20-40% (Good), 40-60% (permissible), 60-80% (Doubtful), % Na >80% (Unsuitable for irrigation)

Residual Sodium Carbonate:
The quality of the water may be affected if the total carbonate levels exceed the total calcium and magnesium levels. Scale is formed when the concentration of carbonates (residuals) in the water exceeds the concentration of calcium and magnesium. As a result, the sodium concentration and SAR both rise. According to Bulletin No. 197 of the USDA, water quality classifications can be modified based on the amount of residual sodium carbonate (RSC) stated in milliequivalent units (meq). It is considered safe to have a residual carbonate concentration of less than 1.25 meq. Those waters that have an RSC of 1.25-2.50 meq fall into the marginal category. A water's RSC is deemed excessively high when it exceeds 2.50 meq, making irrigation use difficult. Crop yields are affected by the continued use of high residual sodium carbonate water in agriculture. Groundwater samples from the study area have RSC values ranging from -3.61 to 4.24, according to the classification (CGWB and CPCB 2000) 7.1% samples are under bad and very bad category and 92.9% samples are fall in to excellent, good and medium category. Soil-applied gypsum may allow the safe use of water with RSC values over the acceptable limit. All of the data are presented in the form of milliequivalents per litre, as shown in Equation 4.

$$RSC = (CO_3^{2-}+HCO_3^{-}) - (Ca^{2+}Mg^{2+})$$

Magnesium Hazard:
MH is also a commonly used parameter to evaluate the suitability of water for agriculture irrigation. Magnesium hazard in irrigation water has a detrimental effect on soil structure. A high Mg^{2+} concentration in groundwater causes soil alkalinity and inhibits soil infiltration, both of which harm crops. Additionally, a substantial amount of water is adsorbed between magnesium and clay particles. Values greater than 50 indicate unsafe and unsuitable groundwater, whilst values less than 50 suggest safe and appropriate groundwater. Due to the high Mg^{2+} concentration in soils, the soil structure and crop yields are likely to be negatively affected [25]. In the study area, magnesium hazard values range from 25.60 to 45.99. Water with MH values more than 50 is regarded unfit for irrigation because of the negative impact on crop productivity. Agricultural irrigation can be done in the research area because all samples are below 50 milliequivalents per litre as stated in Equation 5.

$$MH = \left(\frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}}\right) \times 100$$

Kelley's Ratio:
The KI value is one of the most essential parameters to consider when assessing the quality of the water used in agricultural irrigation. Kelley's ratio values, which are stated in terms of meq/1, were determined by comparing the Na^{+} concentration to that of Ca^{2+} and Mg^{2+}. Values of KI that are greater than one is not suitable for use in agricultural irrigation, while values that are less than one is suitable for use in this application. The values of KI range from 0.43 to 2.14 in the study area. KI was calculated using Equation (6), where all ion concentrations are in meq/l.

$$KR = \left(\frac{Na^{+}}{Ca^{2+}+Mg^{2+}}\right)$$

Electrical Conductivity:
The dissolved solids in natural waterways come from rocks and soil weathering and are the result of high electrical conductivity (EC). The EC values were used to calculate the salinity hazard in this investigation.TDS in groundwater is reflected in electrical conductivity, a reliable indicator of crop salinity hazard. Because plants are unable to compete with ions in the soil solution for water, high EC water has a significant impact on crop productivity. The lower the EC, the less water is available to plants. As you can see, the values are represented in µS/cm.The EC value provides information regarding the amount of dissolved solids that are present in the water. In the current investigation, the range of EC values was from 841.1 to 2356 µS/cm and average value was 1561µS/cm.Water with an electrical conductivity value of less than 250 µS/cmis excellent, the EC values between 250 to 750 µS/cm

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is good for agriculture irrigation, the EC values are between 750 to 2250 µS/cm, water comes under highly saline category. When the EC value of groundwater is more than 2250 µS/cm then the groundwater is unsuitable for irrigation [26]. All values were belonging to highly saline category except one value (2356 µS/cm) which belongs to unfit for agriculture irrigation. The sustained use of water with a high electrical conductivity for irrigation led to the deposition of a large number of solids in the form of cations and anions, which caused the fertility of the soil to decrease, which in turn led to a lower crop yield.

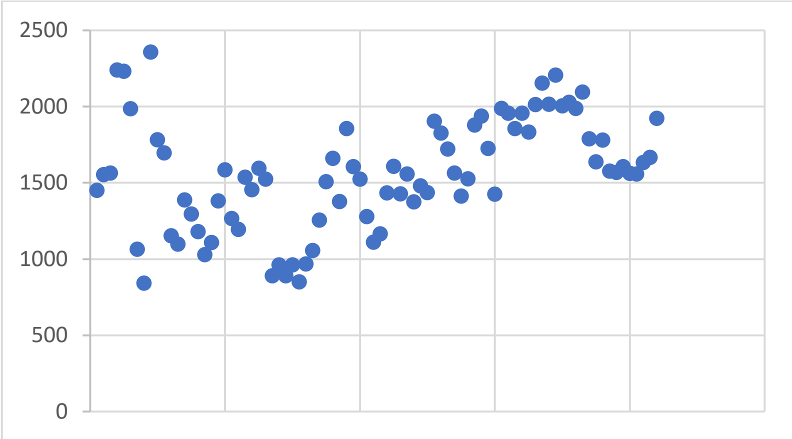

Fig. 1. Dot plot of conductivity (excellent < 250 µS/cm; good 250-750 µS/cm; high saline 750-2250 µS/cm; unsuitable > 2250 µS/cm)

Permeability index (PI):

Long-term irrigation has an effect on the soil's permeability, which in turn is controlled by the Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- levels present in the soil. The values of the PI indicate whether or not groundwater is suitable for use in irrigation. A permeability index that is lower than 60 is regarded as being suitable for irrigation and a result greater than 60 indicates that the groundwater is unfit for agricultural use.Values of the permeability index are varies from 41.58 to 73.33. PI is calculated using Eq.7, where all ion concentrations are in meq/l

$$PI = \left(\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+}\right) \times 100$$

Chloro-alkaline index (CAI)

It represents the ion-exchange between the groundwater and the aquifer both during movement and resting stage of water. CAI (CAI I & CAI II) is expressed in meq/l and was calculated by the equation given by Schoeller[27].

$$CAI\ I = \left(\frac{Cl^- - (Na^+ + K^+)}{CL^-}\right)$$

$$CAI\ II = \left(\frac{Cl^- - (Na^+ + K^+)}{SO_4^{2-} + HCO_3^- + NO_3^- + CO_3^{2-}}\right)$$

CAI is negative - When ion- exchange occurs between Na^+ and K^+ present in aquifer & Mg^{2+} and Ca^{2+} present in groundwater.

CAI is positive- When reverse ion-exchange occurs between Na^+ and K^+ present in groundwater and Mg^{2+} and Ca^{2+} present in aquifers.

Values of CAI are from -1.47 which comes under negative CAI to 0.43 which comes under positive CAI of the groundwater.

Gibbs plot

Many factors affect the chemical composition of natural groundwater: mineral content, geochemical conditions (such as pH and Eh), and exchange activities.[28]. More than 50 years ago, he established a typical groundwater evolution sequence for anions. According to the report, as salinity rises, groundwater chemistry shifts from HCO_3 to Cl^-type water. The dominant cation frequently shifts from Ca to Na, because calcite is found in many soils and aquifer-forming minerals, the evolution series begins with HCO^-_3. Carbonate minerals, due to their high solubility and widespread distribution, frequently dominate the chemical evolution of natural waters, even when present in trace amounts [29]. When rainwater (low TDS, Na-Cl) interacts with sediment and bedrock, it quickly

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changes to Ca-HCO_3 water. On Gibbs Diagram, the majority of fresh groundwater is found in the middle of the boomerang (water-rock interaction). The USGS Brackish Groundwater Database provides groundwater chemistry in Gibbs Diagram space [30].
The Gibbs diagram, 1970, helps comprehend how main processes impact groundwater chemistry. The Gibbs diagram was used to analyze groundwater chemistry and aquifer lithology. Its primary zones (evaporation, precipitation, and rock–water interaction) were studied. It is reported in meq/l for both anion(I) and cation(I).

Gibbs ratio for anion (I) = $\left(\frac{Cl}{Cl+ HCO_3}\right)$

Gibbs ratio for cation (II) = $\left(\frac{Na^{+}+ K^{+}}{Na^{+}+ K^{+} + Ca^{2+}}\right)$

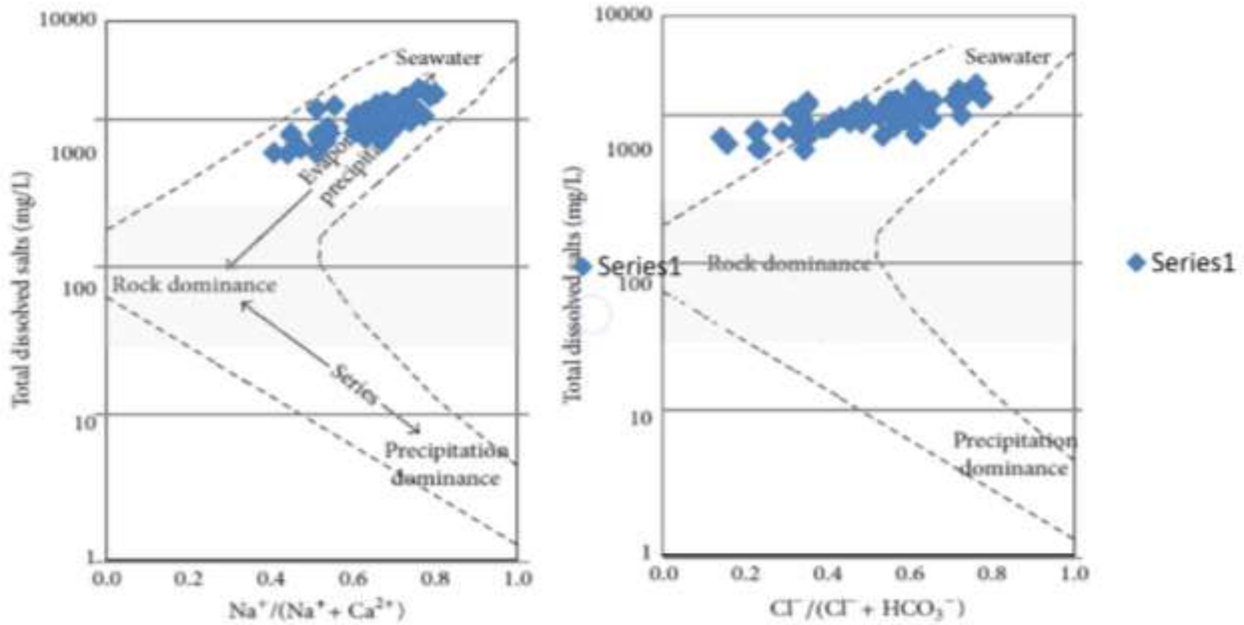

Fig. 2, Gibb's Plot of Tehsil Bah, Agra District

Wilcox's Diagram:

Wilcox (1955) evaluated sodium percentage and specific conductance to determine the suitability of groundwater for irrigation. Sodium percentage determines the ratio of sodium to total cations viz., sodium, potassium, calcium and magnesium. Groundwater samples in the study region show moderately high percentage of sodium and RSC values, When the concentration of sodium ion is high in irrigation water, Na^{+} tends to be absorbed by clay particles in the soil and displaced magnesium and calcium ions. The process of exchange of sodium in water for Ca^{2+} and Mg^{2+} in soil, it results in precipitation of calcium and magnesium bicarbonate,the high values of bicarbonate resulting the reduction of permeability and poor internal drainage in soil. The Wilcox diagram classified, most of the groundwater samples (96.4%) are unsuitable for irrigation, 3.6% samples classified as doubtful to unsuitable.
All the concentration values are expressed in equivalents per million (epm).

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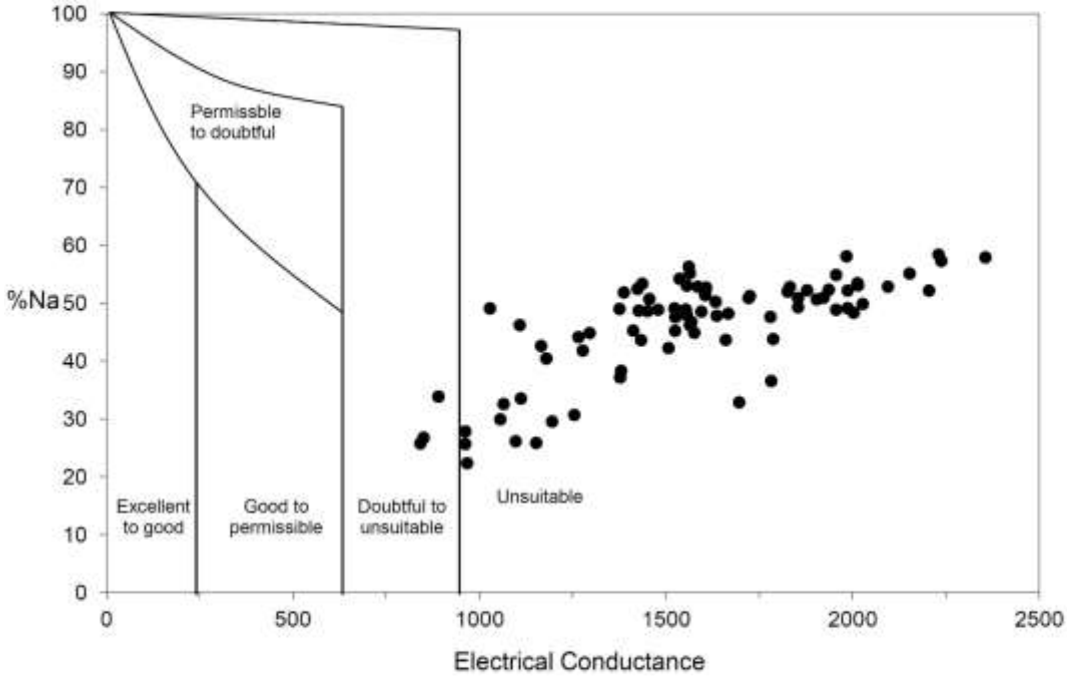

Fig. 3, Water classification and relation of %Na and electrical conductivity

USSL Diagram:

U.S. Salinity Laboratory diagram (1954) interpretation is given in Fig. 2. The water's suitability for irrigation was also determined using EC and SAR together. A semi-logarithm graph was plotted by taking SAR on X-axis and EC on Y -the axis as shown in figure, EC represents the salinity and SAR represents the alkalinity in the groundwater samples.According to SAR and electrical conductivity value plotted in US salinity diagram, it shows that all the samples are fall in to the C3–S1 and C3–S2 water class, it indicates water with a high salinity hazard and a low to medium sodium hazard.

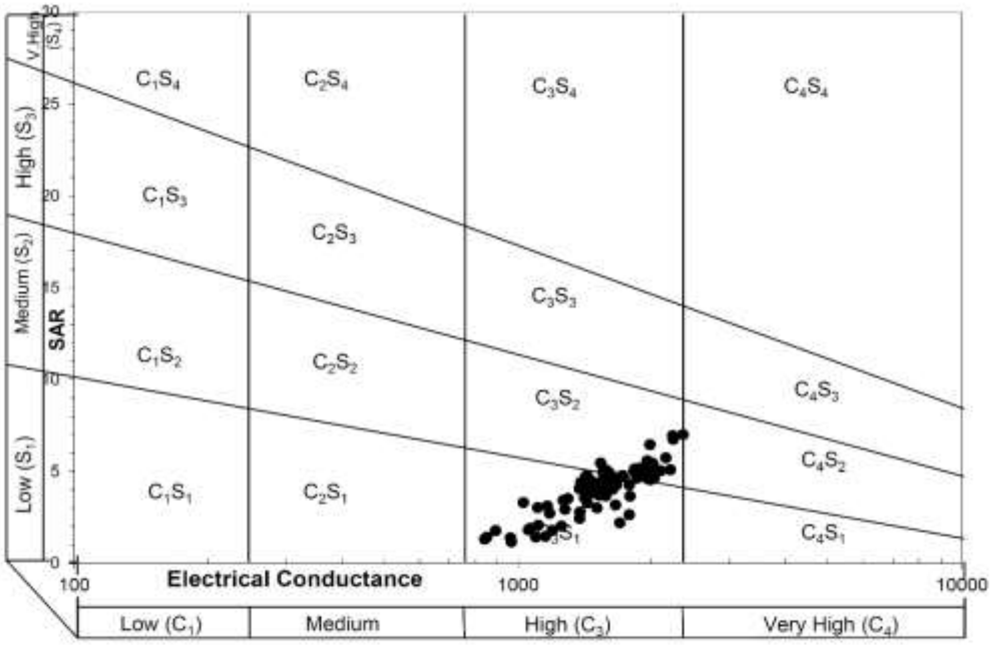

Fig.4, Classification and relation of salinity and sodium hazard

CONCLUSION

The suitability of groundwater quality of the Tehsil- Bah, Agra District was assessed by analysing various water quality parameters. The Wilcox diagram classified the groundwater samples (96.4%) are unsuitable for irrigation, 3.6% samples classified as doubtful to unsuitable.EC values are from 841.1 to 2356 µS/cm, the sustained use of water with a high electrical conductivity for irrigation led to the deposition of a large number of solids in the form of cations and anions, which caused the fertility of the soil to decrease, which in turn led to a lower crop yield. According to SAR and electrical conductivity value plotted in US salinity diagram, it shows that all the samples are fall in to the C3–S1 and C3–S2 water class, it indicates water with a high salinity hazard and a low to medium sodium hazard.RSC values are in the range from -3.61 to 4.24 in which 7.1% samples are under bad and very bad category and not fit for irrigation use and remaining 92.9% samples are fall in to excellent, good and medium category, according to the classification, excessively high RSC water (≥2.50 meq) making irrigation use difficult, crop yields are affected by the continued use of high residual sodium carbonate water in agriculture. In the study area, magnesium hazard values range from 25.60 to 45.99. Water with MH values more than 50% is regarded unfit for irrigation because of the negative impact on crop productivity, all samples are below 50%.Values of KI that are greater than one are not suitable for use in agricultural irrigation, while values that are less than one are suitable for use in this application. The values of KI range from 0.43 to 2.14 in the study area. A permeability index that is lower than 60 is regarded as being suitable for irrigation. And a result greater than 60 indicates that the groundwater is unfit for agricultural use. Values of the permeability index are varies from 41.58 to 73.33, All the reported values of Na% are come under the category of good and medium category.

It is found that water quality of the area is under declining stage as 96.4% of the samples are unsuitable for irrigation and all the samples are under high salinity. 7.1% samples of RSC are under bad and very bad category and not fit for irrigation use. Over exploitation of groundwater for irrigation and other purposes are the main reason behind the declining of groundwater quality of the study area. Good management practices to recharge and replenishment of groundwater is strongly recommended.

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