CURRENT WORLD ENVIRONMENT

ISSN: 0973-4929, Vol. 16, No. (1) 2021, Pg. 18-33

Current World Environment

www.cwejournal.org

Hydro chemical Assessment of Ground Water in North-Eastern Region of India: a Case Study of Western Suburb of Jorhat Town of Assam, India

PARAN JYOTI KALITA[1, 2], CHAMPA GOGOI[1, 3], SAUSTHOV MAUNASH BHATTACHARYYA[4] and RAJIB LOCHAN GOSWAMEE[1]*

[1]Advanced Materials Group, Materials Science & Technology; Technology Division, CSIR-North East Institute of Science & Technology; Technology, Jorhat, Assam.
[2]Dept. of Chemistry, Gauhati University, Guwahati, Assam, India.
[3]Dept. of Chemistry, CNB College, Bokakhat, Golaghat, Assam, India.
[4]Geo Sciences & Technology; Technology Division, CSIR-North East Institute of Science & Technology; Technology, Jorhat, Assam.

Abstract

In the current study, the quality of ground water (GW) from an area of western part of Jorhat district of Assam (India) was assessed in order to ensure the safety of its use in irrigation and drinking purposes. The physico-chemical parameters of the collected GW samples were evaluated and compared the data with the Indian Standards (IS) for drinking purposes. The investigation was mainly emphasised on the evaluation of Water Quality Index (WQI) and different parameters for the quality measurement of water for drinking and irrigation purposes, respectively. Correlations among the physico-chemical parameters were evaluated through statistical analysis. The physico-chemical parameters revealed that almost all the parameters except iron were within the permissible limit. Arsenic was found to be present in few water samples in both seasons (pre and post monsoon). In both the seasons, the WQI of the majority of collected water samples were observed to be falling under the poor category for drinking. Almost all the collected water samples were found to be fit for irrigation purposes. However, based on sodium percentage (Na %), Kelly's ratio (KR), and Magnesium ratio (MR), few of the water samples are classified to be doubtful and inappropriate for irrigation.

Article History
Received: 08 June 2020
Accepted: 01 January 2020

Keywords
Drinking Water Quality;
Ground Water;
Irrigation Water Quality;
Water Quality Index.

CONTACT Rajib Lochan Goswamee goswamirl@neist.res.in Advanced Materials Group, Materials Science & Technology; Technology Division, CSIR-North East Institute of Science & Technology; Technology, Jorhat, Assam.

© 2021 The Author(s). Published by Enviro Research Publishers.
This is an Open Access article licensed under a Creative Commons license: Attribution 4.0 International (CC-BY).
Doi: http://dx.doi.org/10.12944/CWE.16.1.04

Introduction

In this world, clean and safe water for drinking is one of the important fundamental needs for the survival of human being on earth.[1] In India accessibility of drinking water is a challenging task. In recent years, resources of fresh water system have been affected by the rapid population growth as well as development of economic system.[2, 3] All over the world, water plays the key role in the transmission of different water borne diseases and hence maintenance of the quality of drinking water has become a universal health concern.[4] Throughout the world, natural potable water resources are exceedingly decreasing due to disturbances caused by human race. In addition to this, occurrence of various types of pollutants, including the heavy metals, introduced to water through natural or anthropogenic activities causes toxic and harmful effects to the individuals and the environment.[5] In India, arsenic and fluoride are such pollutants of groundwater which have been identified as a major problem and therefore, mitigation measures are in progress to solve these issues. Presence of many inorganic anions and oxy-anions in water such as AsO_4^- , AsO_3^-, F^-, Cl^-, HCO_3^-, SO_4^{2-}, PO_4^{3-}, NO_3^- in elevated amounts can also deteriorate the quality of water. So, assessment of these ions in water is of utmost importance for safety of people and environment. Apart from chemical composition, the accessibility of safe water with high quality index for its use in agriculture, irrigation, and drinking purposes is important for disease free high quality life. In India, ground water is the most reliable source for drinking, agriculture, and irrigation.[6] Most of the people in India, rely on ground water supply for drinking as well as for irrigation.[7,8] Therefore, the public health-related issues are of immense concern to the government. In rural areas, people are more dependent on ground water for drinking, and hence the quality evaluation of ground water is an essential concern for the heath of rural people.[9, 10] To know about the usability of a water source of particular region, the water quality assessment is highly essential for the region.

In our present study, 69 number of ground water samples from Saroocharai and Charaibahi *Mouza* (a unit of cluster of villages made for land revenue collection) in western sub urban fringe of Jorhat town of Jorhat District, Assam were collected for evaluation of quality to know about their usability for irrigation and drinking. The area is selected for study due to its importance as one of the important academic, business and strategic centre of North East India. The area under investigation has strong presence of both tea and oil industry. It is a mix of urban, urban over growth, semi urban and rural localities where most of the people are dependent on ground water for drinking and domestic uses. The chosen Charaibahi *Mouza* have important research and academic institutions like two national laboratories, two universities, minimum five hospitals, three medical education institutes, one management institute, a historical government prison, airport, important defence and police establishments, several high schools etc. On the hand the Saroocharai *Mouza* situated to the north and separated from the adjoining Charaibahi *Mouza* by national highway no 37 is predominantly an agricultural area with some large tea garden and a big ancient paddy field called *Malow Pathar* as the mainstay of the agricultural background. With increasing population, urbanisation, and real estate development, both these areas are growing areas for future denser settlement development as well as immediate agricultural, dairy, and animal products source zones.

To know about the usability of ground water of these two areas for drinking, various physicochemical parameters were determined and checked their permissibility limit with the available standards. WQI of the each water samples were evaluated in order to know the quality of GW for drinking. Also, various parameters such as Sodium Adsorption Ratio (SAR), Sodium Percentage, Kelly's Ratio (KR), Magnesium Ratio (MR), and Corrosivity Ratio (CR), Residual Sodium Carbonate (RSC) were evaluated to check the quality of the ground water for irrigation.

Materials and Methods

Study Area

The sites of Saroocharai and Charaibahi *Mouza* (latitude 26°43.2150 -26°48.2070' N and longitude 94°5.2740'- 94°11.5500'E) of western part of Jorhat town of Assam, India as depicted in Figure 1 were selected for the collection of GW sample. The climate of Jorhat District is sub-tropical humid (wet) with dry winters. The average temperature in winter season is 16.6°C and in summer it is 28.9°C. However, the minimum temperature in winter can come down to 9.9°C and in summer maximum temperature can go up to 36.8°C. The annual rain fall in Jorhat District in 2017 was 2107 mm with a monthly average rain fall of 176 mm. The northern part of the investigated area is situated on the flood plains of the western banks of Bhogdoi river, a southern bank tributary of Brahmaputra River. The top soil quality of the area is mostly alluvial soil. The water being exploited for drinking and domestic purposes are mainly from shallow tube wells. In our present study, assessment of ground water was done by collecting water from these wells.

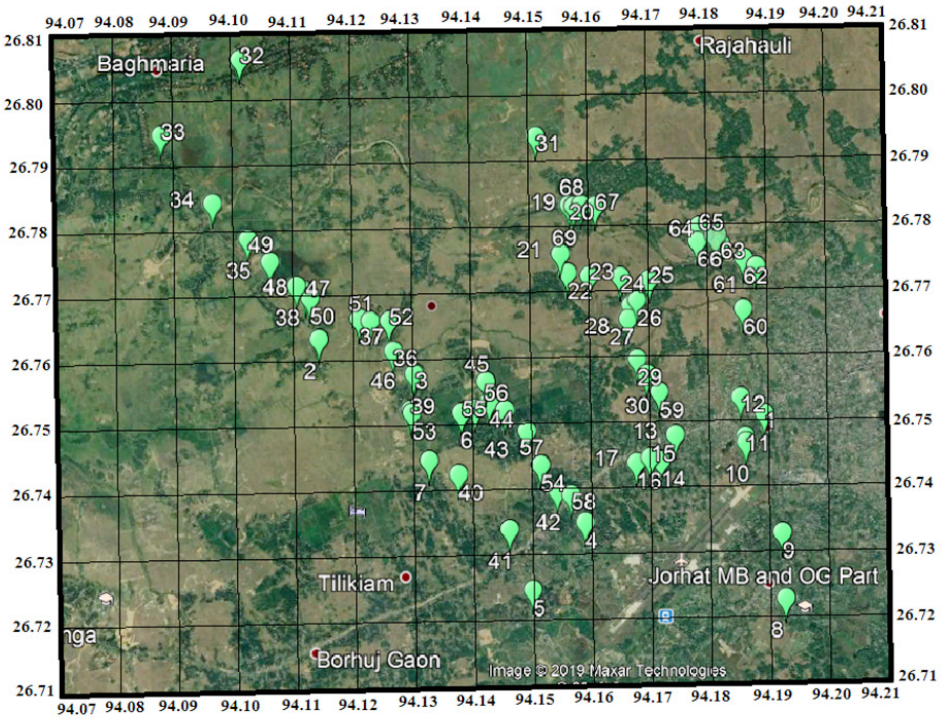

Fig.1: Map of the study area of Saroocharai and Charaibahi *Mouza*, located in the western part of Jorhat Town of Assam (India) modified from Google earth

Ground Water Sampling and Analysis

Total sixty nine ground water (GW) samples were collected from various locations of Saroocharai and Charaibahi *Mouza* of western part of Jorhat town of Jorhat district during pre monsoon period (May to June) and during post monsoon period (November to December) in the year 2017. Hand pumps or bore well water sources were selected for ground water sample collection. Polythene bottles of 1L capacity were used for sample collection after washing with 8 M nitric acid and then with distilled water for several times. The bottles were rinsed with sample water for three times before sample collection.[11] The water samples taken for arsenic (As) determination were maintained at pH (<2) and was kept at 4°C in laboratory refrigerator (Remi RRF-250). The water samples were taken for determination of physicochemical parameters like pH, total hardness (denoted as TH), total alkalinity (denoted as TA), crucial anions such as HCO_3^-, Cl^- NO_3^-, and SO_4^{2-}; component such as F^-, PO_4^{3-}, primary cations- Na^+, and K^+, Mg^{2+}, Ca^{2+}; and heavy metal like iron were kept at 4°C in a laboratory refrigerator (Remi RRF-250). Flame photometer (Systronic Flame photometer 128) was used to determine Na^+ and K^+, the anions SO_4^{2-}, PO_4^{3-}, NO_3^--, Cl^- were determined by using an 881 Compact IC pro Metrohm ion chromatograph (Made Switzerland). Total dissolved solid (denoted as TDS) was determined with TDS meter, (EUTECH Instruments). Ca^{2+}, Mg^{2+} and HCO_3^- were determined by titrimetric method (APHA 1988).[11] The concentration of iron was measured by 1, 10-Phenanthroline method using an UV visible spectrophotometer (Shimadzu 05500) at 510 nm (APHA 1988).[11] Arsenic concentrations were determined in atomic absorption spectrometer, Make: Perkin Elmer, Model: AAnalyst-700. Orion 4 star (pH/ISE) ion selective electrode was used to detect the presence of fluoride (F-) in water samples after calibration with 0.1, 1, 10 mgL^{-1} standard fluoride solutions. Conductivity meter 306 (Made Systronic) was used to measure electrical conductivity (EC). pH was measured at the time of collection of water sample by using a hand pH meter (Model: pHep made by Hanna Instruments).

Statistical analysis was done by using Statistical Package for Social Sciences (IBM SPSS statistics Version 25). The software was used to determine descriptive statistics and to evaluate the correlation among different parameters. Origin software was used to draw different plots. The Longitude and Latitude of the regions under the study are listed in Table 1.

Table 1: Description of sample collection site

Sample Code No	Latitude (deg N)	Longitude (deg E)	Sample Code No	Latitude (deg N)	Longitude (deg E)
1	26.74821	94.18938	36	26.75860	94.12673
2	26.76056	94.11420	37	26.76361	94.12103
3	26.75510	94.13041	38	26.76871	94.11051
4	26.73218	94.15880	39	26.74958	94.12948
5	26.72208	94.14976	40	26.73975	94.13748
6	26.74966	94.14051	41	26.73130	94.14598
7	26.74190	94.13253	42	26.73701	94.15416
8	26.72025	94.19249	43	26.74611	94.14916
9	26.73021	94.19208	44	26.75073	94.14288
10	26.74395	94.18620	45	26.75371	94.14233
11	26.74478	94.18608	46	26.75505	94.13018
12	26.75078	94.18540	47	26.76771	94.11211
13	26.74521	94.17426	48	26.76796	94.11208
14	26.74128	94.17175	49	26.77248	94.10608
15	26.74181	94.16998	50	26.76685	94.11278
16	26.74108	94.16759	51	26.76323	94.12289
17	26.74110	94.16766	52	26.76320	94.12609
18	26.74108	94.16764	53	26.74916	94.12973
19	26.780216	94.15768	54	26.74096	94.15141
20	26.78040	94.15693	55	26.74906	94.13813
21	26.77300	94.15530	56	26.74936	94.14550
22	26.77006	94.15643	57	26.74096	94.15141
23	26.76958	94.16011	58	26.73640	94.15648
24	26.76936	94.16540	59	26.75175	94.17166
25	26.76888	94.17023	60	26.76418	94.18610
26	26.76578	94.16814	61	26.77068	94.18840
27	26.76496	94.16710	62	26.77191	94.18630
28	26.76288	94.16658	63	26.77413	94.18246
29	26.75678	94.16801	64	26.77486	94.18160
30	26.75445	94.16963	65	26.77686	94.17886
31	26.79096	94.15141	66	26.77460	94.17853
32	26.80345	94.10141	67	26.78020	94.16130
33	26.79201	94.08790	68	26.78040	94.15891
34	26.78151	94.09649	69	26.78020	94.15768
35	26.77600	94.10240			

Results and Discussion

Assessment of Ground Water for Drinking

The evaluation of different physicochemical parameters of ground water samples is very much essential to check their suitability for drinking. Therefore, the parameters were evaluated and the statistical summary is listed in Table 2.

Table 2: Physicochemical characteristic of collected water samples in Pre monsoon (pr-) & post monsoon (pos-) season

Parameters	Unit	Minimum		Maximum		Mean		SD		WHO permis -sible Limit
		Pr-	Pos-	Pr-	Pos-	Pr-	Pos-	Pr-	Pos-	
pH	-	5.2	5.5	7.7	7.2	6.5	6.3	0.611	0.433	6.5-8.5
EC	μscm^{-1}	155.8	156.7	224.5	222.4	179.1	181.1	16.9	15.8	1000-2000
Hardness	mgL^{-1}	39.8	40.8	118.4	120.2	66.1	68.7	19.8	33.67	500
TDS	mgL^{-1}	162.9	165.6	212.9	219.7	180.5	184.5	13.0	12.8	1000
Ca^{2+}	mgL^{-1}	6.57	7.13	18.35	18.59	10.98	11.16	2.95	2.99	100
Mg^{2+}	mgL^{-1}	5.36	5.60	17.69	17.98	9.43	9.94	3.12	3.1	150
Na^{+}	mgL^{-1}	2.1	1.1	11.3	14.6	5.7	4.5	2.34	2.68	200
K^{+}	mgL^{-1}	2.00	3.1	14.5	13.5	9.4	9.5	3.46	2.64	12
Fe	mgL^{-1}	0.6	0.6	5.9	5.4	3.1	3.3	1.27	1.2	0.3
Cl^{-}	mgL^{-1}	1.2	3.26	8.0	9.45	6.69	6.35	1.42	1.098	250
SO_4^{2-}	mgL^{-1}	0.138	0.198	0.747	0.946	0.232	0.287	0.0844	0.101	400
PO_4^{3-}	mgL^{-1}	0.18	0.1	2.58	1.33	0.644	0.453	0.438	0.272	0.10
F^{-}	mgL^{-1}	BDL	BDL	0.650	0.710	0.303	0.380	0.135	0.146	1.5
NO_3^{-}	mgL^{-1}	0.18	0.12	11.95	10.54	2.77	2.30	2.54	2.31	50
As	mgL^{-1}	BDL	BDL	0.07	0.056	0.007	0.0047	0.014	0.009	0.01
TA	mg/L	92.2	100	108.9	135	95.6	107.8	3.05	7.4	200

The collected ground water (GW) water samples have pH ranges from 5.2 to 7.7 in pre monsoon seasons (mean 6.5) and from 5.5 to 7.2 in post monsoon season (mean 6.3). From the pH data it was found that in pre-monsoon season 20.29 % of water samples and in the post-monsoon season 25 % of water samples have acidic pH. The percentage of GW water samples having alkaline pH in pre monsoon season was found to be 33.33% and in post monsoon season it was 8.83%. However, all the GW samples had pH within permitted range (6.5-8.5) of World Health Organisation (WHO 2011).[12] On the basis of pH values the water sources were found to be appropriate for drinking as well as for irrigation. The presence of slightly acidity in some GW can be attributed to the dissolution of atmospheric carbon dioxide and organic acids like fulvic and humic acid, which are formed from the decay and following leaching of plant materials.[13] Use of ammonium sulphates and super phosphate of lime as fertilizers may also lower the pH since the area is full of agricultural land.[13] On the basis of pH value the water samples were classified in four pH zones as shown in Table 3.

Table 3: Samples Categorization on the basis of pH

Range	% of water sources	
	Ground water	
	Pre-monsoon	Post-monsoon
<6.0	20.3	25
6.0-6.5	30.4	42.6
6.5-7.0	15.9	23.5
>7.0	33.4	8.8
Total	100	100

The TDS values of the GW samples was found to be in the range of 162.9-212.9 mgL^{-1} (Mean 180.5 mgL^{-1}) in the pre-monsoon season and 165.6-219.7 mgL^{-1} (mean 184.5 mgL^{-1}) in the post-monsoon season. All the GW samples were found to have TDS value below the World Health Organisation (1984) limit.[14] As per the threefold classification proposed by Davis and Dewiest (1966), all the water samples could be considered as domestic category (TDS value < 500 mgL^{-1}) as shown in Table 4.[15]

Table 4: Samples Categorization on the basis of Total Dissolved Solid (mgL^{-1})

Range	Water category	% of water sources Ground water Pre-monsoon	% of water sources Ground water Post-monsoon
<300	Excellent	100	100
300-600	Good	0	0
>	Poor and Unacceptable	0	0
Total		100	100

The Hardness (as $CaCO_3$) of the GW samples were found to be in the range of 39.8-118.4 mgL^{-1} (mean value 66.1 mgL^{-1}) in pre-monsoon season and 40.8-120.2 mgL^{-1} (mean value 68.7 mgL^{-1}) in the post-monsoon season. However, all the ground water samples were found to have hardness values below the permissible limit of World Health Organisation (1984), which is 500 mgL^{-1}.[14] According to Durfor and Becker (1964) classifications, the water samples can be classified into four categories as shown in Table 5.[16]

Table 5: Samples Categorization on the basis of Total Hardness (mgL^{-1})

Class	Hardness	% of water sources Ground water Pre-monsoon	% of water sources Ground water Post-monsoon
Soft	0-60	50.7	42
Reasonably hard	61-120	49.3	58
Hard	121-180	0	0
Very Hard	>180	0	0
Total		100	100

The acid neutralising capacity of water is expressed in terms of alkalinity.[17] Alkalinity of ground water originates mainly from carbonates and bicarbonates.[18] The acceptable limit for alkalinity is 200 mgL^{-1} and in the absence of other alternate source alkalinity up to 600 mgL^{-1} could be accepted for drinking purpose (IS 10500-1991).[19] Carbonate alkalinity in the studied samples were absent which is due to the fact that carbonate anion is generally exist in water at pH more than 8.3.[13] The total alkalinity in the studied samples arises from the presence of bicarbonates. The alkalinity of studied water samples were found in the range from 92.2-108.9 mgL^{-1} (mean 95.6mgL^{-1}) in the pre-monsoon period and 100.0-135.0 mgL^{-1} (mean 107.8 mgL^{-1}) in the post-monsoon period.

The concentration of ionised substances in water was measured in terms of Electrical Conductivity (EC) of water.[8, 20] In our present study, the EC was found to be varied in the range 155.8 μscm^{-1} to 224.5 μscm^{-1} (mean179.1μscm-$^{-1}$) in the pre monsoon and 156.7 μscm^{-1} to 222.4 μscm^{-1} (mean 181.1 μscm^{-1}) in the post monsoon period.

The Ca^{2+} in the collected GW samples were found to lie in the range of 6.57-18.35 mgL^{-1} (mean 10.98 mgL^{-1}) in pre monsoon period and 7.13-18.59 mgL^{-1} (mean 11.16 mgL^{-1}) in post monsoon period. Similarly, the Mg^{2+} were found to be in the range of 5.36-17.69 mgL^{-1} (mean 9.43 mgL^{-1}) and 5.60 -17.98 mgL^{-1} (mean 9.94 mgL^{-1}) in the pre and post-monsoon periods respectively. In the two seasons all the ground water samples have concentration of Ca^{2+} and Mg^{2+} within the desirable limit set by BIS (2004) which is 75 mgL^{-1} for Ca^{2+} and 30 mgL^{-1} for Mg^{2+}.

The amount of Na^+ in the GW samples were found in the range of 2.1-11.3 mgL^{-1} (mean 5.7 mgL^{-1}) in the pre monsoon season and 1.1-14.6 mgL^{-1} (mean 4.5 mgL^{-1}) in the post monsoon period, respectively. The K^+ content of ground water samples were found to be in the range of 2.0-14.5 mgL^{-1} (mean 9.4 mgL^{-1}) in the pre-monsoon period and 3.1-13.5 mgL^{-1} (mean 9.5) in the post-monsoon period respectively. From the collected data it was found that 23.5 % of ground water samples in pre-monsoon season and 11.8 % GW samples in the post-monsoon period have slightly higher value of K^+ than the desirable limit of 12 mgL^{-1}. WHO (2011) and BIS (2004) recommended value for Na^+ is 200 mgL^{-1} and K^+ is 12 mgL^{-1} in drinking water. However, for all the samples, the Na^+ is found to be within the recommended value of 200 mgL^{-1} (WHO 2011, BIS 2004). From the above results for Na^+ and K^+, it may be stated that the water quality of the ground water in the studied area are suitable for consumption in domestic and drinking purposes.

Amount of iron content in the GW samples were found to be in the range of 0.6-5.9 mgL^{-1} (mean 3.1 mgL^{-1}) in the pre-monsoon period and 0.6-5.4 mgL^{-1} (mean 3.3 mgL^{-1}) in the post-monsoon season respectively. In both the seasons GW has iron content more than the permissible limit of 0.3 mgL^{-1} (IS 10500: 2012).[21] The quality of water samples based on iron content is listed in Table 6. It is already reported that dissolution of iron is about 105 times greater at pH 6 than at pH 8.5.[13] Since our study area is acidic (Average pH <7), it is supposed that when the water percolates down it dissolves large amount of iron from soil.

Table 6: Samples Categorization on the basis of Iron content

Range	% of water sources	
	Ground water	
	Pre-monsoon	Post-monsoon
<0.3 mgL-1	0	0
0.3-1.5	8.7	11.76
1.5-5.0	81.2	82.35
>5.0	10.1	5.88
Total	100	100

GW chloride anion was found to be varying in a wide range of values from 1.2-8.0 mgL^{-1} (mean 6.69 mgL^{-1}) in the pre monsoon season and from 3.26-9.45 mgL^{-1} (mean 6.35 mgL^{-1}) in the post-monsoon seasons. The studied water samples have low chloride content in both the seasons which may be due to the fact that there is no industrial activities and also rate of seepage of domestic and agricultural wastes in to water bodies is very low in the study area.[22] Every samples were found to have chloride content within the permitted limit of WHO (600 mgL^{-1}) and therefore, suitable for drinking and domestic uses.

The range of SO_4^{2-} content in the studied GW samples were found to fall in the range of 0.138-0.747 mgL^{-1} (mean 0.232 mgL^{-1}) in pre-monsoon season and 0.198-0.946 mgL^{-1} (mean 0.287 mgL^{-1}) in post-monsoon season. All the water sources in both seasons have sulphate content within the permitted limit (200 mgL^{-1}, WHO 2004) for drinking and domestic purposes.

The GW samples were found to have NO_3^- in the range of 0.18-11.95 mgL^{-1} (mean 2.77 mgL^{-1}) in the pre-monsoon period and 0.12-10.54 mgL^{-1} (mean 2.30 mgL^{-1}) in the post-monsoon season respectively. However, all the samples in both the seasons were found to have NO_3^- content less than the permitted value of WHO (2004) which is 50 mgL^{-1} for drinking water. High NO_3^- content may cause many health related issues such as methemoglobinemia or blue baby syndrome and cause to develop gastric an intestinal cancer.[23] The NO_3^- content in GW samples of our study area was found to be very low amount to cause such situation.

The concentrations of PO_3^{3-} in our studied samples were found to fall in the range of 0.18-2.58 mgL^{-1} (mean 0.644 mgL^{-1}) in the pre-monsoon period and 0.1-1.3 mgL^{-1} (mean 0.453mgL^{-1}) in the post-monsoon period. However, the WHO permissible limit for PO_4^{3-} is 0.1 mgL^{-1} (WHO 2004). In GW water samples of both seasons the PO_4^{3-} contents are slightly higher than the permissible limit of drinking water. Weathering of rocks containing phosphate and percolation of agricultural runoff carrying residual fertilizers may be the reason of high PO_4^{3-} contents in GW.[13]

The fluoride (F-) content in the collected water samples in both seasons was found to be very low. For GW samples in the pre-monsoon period the range is Below Detectable Limit (BDL) -0.650 mgL^{-1} (mean 0.303 mgL^{-1}) and in the post monsoon-season the range is BDL-0.710 mgL^{-1} (mean 0.380 mgL^{-1}). In India the maximum permitted value of fluoride in drinking water is 1.5 mgL^{-1}.[21] So, in our studied area there is no risk for fluoride (F^-) contaminated water and its health related issues.

Arsenic (As) content in water is a very important parameter to know especially for its suitability for drinking. In our present study, water samples collected in the pre-monsoon season were found to have Arsenic (As) content in variable amount from BDL-0.07 mgL^{-1} (mean 0.007 mgL^{-1}). Twelve numbers of samples (17.4%) were found to have Arsenic (As) content above permitted limit in pre-monsoon season. In post- monsoon, Arsenic (As) content in GW samples was found to fall in the range BDL to 0.056 mgL^{-1} (mean 0.0047 mgL^{-1}). Only seven numbers (10.1%) of samples were found to have Arsenic (As) above WHO permissible limit of 0.01mgL^{-1}. 24

The study clearly revealed that the concentration of most of the water quality constituents are under permissible limit of WHO, except the water samples have elevated concentration of iron, calcium and magnesium. Very few water samples have Arsenic (As) content above the permissible limit of WHO.

To know about the suitability of ground water samples for drinking, WQI of each water samples were evaluated for the wide-ranging depiction of ground water quality. It was calculated in three major steps following the method reported in literature.[10] IS specific for drinking water (BIS 1991), was applied for the computation of WQI.[25] In the first step, different water parameters such as TDS , pH, TH, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, F^-, Ca^{2+}, Mg^{2+}, Fe, As etc were assigned weight (wi) in accordance with their importance in the water quality for drinking. Different weights assigned to each parameter based on their importance are as given in Table7. In second step, the following equation was applied to determined the relative weight (Wi) of each chemical parameter

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi}$$

Where, the relative weight is represented W_i

Weight of each parameter is represented by w_i

Total number of parameters is represented by n.

The computed relative weight (W_i) of each chemical parameter is shown in Table 7.

- Chemical parameters are expressed in mg/L
- Lower values signifies desirable limit, and higher value signifies permissible limit when there is no alternate source.[25]

In the final step, to calculate the quality rating scale (q_i) for the parameters the following equation was used

q_i= (C_i/S_i) X 100

Here,

q_i, the quality rating

Each chemical parameter's concentration in each water sample is represented by C_i in mgL^{-1}. IS of drinking water for each parameter is represented by S_i in mgL^{-1}.

For calculation of WQI, the sub index (SI) for each parameter is determined first according to the equation given below

SIi=Wi X qi

WQI=∑ SIi-n

Here,

SI_i, sub index of i^{th} parameter;

W_i, relative weight of i^{th} parameter.

q_i ,is the rating calculated on the basis of concentration of i^{th} parameter,

n, the number of chemical parameters.

Table 7: Relative weight of chemical parameters

Chemical parameter[1]	Indian Standard[2]	Weight (w_i)	Relative weight (W_i) Wi= $Wi = \frac{wi}{\sum_{i=1}^{n} wi}$
pH	6.5-8.5	4	0.0952
Total dissolved solid(TDS)	500-2000	4	0.0952
Total Hardness(TH)	300-600	2	0.0476
Bicarbonate (HCO_3^-)	244-732	3	0.0714
Chloride (Cl^-)	250-1000	3	0.0714
Sulphate (SO_4^{2-})	200-400	4	0.0952
Nitrate (NO_3^-)	45-100	5	0.1190
Fluoride (F^-)	1-1.5	4	0.0952
Calcium (Ca^{2+})	75-200	2	0.0476
Magnesium (Mg^{2+})	30-100	2	0.0476
Iron(Fe)	0.3-1.0	4	0.0952
Arsenic (As)	0.01-0.05	5	0.1190
		∑ wi= 42	∑ Wi= 1.000

WQI values are listed in the Table 8 and compared the data with the reported literature elsewhere.[10] The WQI classification GW samples in both seasons are shown in Figure 2(a) and figure 2(b) respectively. From the figure it is observed that most of the water samples belong to poor category for drinking. The probable reason for this is the presence of elevated iron content in all water samples.

Table 8: Categorization of water samples for drinking on the basis of WQI

WQI Range	Categorization	Percentage of samples	
		Pre	post
<50	Excellent	1.5	1.5
50-100	Good	19.1	14.7
100-200	Poor	73.5	80.9
200-300	Very poor	5.9	2.9
>300	Unfit for drinking	0	0

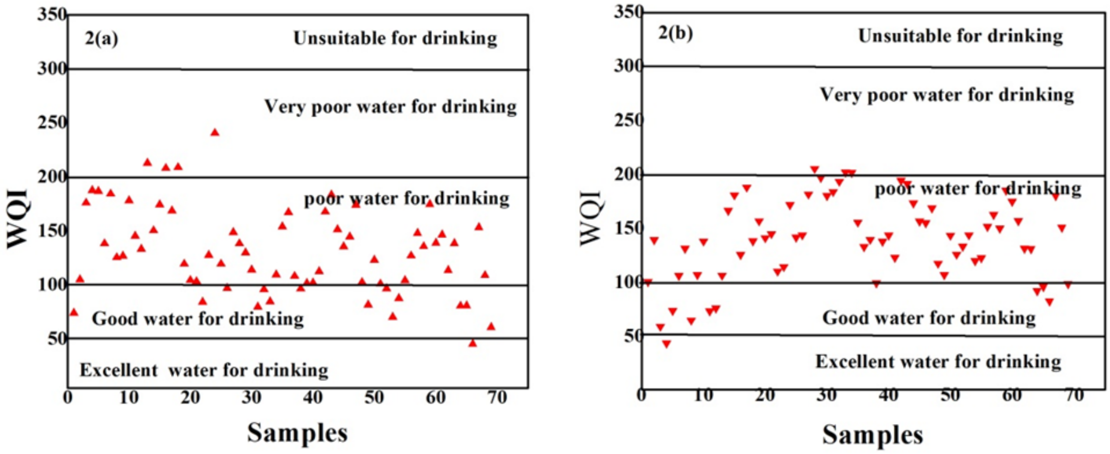

Fig. 2: Classification of GW samples on the basis of WQI. (a) Pre-monsoon season. (b). Post-monsoon season

Classification of Ground Water for Irrigation

The parameters such as Electrical Conductivity (denoted as EC), Total Dissolved Solids (dented as TDS), Sodium Adsorption Ratio (denoted as SAR), Kelly's Ratio (denoted as KR), Sodium Percent (Na %), Residual Sodium Carbonate (denoted as RSC), Magnesium Ratio (denoted as MR), and Corrosivity Ratio (denoted as CR) are adapted to find out the suitability of GW for irrigation.[8]

Elevated value of EC in GW causes salinity of soil. Richard (1954), classified the irrigation water in to five classes based on EC value shown in Table 9.[26] In our present study, all the water samples in both seasons were found be in excellent category.

SAR generally, expresses the sodium alkali hazard. Richards (1954), is used the following equation to calculate the values of SAR for each samples.[26]

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

In this equation concentration of the cations are taken in meqL^{-1}. Predominance of calcium and magnesium implies less alkali hazards but elevated concentration of sodium gives rise to high alkali hazards. SAR values of irrigation water have a notable relationship with the degree of sodium absorbed by the soil. Use of GW with elevated concentration of sodium for irrigation can increases the sodium content in soil which affect the soil texture and its permeability. Consequently, the soil becomes hard to plough and unfit for exposure of seedlings.[27] The SAR values were found to be ranges from 0.16 to 1.07 during pre-monsoon and 0.113 to 1.15 during post-monsoon season. As, the SAR value in both season were found to be <10 for all the GW samples, so all the water samples belongs to excellent category for irrigation as per Richards (1954) classification.

The formula given below is used to calculate Sodium Percentage of water.

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

Where, the concentrations of all cations are taken in meqL^{-1}. The sodium percentage was found to be varied in the range of 39.1 % to 73.6 % in pre-monsoon season and 31.3% to 73.4 % in the post-monsoon season. The outcomes of the results are listed in Table 9.

The ratio of sodium ion to calcium and magnesium ions is known as Kelly's ratio (KR). The concentration of each ion is taken in meqL^{-1}. The KR is calculated by following formula.

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

If KR is found to be greater than 1 for ground water, then it is considered as unfit for irrigation purposes. It is greater than 1 when concentration of Na^{+} is higher, in such situation the clay particle absorb

Na^+ion and displaces Ca^{2+} and Mg^{2+} ions. This affects the internal drainage and results in the reduction of the permeability of the soil.[28] In our studied GW samples, it was found that in the pre monsoon period 68.1 % samples are applicable for irrigation with KR value < 1 whereas in post monsoon period 87% water samples are applicable for irrigation with KR<1.

Table 9: Categorization of Ground water for irrigation purpose

Parameters	Range	Categorization	Quantity of samples	
			Pre monsoon	Post monsoon
Salinity hazards (EC) (μS/cm)	<250	Excellent	69	69
	250-750	Good	0	0
	750-2000	Permissible	0	0
	2000-3000	Doubtful	0	0
	>3000	Inappropriate	0	0
Total dissolved solid (TDS)	<1000	Non saline	69	69
	1000-3000	Slightly Saline	0	0
	3000-10000	Reasonably saline	0	0
	>10000	Extremely Saline	0	0
Sodium Percentage (Na%)	<20	Excellent	0	0
	20-40	Good	1	3
	40-60	acceptable	32	41
	60-80	Doubtful	36	25
	>80	Inappropriate	0	0
Alkalinity Hazard (SAR)	<10	Excellent	69	69
	10-18	Good	0	0
	18-26	Doubtful	0	0
	>26	Inappropriate	0	0
Residual Sodium carbonate (RSC)	<1.25	appropriate	37	69
	>1.25-2.5	Marginally appropriate	32	0
	>2.5	Inappropriate	0	0
Magnesium ratio (MR)	>50%	appropriate	67	69
	<50%	Inappropriate	2	0
Kellys ratio (KR)	<1	appropriate	47	60
	>1	Inappropriate	22	9
Corrosivity ratio (CR)	<1	appropriate	69	69
	>1	Inappropriate	0	0

Magnesium ion to calcium and magnesium ion ratio is known as magnesium ratio (MR).[29] It is expressed as

$$\mathrm{MR} = \frac{\mathrm{Mg}^{2+}}{\mathrm{Ca}^{2+} + Mg^{2+}} * 100$$

Concentration of each ion is expressed in meqL^{-1}. Ground water having MR greater than 50% indicates suitability of water for irrigation purposes. When irrigation water contains higher concentration of Mg^{2+} content, it increases the alkalinity of the soil and decreases the crop production.[30] In the current study, only 2.9 % water samples of pre-monsoon season were found to have MR values greater than 50% and are unsuitable for irrigation. Remaining water samples of both seasons were found to be applicable for irrigation on the basis of MR value with less than 50 %.

High percentage of HCO_3^- and CO_3^{2-} in ground causes natural tendency for precipitation of Ca^{2+} and Mg^{2+} ions. To know the extent of this effect, Eaton

(1950), proposed the term Residual Carbonate (RSC) which is calculated by the following formula.[31] The concentration of each ion taken in meqL^{-1}. Lioyd and Heathcote (1985), categorize water based on RSC values.[32] According to this categorization water samples with RSC below 1.25 are considered as appropriate for irrigation, whereas up to 2.5 RSC value, water is considered as marginally appropriate and above this water is unsuitable.

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

As per LIoyd and Heathcote (1985), classifications based on RSC value, 53.6% GW samples in pre-monsoon period were appropriate for irrigation and remaining 46.4 % water samples are marginally appropriate for irrigation.[32] In post monsoon period all the water samples were found to be appropriate for irrigation having RSC value below 1.25.

The corrosivity ratio (CR) is calculated by the formula given below where concentration of each ion is expressed in meqL^{-1}.

$$CR = \frac{Cl^-/35.5 + 2(SO_4{}^{2-})/96}{2(\frac{HCO_3{}^- + CO_3{}^{2-}}{100})}$$

CR Values indicates the degree of corrosivity of ground water. For safe transportation of ground water by pipes the CR should be less than 1. CR value greater than 1 implies corrosive nature of water and unsafe for transportation by pipes.[33] All the ground water samples in both seasons were ascertained to be suitable for transportation through pipes with CR value less than 1.

US salinity Laboratory diagram (USSL) was also used to determine the class/type of water for irrigation purpose.[34] USSL diagram is a plot of obtained values of EC (Salinity hazards) against SAR. In our present study, the diagram revealed that all the ground water samples of both season are C1-S1 water type (low salinity and low SAR) and are suitable for most of the crops on most of the soils. The USSL diagram is shown in figure 3(a) and 3(b).

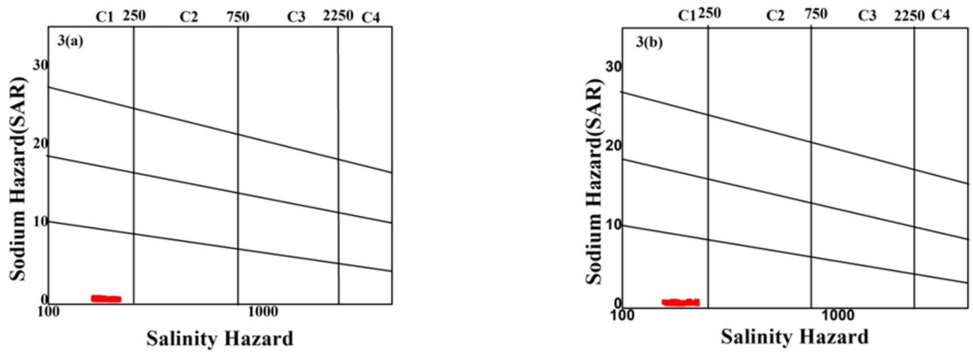

Fig. 3: (a)Universal Salinity Library diagram for GW samples of Pre- and (b) Post –monsoon season respectively

Multivariate Statistical Analysis

Correlation Matrix Analysis

Correlation matrix analysis is a useful tool to know the extent of linear relationship among the significant physicochemical parameters and the primary cation and anion. The correlation matrix analysis study is presented in Table 10 and Table 11 for both pre and post monsoon seasons. For positive correlation between two parameters, the correlation coefficient (r) should be closure to +1 and when the correlation coefficient (r) closure to -1 it indicates negative linear correlation.[35] Two parameters with positive correlation indicate their common source and negative correlation indicates that they are originated from different source. When r>0.50, the correlation is strong, for r=0.50 correlation is good and when it is less than 0.50 correlation is poor.

From the Table 9, it is observed that the pre-monsoon GW samples show strong positive correlation among the parameters like EC-TH, EC-Ca^{2+}, EC-Mg^{2+}, EC-TA, TDS-TH, TH-Ca^{2+}, TH-Mg^{2+}, TH-TA, Ca^{2+}-Mg^{2+}, Ca^{2+}-TA, Mg^{2+}-TA. In addition to this, significant positive correlation was found among EC-TDS, EC-SO_4^{2-}, TH-SO_4^{2-}, TDS-Ca^{2+}, TDS-Mg^{2+}, TDS-TA, TDS-SO_4^{2-}, Ca^{2+}-SO_4^{2-}, Mg^{2+}- SO_4^{2-}.

From the Table 10, it is observed that in the GW samples of post-monsoon season strong positive correlation was found among EC-TH , EC-Ca^{2+}, EC-Mg^{2+},TDS-TH, TH-Ca^{2+}, TH-Mg^{2+}, TH-TA, Ca^{2+}-Mg^{2+}. In addition to this, significant positive correlation was found among EC-TDS, EC-TA, EC-SO_4^{2-}, TH-SO_4^{2-}, TDS-Ca^{2+}, TDS-Mg^{2+}, TDS-TA, TDS-SO_4^{2-}, Mg^{2+}-SO_4^{2-}. Ca^{2+}-TA, Mg^{2+}-TA.

Table 10: Correlation Matrix (Pre-monsoon Season)

Parameters	pH	EC	TDS	TA	TH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	F^-
pH	1.000											
EC	.127	1.000										
TDS	.151	.975	1.000									
TA	.067	.835	.824	1.000								
TH	.106	.994	.974	.834	1.000							
Na	.087	.023	.044	-.004	.014	1.000						
K	.194	.081	.071	.080	.082	-.124	1.000					
Ca^{2+}	.099	.973	.955	.809	.976	.037	.075	1.000				
Mg^{2+}	.107	.985	.964	.830	.992	.000	.084	.941	1.000			
Cl^-	.039	.113	.108	.083	.106	.083	-.206	.064	.128	1.000		
SO_4^{2-}	.018	.856	.797	.688	.847	-.029	.076	.859	.822	.085	1.000	
F^-	.095	.165	.126	.035	.161	-.108	-.037	.134	.173	.119	.154	1.000

Table 11: Correlation Matrix (Post-monsoon Season)

Parameters	pH	EC	TDS	TA	TH	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	F^-
pH	1.000											
EC	.104	1.000										
TDS	.131	.963	1.000									
TA	.075	.784	.827	1.000								
TH	.151	.958	.979	.837	1.000							
Na	.037	.367	.403	.371	.461	1.000						
K	-.022	-.022	-.013	.060	-.015	-.055	1.000					
Ca^{2+}	.161	.946	.966	.827	.984	.443	.020	1.000				
Mg^{2+}	.143	.951	.973	.830	.995	.465	-.036	.961	1.000			
Cl^-	.232	-.063	-.072	-.103	-.107	-.048	-.003	-.113	-.102	1.000		
SO_4^{2-}	.069	.440	.475	.400	.488	.278	.100	.516	.465	-.184	1.000	
F^-	.041	.153	.142	.076	.108	.099	.018	.140	.087	.244	-.101	1.000

Conclusion

The quality assessment of the GW samples revealed, that most of the water samples have physico-chemical parameters within the acceptable range of BIS (2012) for drinking. So, on the basis of physico-chemical parameters the water samples can be considered as suitable for domestic uses. From the WQI, it was observed that 1.5 % of the collected water samples were found to be excellent, 19.1 % good, 73.5 % poor, and 5.9 % to be of very poor quality for drinking in the pre-monsoon season. Similarly, in the post-monsoon season WQI showed that 1.5 % of water samples were excellent, 14.7 % good, 80.9 % poor and only 2.9 % of water samples were found to be very poor for drinking .The probable reason for poor WQI in most of the water samples is due to the presence of more iron than the permissible limit. It was classified on the basis of sodium percentage that 46.3 % of water samples in pre-monsoon and 36.2% of samples in post monsoon season were doubtful for irrigation. RSC values indicated that 46.3 % water samples in pre-monsoon periods were marginally appropriate for irrigation and in post-monsoon period all the samples were appropriate. The MR values indicated that 2.9 % samples in pre-monsoon period inappropriate for irrigation. From the KR values it was classified that 31.8 % samples in pre-monsoon period and 13.04 % samples in post-monsoon period were inappropriate for irrigation. The values of other parameters such as TDS, EC, SAR, and CR indicated that all water samples in both season were appropriate for irrigation for most of the crops. The contaminant like fluoride was found absent in all the water samples. So, ground water samples were found safe for drinking on the basis of fluoride contamination. Accordingly, it may be stated the area where the limited study was carried out is relatively free from these toxic contaminants. However, to have a full proof conclusion a thorough and round the year monitoring with wider sets of data collection is extremely important. Arsenic was found in few GW samples in both seasons. In pre-monsoon season 17.3 % water samples have Arsenic (As) above permissible limit and in post monsoon season 10.14 % water samples have Arsenic (As) above permissible limit.

Acknowledgements

The authors are thankful to the Director, CSIR-NEIST, Jorhat, India for allowing to carry out the work .The authors are also thankful to Chemistry Department, Gauhati University, Assam, India for giving the opportunity to register under Ph. D programme.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict Of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Meride Y, Ayenew B. Drinking water quality assessment and its effects on residents health in Wondo genet campus, Ethiopia. *Environ Syst Res* 2016; 5(1). DOI 10.1186/s40068-016-0053-6.
2. Okello C, Bruno T, Greggio N, Wambiji N, Antonellini M. Impact of Population Growth and Climate Change on the Freshwater Resources of Lamu Island, Kenya. *Water* 2015;7(3):1264-1290.
3. Kaur T, Bhardwaj R, Arora S. Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Malwa region, southwestern part of Punjab, India. *Appl. Water Sci.* 2017; 7,3301–3316.
4. Ashbolt N. J. Microbial contamination of drinking water and disease outcomes in developing regions. *Toxicology* 2004; 198 (1-3):229–238.
5. Chetia M, Chatterjee S, Banerjee S, Nath M. J., Singh L, Srivastava R. B., Sarma H. P. Groundwater arsenic contamination in Brahmaputra river basin: a water quality assessment in Golaghat (Assam), India. *Environ Mmonit Assessment.* 2010; 173(1-4):371-85.
6. Jain C.K., Bandyopadhyay A, Bhadra A. Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand. India. *Environ Monit Assessment.* 2010; 166,663-676.
7. Kundu A, Nag S. K. Assessment of groundwater quality in Kashipur Block, Purulia district, West Bengal. *Appl. Water Sci.* 2018; 8, 33. https://doi.org/10.1007/s13201-018-0675-0.
8. Jain C.K., Vaid U. Assessment of ground water quality for drinking and irrigation purposes using hydrochemical studies in Nalbari district of Assam, India. *Environ. Earth sci.* 2018; 77,254.
9. Madhava S, Ahamad A, Kumar A, Kushawaha J, Singh P, Mishra P. K. Geochemical assessment of groundwater quality for its suitability for drinking and irrigation purpose in rural areas of Sant Ravidas Nagar (Bhadohi),

Uttar Pradesh. *Geology, Ecology, and Landscapes*. 2018; 2(2):127–136.
10. Batabyal A.K., Chakraborty S. Hydrogeochemistry and Water Quality Index in the Assessment of Groundwater Quality for Drinking Uses. WER 2015; 87 (7):607-617.
11. APHA, Awwa (American Public Health Association) (1988) standard methods for the examination of water and wastewater. American Public Health Association, Washington DC.
12. World Health Organisation (WHO)(2011) Guidelines for drinking water quality , 4th edn. World Health Organisation, Geneva.
13. Khound N.J., Bhattacharyya K.G. Assessment of water quality in and around Jia-Bharali river basin, North Brahmaputra Plain, India, using multivariate statistical technique. *Appl. Water Sci*. 2018; 8, 221.
14. WHO (World Health Organisation) (1984) Guidelines for drinking water quality, vol 2.Health crieteria and other supporting information WHO Publ., Geneva, p 335.
15. Davis S, DeWies,t R.M. Hydrogeology. Wiley, New York (1966).
16. Durfor C.N., Becker E. Publick water supplies of 100 largest cities in the United State, 1962. Geological Survey. *Water supply paper.* 1964; 1812. doi: https://doi.org/10.3133/wsp1812.
17. Bidhuri S, Khan M.M.A. Assessment of Ground water Quality of Central and Southeast District of NCT of Delhi. *Jour. Geological Society of India.*2020; 95,95-103.
18. Kumar P.J.S., James E.J. Physicochemical parameters and their sources in groundwater in the Thirupathur region, Tamil Nadu, South India. *Appl Water Sci.*2013; 3,219–228 DOI 10.1007/s13201-012-0074-x.
19. IS 10500: 1991 Drinking Water-Specification (First Revision).
20. Pal S.K., Rajpaul, Ramprakash, Bhat, M.A., Yadav S.S. Assessment of ground water quality for irrigation use in Firozpur-jhirka block in Mewat district of Haryana, north India. JSSWQ .2018; 10(2):157-167.
21. IS 10500: 2012 Drinking Water-Specification(Second Revision).
22. Mariappan P., Yegnaraman V., Vasudeva T. Groundwater quality fluctuation with water table in Thiruppathur block of Sivagangai district, Tamil Nadu. Pollut. Res.. 2000; 19(2):225–229.
23. Fewtrel L. Drinking-Water Nitrate, Methemoglobinemia, and Global Burden of Disease: A Discussion. Environ Health Prospect 2004;112(14):1371-1374.
24. WHO (World Health Organisation) (2017) Guidelines for drinking-water quality: fourth edition incorporating the first addendum ISBN 978-92-4-154995-0.
25. Bureau of Indian Standards (1991) Indian Standard Drinking Water Specification. 1st rev. Bureau of Indian Standards: New Dehli, India.
26. Richards L.A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. Agricultural Handbook No. 60. United States Department of Agriculture, Washington DC.
27. Keesari T., Ramakumar K.L., Chidambaram S., Pethperumal S., Thilagavathi R. Understanding the hydrochemical behavior of groundwater and its suitability for drinking and agricultural purposes in Pondicherry area, South India—a step towards sustainable development. Ground w. for Sustain. Dev.2016; 23,143–153.
28. Karnath K.R., Groundwater assessment, development and management1987, Tata-MCGRAW-Hill, New Delhi.
29. Szabolcs I., Darab C. The influence of irrigation water of high sodium carbonate of soils. In: Proceedings of 8th international congress of ISSS, transmission.1964;2:803-812
30. Kaur, T., Bhardwaj R., Arora S. Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Malwa region, southwestern part of Punjab, India. *Appl Water Sci*. 2017; 7:3301–3316
31. Eaton F.M., Significance of carbonates in irrigation waters. *Soil Sci*.1950;69;2:123-134
32. Lloyd J.W., Heathcote J.A.,Natural inorganic hydrochemistry in relation to ground water . Clarendon, Oxford.1985; 294.
33. Mishra U.K., Tripathi A.K. ,Tiwari S.,Mishra A. Assessment of Quality and Pollution Potential of Groundwater around Dabhaura Area, Rewa District, Madhya Pradesh, India. Earth *Science Research*.2012;1(2):249-261
34. Keesari T., Sinha U.K., Kamaraj P., Sharma D.A. Groundwater quality in a semi-arid

region of India: Suitability for drinking , agriculture and fluoride exposure risk .*J.Earth Sys.Sci.*.2019;128:1-24

35. Sukanya S., Joseph S. Water Quality Assessment using Environmetrics and Pollution Indices in A Tropical River, Kerala, SW Coast of India. *Curr. World Environ.*2020;