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ASSESSMENT OF GROUNDWATER QUALITIES IN SOME VILLAGES OF CHURACHANDPUR DISTRICT OF MANIPUR, INDIA FOR DRINKING AND IRRIGATION PURPOSES

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ABSTRACT

Groundwater is the main source of water for drinking as well as irrigation purposes for the local people in some villages of Churachandpur district of Manipur, India. Twenty (20) groundwater samples (dug well) were collected from three (3) villages of Churachandpur district during the period of pre-monsoon (2019) and they were examined for some important physico-chemical parameters like temperature (°C), total alkalinity (TA), pH, total hardness (TH), TDS (total dissolved solids), Ca^{2+} (calcium), K^+ (potassium), CO_3^{2-} (carbonate), Mg^{2+} (magnesium), Cl^- (chloride), Na^+ (sodium), SO_4^{2-} (sulfate) and HCO_3^- (bicarbonate). Study data revealed that the majority of the studied parameters for different groundwater possessed their values and concentrations within/below their corresponding desirable limits of BIS and WHO. Ca^{2+} and HCO_3^- were recorded as the dominant ions among the cations and anions respectively. WQI values confirmed that the majority of the groundwater fall under 'excellent' to 'good water' category and was fit for drinking purposes. RSC, SAR, and %Na showed that all analysed 20 samples were observed as 'fit' for irrigation (agricultural) purposes. Correlation coefficient (r) values proved that TA of the different groundwater was mainly because of dissolved $Ca(HCO_3)_2$, $NaHCO_3$, and $Mg(HCO_3)_2$ whereas, TH of different groundwater was mainly because of temporary hardness, possessed by the presence of dissolved bicarbonates of calcium, sodium, and magnesium but permanent hardness contribute to a lesser extent.

Keywords: Physico-Chemical Parameters, BIS, WHO, WQI, and Correlation Coefficient.

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INTRODUCTION

Water of good quality is very much essential for the existence of life for human beings, plants, and animals on the earth. Water (H_2O) covers around 70% of the earth's surface and it is found in many forms but mainly available in the form of surface water and groundwater. However, the quality of both surface water and groundwater is degrading continuously due to undesirable anthropogenic activities of human beings which make water polluted to a high level. Besides these, a large number of surface water bodies are decreasing day by day because of enlargement of the urbanization rate and also extension of urban/municipal regions.[1] Such increasing urbanization rate and extension of urban regions lead to encroachment of many surface water bodies for the creation of houses, establishment of institutions and commercial areas, industrial areas, and so on. Hence, people start utilizing groundwater besides surface water, to meet the requirements of daily activities in various places of the world. Management along with identification of the quality of groundwater is important for preserving freshwater resources in both the areas of semi-arid and arid, which is necessary for sustainable development.[2] In India, there is severely increase in groundwaters contamination since 2010, because of the over-consumption of underground water, inappropriate conjunctive used of water resources, unprocessed industrial effluent, endless domestic waste products along with irrigation return flow.[3] Groundwater is one of the integral sources of freshwater as it provides various human needs and requirements in different parts of the world.[4] The geochemical reactions along with dissolved minerals that take place within the groundwater have a serious effect on the quality of water.[5] The degradation of groundwater quality is crucial because of the geogenic process as well as human induced activities.[6] The amount of the soluble salts is a critical factor for assessing the irrigation water qualities.[7] Because of having different hydrology and geochemical processes, groundwater related environmental problems and effects also vary from one location to another location. Therefore, many researchers and scientists of different countries had performed researches on groundwaters quality, in order to monitor whether they can be utilized for drinking and irrigation (agricultural) purposes mainly.[8-11] Likewise in India, many researchers/scientists of various states had reported about the qualities of groundwaters for drinking and irrigation purposes.[12-15] Also, WQI (Water Quality Index) is computed for determining the pollution status or quality of water for drinking purposes. This research work plans to execute an assessment of groundwater qualities in three (3) villages of Churachandpur district of Manipur (India) for drinking and irrigation purposes. People of these villages are very much dependent on groundwater, mainly for drinking and agricultural purposes.

EXPERIMENTAL

Study Area

Churachandpur is one of the districts of Manipur, India. It is located in the South-Western part of Manipur. This district has the total area of 4570 sq.km., which lies between latitudes 23°56’43”N to 24°42’N and longitudes 92°58’E to 93°52’8”E approximately.[16] Churachandpur district has 274,143 persons and out of this 138,820 are males and 135,323 are females as per Census 2011.[16] This district varies from (110 – 1915) meter above mean sea level and the rock comprises of sediments of Tertiary along with Quaternary age covering from Eocene up to Recent times.[17] The climate of this region is moderate and the average rainfall (annually) is about 1638.83 mm.[17] The geographical positions for various locations were measured by GPS (global positioning system) instrument and they are given in Table-1.

Table-1: Different Sampling Sites of Groundwaters Along With GEOGRAPHICAL POSITIONS

Sample no. (Sources)	Sampling sites (locations)	Longitude	Latitude
S-1 (Dug well)	Khengjang Lhangnem (Lakhogen Kipgen’s residence)	$93^{0}42^{/}15^{//}$E	$24^{0}23^{/}31^{//}$N
S-2 (Dug well)	Khengjang Lhangnem (Khangthang Kipgen’s residence)	$93^{0}42^{/}15^{//}$E	$24^{0}23^{/}33^{//}$N
S-3 (Dug well)	Khengjang Khaikholun (Kimnu Touthang’s residence)	$93^{0}42^{/}16^{//}$E	$24°23^{/}25^{//}$N
S-4 (Dug well)	Khengjang (Henkhogin’s residence)	$93^{0}42^{/}16^{//}$E	$24^{0}23^{/}25^{//}$N
S-5 (Dug well)	Khengjang (Sehjalal Singson’s residence)	$93^{0}42^{/}18^{//}$E	$24^{0}23^{/}24^{//}$N
S-6 (Dug well)	Khengjang (Khengjang's Ningthou’s residence)	$93^{0}42^{/}13^{//}$E	$24^{0}23^{/}21^{//}$N
S-7 (Dug well)	Khengjang (J.K Kipgen’s residence)	$93^{0}42^{/}15^{//}$E	$24^{0}23^{/}21^{//}$N
S-8 (Dug well)	Khengjang (LKhotinthang Kipgen’s residence)	$93^{0}42^{/}9^{//}$E	$24^{0}23^{/}24^{//}$N
S-9 (Dug well)	Molnom Changlei village (near mainroad and car workshop)	$93^{0}42^{/}23^{//}$E	$24^{0}22^{/}29^{//}$N
S-10 (Dug well)	Molnom Changlei village (Ngamkholen Haokip’s residence)	$93^{0}42^{/}24^{//}$E	$24^{0}22^{/}28^{//}$N
S-11 (Dug well)	Molnom Changlei village (Yamlal Haokip’s residence)	$93^{0}42^{/}25^{//}$E	$24^{0}22^{/}28^{//}$N
S-12 (Dug well)	Molnom changlei village (Jangkhosat Haokip’s residence)	$93^{0}42^{/}26^{//}$E	$24^{0}22^{/}27^{//}$N
S-13 (Dug well)	Molnom Thingjabuong (Sl. Chongloi’s residence)	$93^{0}42^{/}28^{//}$E	$24^{0}22^{/}29^{//}$N
S-14 (Dug well)	Molnom Thingjabuong (Lhaikim Chongloi’s residence)	$93^{0}42^{/}29^{//}$E	$24^{0}22^{/}30^{//}$N
S-15 (Dug well)	Molnom Thingjabuong (Pastor James’s residence)	$93^{0}42^{/}31^{//}$E	$24^{0}22^{/}30^{//}$N
S-16 (Dug well)	Koite village (Letcha Kipgen's residence)	$93^{0}42^{/}17^{//}$E	$24^{0}22^{/}58^{//}$N
S-17 (Dug well)	Koite village (Khaikholal kipgen’s residence)	$93^{0}42^{/}17^{//}$E	$24^{0}23^{/}0^{//}$N
S-18 (Dug well)	Koite village (Thongkholal kipgen's residence)	$93^{0}42^{/}18^{//}$E	$24^{0}22^{/}55^{//}$N
S-19 (Dug well)	Koite village (Tongmang Sitlhou’s residence)	$93^{0}42^{/}19^{//}$E	$24^{0}22^{/}55^{//}$N
S-20 (Dug well)	Koite village (Sehjalum kipgen’s residence)	$93^{0}42^{/}17^{//}$E	$24^{0}22^{/}56^{//}$N

Material and Methods

Twenty (20) dug well groundwater samples were collected from the villages, namely, Khengjang village, Koite village (Kumbi Pukhri village) and Molnom village of Churachandpur district of Manipur, India. All the selected dug wells samples are collected from densely populated regions, which are mainly used by the local people for drinking, domestic and irrigation/agriculture purposes. The depth of the dug wells varies from 14 to 25 meters. The chosen groundwaters were collected during pre-monsoon of 2019, in well sterilized bottles for each water sample. Before sampling, all the bottles were rinsed with the water to be collected. Strict guidelines of APHA were followed for sampling and preservation of samples.[18] All the twenty groundwaters were examined for some important parameters like temperature (°C), pH, TDS (total dissolved solids), total alkalinity (TA), total hardness (TH), Ca^{2+} (calcium), K^+ (potassium), CO_3^{2-} (carbonate), Mg^{2+} (magnesium), Cl^- (chloride), Na^+ (sodium), SO_4^{2-} (sulphate) and HCO_3^- (bicarbonate). The chemicals and reagents used for this research work were HCl, $BaCl_2$, NaOH, indicators such as phenolphthalein, methyl orange, Eriochrome Black T (EBT) and murexide, disodium salt of EDTA, NH_4OH, $MgSO_4.2H_2O$, NaCl, $AgNO_3$ solution, conditioning reagent, NH_4Cl and K_2CrO_4. Temperature and TDS were measured by TDS Meter of (TDS-3) (TDS/Temp.), whereas pH was measured by pH Meter of Pocket-sized - HI98107 at sampling locations. Other parameters were examined at research lab by utilizing standard methods of APHA.[18] TA was obtained by titrimetric against standard solution (HCl), utilizing both phenolphthalein and methyl orange indicators. TH and Ca^{2+} were examined by EDTA titrimetric (using EBT indicator for TH and murexide indicator for Ca^{2+}). Further, concentrations of Mg^{2+} were calculated from the values of TH and Ca^{2+}. Flame Photometer 128 was used for determining Na^+ and K^+. Again, Cl^- and SO_4^{2-} were determined by argentometric titration and UV/Visible spectrophotometer respectively. Concentrations of CO_3^{2-} and HCO_3^- of the groundwaters were calculated from the TA values.

Evaluation of Water Quality Index/WQI

WAWQI – 'weighted arithmetic water quality index' method is employed for determining the suitability of groundwaters for drinking purposes. It is calculated using eq.(1).

$$WQI = \frac{\sum Qi\ Wi}{\sum Wi} \tag{1}$$

Where, Q_i is termed as quality rating scale of an i[th] parameter and W_i is called unit weight of an i[th] water quality parameter. Q_i is calculated from eq.(2).

$$Q_i = \left[\frac{(Vi - Vo)}{(Si - Vo)}\right] \times 100 \tag{2}$$

Where, V_i refers to experimental value of i[th] water quality parameter, V_o denotes ideal value of the parameter which is taken as 0 (zero) except pH = 7.0 and S_i represents suggested standard value of i[th] parameter.

For each parameter, W_i is evaluated from eq.(3).

$$W_i = \frac{K}{Si} \tag{3}$$

Where, K is the proportionality constant which is calculated as given below:

$$K = \frac{1}{\sum(\frac{1}{Si})}$$

Calculated WQI values are divided into five sections, in which WQI value of less than 25 is termed as 'excellent water', WQI value (26-50) is treated as 'good water', WQI value (51-75) is entitled as 'poor water', WQI value (76-100) is termed as 'very poor water' and lastly, WQI value of greater than 100 is 'unfit' for drinking purposes.[19]

Assessment of Irrigation Water Quality

For determining the quality of groundwaters for irrigation/agricultural purposes, the following given parameters are evaluated. All the ionic concentrations of the studied parameters are expressed in 'meq/L'.

RSC/ Residual Sodium Carbonate

RSC values are calculated by using eq.(4), for which its value is classified into three (3) categories in which RSC < 1.25 (good), RSC ranges (1.25 - 2.50) falls under 'marginal water quality' and the RSC > 2.50 is treated as unsuitable for irrigation.[20]

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \tag{4}$$

SAR/ Sodium Adsorption Ratio

SAR values are computed using eq.(5) and its value is divided into four (4) classes in which SAR < 10 belongs to 'excellent water quality', SAR (10 – 18) belongs to 'good water quality', SAR (18 – 26) is entitled as doubtful and SAR > 26 is termed as unsuitable for irrigation.[21]

$$\text{SAR} = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (5)$$

%Na/ Percent Sodium

%Na values are evaluated by using eq.(6) and its value is classified into five (5) classes, in which %Na < 20% is called as excellent, good (20 – 40)%, permissible (40 – 60)%, doubtful (60 – 80)% and %Na > 80% is treated as unsuitable for irrigation.[21]

$$\%\text{Na} = \frac{Na^+ + K^+}{Ca^{2+} + M\ ^{2+} + Na^+ + K^+} \times 100 \quad (6)$$

RESULTS AND DISCUSSION

Twenty groundwaters (S-1 to S-20) are observed as odorless and colorless. Table-2 comprises the values and concentrations of the studied physico-chemical parameters whereas Table-3 comprises its statistical summary briefly. The results obtained are compared with BIS and WHO standard values.[22-23]

Table-2: Values / Concentrations of the Studied Physico-Chemical Parameters for Twenty Groundwaters

Sample code no.	Temp. (°C)	pH	TDS (mg/L)	TA - $CaCO_3$ (mg/L)	TH - $CaCO_3$ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	CO_3^{2-} (mg/L)	HCO_3^- (mg/L)
S-1	24.2	8.1	114	84.8	60	12.8	6.8	21.1	3.6	21.3	16.0	0	103.5
S-2	23.2	7.6	199	222.6	118	24.8	13.6	43.1	1.7	2.8	3.3	0	271.6
S-3	22.8	7.4	197	79.5	112	27.3	10.7	26.7	6.6	55.3	12.4	0	97.0
S-4	23.4	7.2	114	58.3	60	14.4	5.8	20.0	1.9	38.3	8.3	0	71.1
S-5	22.8	7.0	103	74.2	74	19.2	6.3	15.2	1.7	22.6	5.4	0	90.5
S-6	23.6	7.2	102	84.8	80	23.2	5.3	8.3	1.4	11.3	2.8	0	103.5
S-7	23.4	7.7	128	47.7	70	14.4	8.3	18.8	1.3	32.6	2.4	0	58.2
S-8	24.0	8.2	151	132.5	94	26.5	6.8	24.6	2.1	15.6	19.0	0	161.7
S-9	24.0	8.8	83	90.1	54	12.0	5.8	14.3	5.8	5.7	7.9	0	109.9
S-10	22.9	7.4	122	100.7	92	26.5	6.3	16.3	1.5	17.0	7.1	0	122.9
S-11	23.1	7.3	153	111.3	104	29.7	7.3	21.2	2.3	21.3	4.6	0	135.8
S-12	23.4	7.4	80	90.1	60	11.2	7.8	11.8	0.7	8.5	3.6	0	109.9
S-13	23.7	7.7	153	84.8	102	28.9	7.3	21.0	2.2	32.6	17.5	0	103.5
S-14	23.4	7.6	194	127.2	154	42.5	11.7	17.9	2.8	22.7	19.4	0	155.2
S-15	23.5	8.3	118	79.5	70	20.0	4.9	18.9	5.0	18.4	12.0	0	97.0
S-16	22.9	7.2	102	90.1	64	8.0	10.7	19.8	1.4	17.0	7.0	0	109.9
S-17	23.4	8.3	156	42.4	58	7.2	9.7	31.2	5.0	42.5	20.8	0	51.7
S-18	23.6	7.5	124	74.2	72	10.4	11.2	21.7	1.2	22.7	31.3	0	90.5
S-19	23.4	8.2	283	190.8	220	72.1	9.7	24.9	5.0	38.3	20.8	0	232.8
S-20	23.0	7.8	111	100.7	74	12.0	10.7	19.4	1.3	14.2	3.8	0	122.9

Table-3: Statistical Summary along with BIS and WHO Standard Values

Para-meters	Min.	Max.	Mean	S.D.	Standard error	Skew-ness	Kurtosis	BIS 2012 - acceptable limit	WHO 2011- standard value
Temp. (°C)	22.8	24.2	23.39	0.400	0.0895	0.3136	-0.401	-	-
pH	7.0	8.8	7.70	0.477	0.107	0.683	-0.23	6.5 - 8.5	6.5 – 8.5
TDS (mg/L)	80	283	139.35	48.833	10.9194	1.4699	2.667	500	600
TA (mg/L)	42.4	222.6	98.32	43.586	9.746	1.666	3.143	200	-
TH (mg/L)	54	220	89.60	39.771	8.893	2.1598	5.503	200	-
Ca^{2+} (mg/L)	7.2	72.1	22.16	14.855	3.322	2.1597	6.193	75	-

Mg^{2+} (mg/L)	4.9	13.6	8.34	2.482	0.555	0.4774	-0.8376	30	-
Na^{+} (mg/L)	8.3	43.1	20.81	7.339	1.641	1.368	3.7968	-	200
K^{+} (mg/L)	0.7	6.6	2.73	1.776	0.397	1.002	-0.3581	-	-
Cl^{-} (mg/L)	2.8	55.3	23.04	13.302	2.974	0.7453	0.3519	250	250
SO_4^{2-} (mg/L)	2.4	31.3	11.27	8.062	1.803	0.8617	0.1088	200	250
CO_3^{2-} (mg/L)	0	0	-	-	-	-	-	-	-
HCO_3^{-} (mg/L)	51.7	271.6	119.96	53.187	11.893	1.665	3.1400	-	-

Physico-Chemical Parameters

Temperature

Temperatures of twenty groundwaters (S-1 to S-20) are in the range (22.80°C - 24.20°C) and (mean = 23.39°C) (Table-3). Each of S-3 and S-5 has the minimal temperature (22.80°C) whereas that of S-1 is the greatest (24.20°C). Groundwater temperature plays a significant role in both biological and physical processes and also in geochemical functions. The increase in groundwater temperature leads to the speeding up of chemical reactions. Global warming, the evolution of subsurface infrastructure, and also an extension of urbanization such as sewage systems, sub-ways, ground source heat pump (GSHP) systems, and shopping complexes cause fast increases in the temperature of shallow groundwater reservoirs.[24]

pH Value

pH value of the studied groundwaters varies from 7.0 to 8.8 and (mean = 7.70) (Table-3). S-5 has the least pH value (7.0) whereas S-9 has the greatest value of it (8.8). Except for S-9, other leftover samples (S-1 to S-8 and S-10 to S-20) have their pH values within the desirable limit (6.5-8.5), as given by both BIS and WHO for drinking water.[22-23] The groundwater samples are observed as neutral to slightly alkaline. Alkaline water may have an unpleasant taste. pH value depend upon the equilibrium of CO_3^{2-} (carbonate), CO_2 (carbondioxide) and HCO_3^- (bicarbonate) in majority of the natural waters.

TDS/Total Dissolved Solids

Values of TDS for twenty groundwaters are in the range 80 - 283 mg/L and (mean = 139.35 mg/L) (Table-3). S-12 has the smallest value of TDS (80 mg/L) whereas that of S-19 is the maximum (283 mg/L). All the TDS values for the twenty groundwaters are below 500 mg/L (acceptable limit) of BIS and WHO (600 mg/L) for drinking water.[22-23] All the groundwaters found their TDS value within 1000 mg/L and hence, all of them fall under the freshwater category.[21] Using groundwaters that have high TDS values may cause many problems like gastrointestinal irritation, heart diseases, nausea, kidney stones, and so on.

Total Alkalinity/TA

TA is usually caused by the presence of OH^- (hydroxides), carbonate, and bicarbonate ions. TA values are in the range of 42.40 – 222.60 mg/L and (mean = 98.32 mg/L) (table-3). S-2 has the maximum value of TA (222.60 mg/L) whereas S-17 is the least (42.4 mg/L). TA values of the groundwaters (S-1 and S-3 to S-20) are below 200 mg/L (acceptable limit) of BIS whereas S-2 is above 200 mg/L but below 600 mg/L (permissible limit) of BIS.[22]

Total Hardness/TH

TH values of twenty water samples range from 54 mg/L to 220 mg/L and (mean = 89.60 mg/L) (Table-3). S-9 has the smallest value of TH (54 mg/L) and S-19 is the maximum (220 mg/L). The values of TH for groundwaters (S-1 to S-18 and S-20) are below 200 mg/L (acceptable limit) but S-19 is above 200 mg/L but within 600 mg/L (permissible limit) of BIS.[22] The classification of groundwaters as per TH values (Table-4), it is revealed that 55% of the groundwaters fall under the 'soft water category', 35% of the groundwaters belong to the 'moderately hard category' and only 10% of the groundwaters come under hard water category.[25] Hard waters are likely to occur in the region where thick topsoils overlap limestone formation and also they are not suggested for household purposes.[21]

Calcium/Ca^{2+} and Magnesium/Mg^{2+}

In groundwaters, the main source of Ca^{2+} and Mg^{2+} comes from the erosion of rocks (dolomite and limestone) and some minerals like magnesite and calcite.[26] Concentrations of Ca^{2+} of twenty groundwaters are in the range 7.2 - 72.1 mg/L and (mean = 22.16 mg/L) (Table-3). S-17 possesses the least concentration of Ca^{2+} (7.2 mg/L) and S-19 has the maximum concentration of it (72.1 mg/L). Concentrations of Ca^{2+} for twenty samples are within 75 mg/L (acceptable limit) as prescribed by BIS.[22] Ca^{2+} is the dominant ion among the cations, based on mean values (Table-3). Also, concentrations of Mg^{2+} of groundwaters (S-1 to S-20) are in the range of 4.9 - 13.6 mg/L and (mean = 8.34 mg/L) (Table-3). S-15 has the smallest concentration of Mg^{2+} (4.9 mg/L) and S-2 (13.6 mg/L) has the highest concentration of it. Hence, Mg^{2+} concentrations for all twenty samples are below 30 mg/L (acceptable limit) as given by BIS.[22]

Sodium/Na^{+} and Potassium/K^{+}

Na^{+} concentrations for twenty groundwaters range from 8.3 to 43.1 mg/L and (mean = 20.81 mg/L) (table-3). S-6 has the smallest concentration of Na^{+} (8.3 mg/L) whereas S-2 is the highest (43.1 mg/L). All the Na^{+} concentration values are found below 200 mg/L (threshold limit) as given by WHO.[23] using the groundwaters, which have high concentrations of Na^{+} may cause health problems such as rising blood pressure, hyperosmolarity, arteriosclerosis, and edema.[27] K^{+} concentrations for the twenty groundwaters are in the range of 0.7 - 6.6 mg/L and (mean = 2.73 mg/L) (Table-3). S-12 has the minimal concentration of K^{+} (0.7 mg/L) whereas S-3 possesses the greatest concentration of it (6.6 mg/L). The concentration of potassium is found very low in the studied groundwater samples as compared to other ions.

Chloride/Cl^{-}

Cl^{-} concentrations of twenty groundwaters are in the range of 2.8 – 55.3 mg/L and (mean = 23.04 mg/L) (table-3). S-2 has the minimum concentration of Cl^{-} (2.8 mg/L) whereas S-3 has the greatest (55.3 mg/L). Cl^{-} concentrations for all the samples are below 250 mg/L (acceptable limit) of BIS and WHO for drinking water.[22-23] In this study, the sources of Cl^{-} contamination in groundwater may be mainly as a result of domestic wastes, leaching of chloride-containing minerals/ores of the earth's crust. Cl^{-} value greater than the acceptable limit may harm agricultural crops as well as metallic pipes.[28]

Sulphate/SO_4^{2-}

SO_4^{2-} concentrations of twenty groundwaters range from 2.4 mg/L to 31.3 mg/L and (mean = 11.27 mg/L) (Table-3). S-7 has the smallest concentration of SO_4^{2-} (2.4 mg/L) and S-18 possesses the greatest (31.3 mg/L). SO_4^{2-} concentration of all groundwaters is below 200 mg/L (acceptable limit) of BIS and WHO (250 mg/L) for drinking water.[22-23] The major sources of sulfate in the groundwaters include domestic wastes, fertilizers, geothermal processes, mineral dissolution, atmospheric deposition, etc.

CO_3^{2-}/Carbonate and HCO_3^{-}/Bicarbonate

CO_3^{2-} concentrations of twenty groundwaters are found as zero since the phenolphthalein alkalinity is observed as zero (Table-2). On the other hand, the concentrations of HCO_3^{-} are in the range (51.7 – 271.6) mg/L and (mean = 119.96 mg/L) (Table-3). S-17 has the minimum concentration of HCO_3^{-} whereas S-2 has the highest concentration of it. Among the anions, HCO_3^{-} is observed to be the dominant ion.

Water Quality Index/WQI

For computing the WQI values, parameters (pH, TDS, TA, TH, Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-} and SO_4^{2-}) have been considered. Table-5 shows the standards (Si), recommended agency, and unit weight (Wi) of the various parameters. Also, Table-6 shows the WQI values for 20 (twenty) groundwaters. For this study, WQI values range from 8.096 (S-5) to 81.095 (S-9) (Table-6). Table-7 indicates that 35% of groundwaters have 'excellent water quality' and also another 35% of the groundwaters fall under 'good water quality', 25% (have poor water quality) and only 5% (have very poor water quality). The majority of the groundwaters fall under the 'excellent' to 'good water' category and are fit for drinking purposes (human consumption).

Table-4: Class of Water Samples, Based on TH Values (Sawyer and McCarty)[25]

S. No.	TH values (mg/L)	Class	Sample code no.	No. of samples	%
1.	(0 – 75)	Soft water	S-1, S-4, S-5, S-7, S-9, S-12, S-15, S-16, S-17, S-18 and S-20	11	55%
2.	(75 – 150)	Moderately hard water	S-2, S-3, S-6, S-8, S-10, S-11 and S-13	7	35%
3.	(150 – 300)	Hard water	S-14 and S-19	2	10%

Table-5: Water Quality Standards (Si), Recommended Agency and Unit Weight (Wi) of Different Parameters

S. No.	Parameters	Standards (Si)	1/Si	Recommended Agency	Unit Weight (Wi)
1.	pH	8.5	0.11765	BIS/WHO	0.6182
2.	TDS (mg/L)	500	0.002	BIS	0.0105
3.	TA (mg/L)	200	0.005	BIS	0.0263
4.	TH (mg/L)	200	0.005	BIS	0.0263
5.	Ca^{2+} (mg/L)	75	0.01333	BIS	0.0701
6.	Mg^{2+} (mg/L)	30	0.03333	BIS	0.1751
7.	Na^{+} (mg/L)	200	0.005	WHO	0.0263
8.	Cl^{-} (mg/L)	250	0.004	BIS	0.0210
9.	SO_4^{2-} (mg/L)	200	0.005	BIS	0.0263
				Total	$\sum$Wi=1.0000

Table-6: Computed WQI Values of 20 (twenty) Groundwaters

Sample code no.	Computed WQI values	Rating of water quality for drinking purposes	Grading of water
S-1	53.307	Poor water	C
S-2	40.509	Good water	B
S-3	29.190	Good water	B
S-4	15.461	Excellent water	A
S-5	8.096	Excellent water	A
S-6	16.124	Excellent water	A
S-7	37.407	Good water	B
S-8	59.896	Poor water	C
S-9	81.095	Very poor water	D
S-10	25.876	Excellent water	A
S-11	23.068	Excellent water	A
S-12	24.498	Excellent water	A
S-13	39.365	Good water	B
S-14	40.310	Good water	B
S-15	61.077	Poor water	C
S-16	17.970	Excellent water	A
S-17	62.598	Poor water	C
S-18	31.184	Good water	B
S-19	68.766	Poor water	C
S-20	43.290	Good water	B

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Table-7: Summary Classification of WQI Values

S. No.	WQI Values/ranges	Rating of water quality	Sample code no.	No. of samples	%
1.	(0 – 25)	Excellent	S-4, S-5, S-6, S-10, S-11, S-12 and S-16	7	35%
2.	(26 – 50)	Good	S-2, S-3, S-7, S-13, S-14, S-18 and S-20	7	35%
3.	(51 – 75)	Poor	S-1, S-8, S-15, S-17 and S-19	5	25%
4.	(76 – 100)	Very poor	S-9	1	5%
5.	> 100	Unsuitable	Nil	-	-

Groundwater Quality for Irrigation (Agricultural) Purposes

Table-8 shows the evaluated values of RSC, SAR, and %Na for the twenty groundwaters (S-1 to S-20). Also, the class for qualities of water for irrigation is given in Table-9.

Table-8: Values of RSC, SAR and %Na for Twenty Groundwaters

Sample Code no.	RSC (meq/L)	SAR	%Na
S-1	0.50	1.19	45.73
S-2	2.10	1.73	44.87
S-3	-0.65	1.10	37.23
S-4	-0.03	1.12	43.44
S-5	0.01	0.77	32.30
S-6	0.10	0.40	19.93
S-7	-0.45	0.98	37.78
S-8	0.77	1.10	37.38
S-9	0.73	0.85	41.72
S-10	0.17	0.74	28.87
S-11	0.14	0.90	32.01
S-12	0.60	0.66	30.67
S-13	-0.35	0.90	32.18
S-14	-0.54	0.63	21.61
S-15	0.19	0.98	40.40
S-16	0.52	1.08	41.21
S-17	-0.31	1.78	56.20
S-18	0.04	1.11	40.35
S-19	-0.58	0.73	21.59
S-20	0.54	0.98	37.22
Min.	-0.65	0.40	19.93
Max.	2.10	1.78	56.20
Mean	0.175	0.987	36.135
S.D.	0.635	0.331	9.000

Table-9: Classification of Water Quality Status for Irrigation Purposes

S. no.	Parameters	Values/ranges	Class	Sample code no.	No. of samples	%
1.	RSC (meq/L)	< 1.25	Safe/good	S-1, S-3 to S-20	19	95%
		(1.25 - 2.50)	Marginal	S-2	1	5%
		> 2.50	Unsuitable	Nil	-	-
2.	SAR	< 10	Excellent	S-1 to S-20	20	100%
		(10 – 18)	Good	Nil	-	-
		(18 – 26)	Doubtful	Nil	-	-
		> 26	Unsuitable	Nil	-	-
		< 20%	Excellent	S-6	1	5%

3.	%Na	(20 – 40)%	Good	S-3, S-5, S-7, S-8, S-10, S-11, S-12, S-13, S-14, S-19 and S-20	11	55%
		(40 – 60)%	Permissible	S-1, S-2, S-4, S-9, S-15, S-16, S-17 and S-18	8	40%
		(60 – 80)%	Doubtful	Nil	-	-
		> 80%	Unsuitable	Nil	-	-

RSC/ Residual Sodium Carbonate

RSC values range from -0.65 meq/L for S-3 to 2.10 meq/L for S-2 and (mean = 0.175 meq/L) (table-8). 95% of the groundwater samples fall under safe/good water quality (RSC < 1.25 meq/L) and only 5% of the samples belong to the marginal category (1.25 – 2.50) meq/L (Table-9). Hence, based on the RSC values, all groundwaters are recorded as fit for irrigation/agricultural purposes (Table-9).[20] Negative (-ve) RSC value confirmed that both calcium and magnesium concentrations are found in excess. Water having an RSC value which is higher than 2.5 meq/L may block the flow of water by plugging soil pores and finally degrade the quality of the soil.

SAR/Sodium Adsorption Ratio

For this study, SAR values range from 0.40 (S-6) to 1.78 (S-17) and (mean = 0.987) (table-8). 100% of the groundwaters belong to 'excellent water quality' since all SAR values are observed less than 10 and thus, all the groundwaters (S-1 to S-20) are recorded as fit for irrigation (Table-9).[21]

%Na/ Percent Sodium

For all the twenty samples, the values of %Na are in the range (19.93-56.20)% and (mean = 36.135%) (table-8). S-6 has the minimum value of %Na and S-17 has the greatest value of %Na (table-8). 55% of groundwaters fall under 'good water quality', 40% (permissible category), and only 5% (excellent water quality) (Table-9). %Na values for all groundwaters are observed less than 80% and hence all of them can be utilized for irrigation (Table-9).[21] Using waters that have a high percentage of sodium can affect the plant's growth. Based on the calculated values of RSC, SAR, and %Na, it can be concluded that all the groundwaters (S-1 to S-20) are fit for irrigation/agricultural purposes.

Pearson's Correlation Coefficient (R) Values

'Correlation coefficient (r) values' are calculated by utilizing Microsoft Excel, which is given in table-10. Table-10 proved that TDS exhibits a very strong +ve correlation with TH (r = 0.910). This shows that with an increase in TDS values of different water samples, corresponding TH values also increased. TA also exhibits a strong +ve correlation with TH (r = 0.715). Again, TA reveals a very strong +ve correlation with HCO_3^- (r = 1.000). Further, TA also reveals a strong +ve correlation with Ca^{2+} and Na^+ but a moderate +ve correlation with Mg^{2+} (r = 0.644, 0.506, and 0.448 respectively). From the above correlation coefficient data of TA with HCO_3^-, Ca^{2+}, Na^+, and Mg^{2+}, it establishes the fact that TA of the different water samples is mainly because of containing dissolved $Ca(HCO_3)_2$, $NaHCO_3$, and $Mg(HCO_3)_2$. Besides these, TH exhibits a very strong +ve correlation with Ca^{2+} but weak positive correlations with Mg^{2+}, Na^+, and K^+ (r = 0.967, 0.385, 0.293, and 0.233 respectively).

Table-10: Correlation Coefficient (r) Values of the Analysed Physico-Chemical Parameters

	Temp.	pH	TDS	TA	TH	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	HCO_3^-
Temp.	1.000											
pH	0.633	1.000										
TDS	-0.123	0.152	1.000									
TA	-0.029	0.111	0.640	1.000								
TH	-0.140	0.048	0.910	0.715	1.000							
Ca^{2+}	-0.057	0.081	0.836	0.644	0.967	1.000						
Mg^{2+}	-0.339	-0.108	0.513	0.448	0.385	0.138	1.000					

Na^+	-0.095	0.195	0.604	0.506	0.293	0.140	0.635	1.000				
K^+	0.158	0.620	0.392	-0.006	0.233	0.263	-0.046	0.233	1.000			
Cl^-	-0.210	-0.058	0.462	-0.340	0.250	0.242	0.101	0.212	0.462	1.000		
SO_4^{2-}	0.396	0.356	0.401	0.004	0.291	0.248	0.234	0.243	0.314	0.383	1.000	
HCO_3^-	-0.029	0.111	0.640	1.000	0.715	0.644	0.448	0.506	-0.006	-0.340	0.004	1.000

Above all, TH also exhibits a weak +ve correlation with Cl^- and SO_4^{2-} but a very strong +ve correlation with HCO_3^- (r = 0.250, 0.291, and 0.715 respectively). This shows that the TH of the different groundwaters is mainly because of temporary hardness possessed by having dissolved bicarbonates of calcium, sodium, and magnesium while permanent hardness contributes to a lesser extent to the TH as is confirmed by the above-mentioned correlation coefficient (r) values showing the relation between TH with calcium, sodium, magnesium, bicarbonates, chloride, and sulfate.

CONCLUSION

1. The groundwater samples of the study areas of Churachandpur district, Manipur are observed as neutral to slightly alkaline. Most of the parameters of different water samples have recorded their values and concentrations within/below their corresponding desirable limits, as suggested by BIS and WHO. All the twenty samples (S-1 to S-20) belong to the 'freshwater category' and the TH values show that the majority of the groundwater falls under soft to moderately hard water category. WQI values also reveal that most of the groundwater falls under 'excellent' to 'good water category' and are fit for drinking purposes.
2. Based on mean values, the decreasing order of dominancy of cations is observed as, $Ca^{2+} > Na^+ > Mg^{2+} > K^+$, whereas that of anions is recorded as, $HCO_3^- > Cl^- > SO_4^{2-}$.
3. The evaluated values of RSC, SAR, and %Na indicate that all the analyzed 20 samples (S-1 to S-20) are observed as fit for irrigation/agricultural purposes.
4. Correlation coefficient (r) values also reveal that TA of the different groundwater is mainly because of having dissolved $Ca(HCO_3)_2$, $NaHCO_3$, and $Mg(HCO_3)_2$. Also, TH of the different water samples is mainly because of temporary hardness possessed by the presence of dissolved bicarbonates of calcium, sodium, and magnesium whereas permanent hardness contributes to a lesser extent.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

All the authors contributed significantly to this manuscript, participated in reviewing/editing, and approved the final draft for publication. The research profile of the authors can be verified from their ORCID IDs, given below:

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