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Research Article

Investigation on groundwater quality for drinking and irrigation purpose in certain regions of Bishnupur District in Manipur, India

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Abstract
In Bishnupur district, Manipur, India, there is shortage of surface water due to the increase in population growth. Most people are below the poverty line and depend very much on groundwater for drinking and other domestic and irrigation purposes. This study investigates groundwater quality and its appropriateness for drinking and irrigation purposes in Bishnupur district. A total of 27 groundwater samples (S-1 to S-27) were taken and were analysed parameters, viz. temperature, Ca^{2+}, total dissolved solids (TDS), K^+, total hardness (TH), Mg^{2+}, HCO_3^-, Cl^-, total alkalinity (TA), CO_3^{2-}, SO_4^{2-}, pH, NO_3^-, Na^+, As, Pb and Hg. Most of the groundwater samples were observed to be 'fit' for drinking. Water quality index values confirmed that 14.815% of water possessed as 'excellent', 14.815% as 'good', 33.333% as 'poor', 14.815% as 'very poor' and 22.222% as 'unsuitable' for drinking purpose. Anthropogenic activities like improper disposal of domestic waste and extensive use of fertilizers, pesticides, herbicides, etc. may be the reason for deteriorating groundwater quality. Values of residual sodium carbonate, Kelly's ratio, sodium adsorption ratio, permeability index, and percent sodium showed that all samples were observed to be 'fit' for irrigation purposes. Correlation coefficient (r) values showed that TH of the samples was mostly due to temporary hardness, whereas that of TA was mostly due to dissolved $Mg(HCO_3)_2$ (magnesium bicarbonate) but also by having $Ca(HCO_3)_2$ (calcium bicarbonate) and $NaHCO_3$ (sodium bicarbonate) to a smaller extent. The study's outcome will also be very beneficial to the villagers of the study area mainly.

Keywords: Bureau of Indian Standards (BIS), Groundwater, Heavy metals, Physico-chemical parameters, World Health Organization (WHO), Water Quality Index (WQI)

INTRODUCTION

Not only is it conducive for human beings mainly, but water is also essential for plants. Such water is mainly available as surface water and groundwater. The loss of surface water bodies is mainly caused by urbanization, which converts land from water (Palazzoli *et al*., 2022). Additionally, due to the rapid growth of the human population throughout the world, people are facing a scarcity of surface water. By the increase in human population and the development of industrialization, surface water has been polluted, paving the way for sustainable use of groundwater for human beings (Zonunthari *et al*., 2023). This leads to the exploration of more and more groundwater for the needs of human beings, other animals and plants. Such groundwater should not be taken as safe for drinking and agricultural activities (irrigation). Around the world, billions of people are compelled to use contaminated water because of the scarcity of potable water and hence, the shortage of groundwater is an alarming threat to humans (Ali *et al*., 2024). Undoubtedly, numerous environmental problems and issues have been caused as the impact of population expansion, development of industrialization and technological progress. The different material around the groundwater or dissolving from the aquifer matrix is significantly reflected in different physicochemical parameters of groundwater (Atta *et al*., 2022). It is essential to examine the groundwater quality not only for drinking purposes but also for irrigation purposes. Hydro-chemical processes influence groundwater's ionic composition since they move to the discharge areas from the recharge areas and interact with the rock minerals (Alshehri and Abdelrahman, 2023). Both anthropogenic processes and natural activities affect the chemical compositions of groundwater resources.

In India, there has been a severe increase in groundwater contamination since 2010 because of the over-consumption of underground water, inappropriate conjunctive use of water resources, unprocessed industrial effluent, endless domestic waste products along with irrigation return flow (Kumar *et al*., 2024). The problem of groundwater pollution is now a global concern since it adversely affects the development of the environment economically, socially and environmentally (Soceanu *et al*., 2021). Some important geochemical phenomena that control the composition of groundwater are the weathering of rocks, deposition, evaporation and dissolution. The chemical fertilizers and their products, pesticides, etc., which are utilized for agricultural activities affect the qualities of groundwater in several ways. Hence, many scientists and researchers in different countries such as Nigeria, Pakistan, Ethiopia, Libya and Iran analysed and examined the quality of groundwater to check whether it can be consumed for drinking and agricultural activities (irrigation) effectively (Falowo *et al*., 2017; El-Aziz, 2017; Kawo and Karuppannan, 2018; Khanoranga and Khalid, 2019 and Abbasnia *et al*., 2019). Moreover, in India also, researchers from Tamil Nadu, Telangana, Kerala, Assam and Punjab had studied the groundwater qualities both for irrigation and drinking purposes mainly (Kaur *et al*., 2017; Jain and Vaid, 2018; Manjula and Warrier, 2019; Adimalla *et al*., 2020 and Balamurugan *et al*., 2020). Again, water quality index (WQI) has been regarded as an 'effective method' for ascertaining the quality of groundwater for drinking purposes (Khan and Jhariya, 2017; Ameen, 2019 and Saikrishna *et al*., 2020).

Moreover, the study of heavy metals in groundwater is very important nowadays since their excess presence deteriorates the water quality, which can cause multiple health problems and may be life-threatening. Contamination of heavy metals is considered as a severe environmental health problem because of their toxicity even at trace concentrations, persistent nature and bioaccumulation potential (Olagunju *et al*., 2020). Activities like urbanization, improper use of fertilizers, inappropriate sewage disposal, pesticides, toxic chemical solid waste products, and some natural phenomena like erosion, precipitation, etc. enhance the heavy metals in both soil and water (Reddy and Sunitha, 2023). Global health issues are related with heavy metal contamination of water bodies and soil, which plants absorb and ultimately enter the human body through drinking water and the food chain (Goyal *et al*., 2022).

The present study aimed to investigate groundwater quality in certain regions of Bishnupur district, Manipur, India, for drinking and irrigation of agricultural activities. People living in these study areas are only dependent on groundwater resources for potable use. Most of them are economically deprived and cannot purchase water purification appliances.

MATERIALS AND METHODS

Study area

Bishnupur district is situated in the south-western part of Manipur state, India. Geographically, this district has an area of 496 km^2 and lies between latitude 24°18'49" N and 24°42'16" N and longitude 93°47'2" E and 93° 53'6" E approximately (District Census, 2011). This district has a total population of 2,37,399, of which 1,18,782 are males and 1,18,617 are females (District Census, 2011). The villagers of the study area primarily depend on these groundwater resources, mainly for drinking and agricultural activities. The samples (S-1 to S-27), sampling locations and their corresponding geographical positions are stated in Table 1. Geographical positions were recorded carefully using a global positioning system (GPS) instrument. Fig.1 shows the location map of this study area.

Water sampling and methodology

The total of 27 groundwater samples, comprising of hand pumps (S-1, S-2, S-3, S-4, S-5, S-14, S-15, S-16, S-17, S-18, S-19, S-20, S-21, S-22, S-23, S-24, S-25, S-26, S-27), tube wells (S-6, S-7, S-8, S-9, S-11, S-12) and dug wells (S-10, S-13) were taken from different regions of Bishnupur district (Table 1). The groundwater samples were collected during the monsoon of 2021 to observe the impact of rainfall on the values of physicochemical parameters and heavy metals regarding drinking and irrigation water quality. The S-1 to S-27 numbers indicate the groundwater samples' sample code number (Table 1). The distance is generally about half a kilometre (1/2 Km) between two consecutive sampling sites. The chosen sampling sites are situated near residential areas, foothills and irrigated land areas, and the native population often utilizes all of them for drinking and agricultural activities. The samples were taken in well sterilized bottles of 2L capacity each to examine physico-chemical parameters. For heavy metals analysis, the samples were separately taken in bottles of 1L capacity each morning, at around 7.00 - 10.00 a.m. Before sampling, all the sterilized bottles were rinsed away with the sampling water to be taken. The sampling and preservation processes were performed following the guidelines of APHA, 1992. The AR grade chemical compounds and reagents were used to analyze the samples.

Table 1. Details of study area with geographical positions

Sample code (sources)	Sampling locations (sites)	Longitudes	Latitudes	Depth (meter)
S-1 (Hand pump)	Maibam Lotpa Chingning Awang Leikai (1) (near leirak machine and foothill)	93°48´54″E	24°42´11″N	49
S-2 (Hand pump)	Maibam Lotpa Chingning Awang Leikai (2) (near foothill and house)	93°48´56″E	24°42´5″N	47
S-3 (Hand pump)	Maibam Lotpa Chingning Awang Leikai (3) (near foothill)	93°48´57″E	24°42´4″N	51
S-4 (Hand pump)	Ishok Maning Chingya (near foothill)	93°50´40″E	24°40´40″N	53
S-5 (Hand pump)	Ishok Chengphu, Terapokpi	93°50´32″E	24°41´10″N	49
S-6 (Tube well)	Bishnupur Bazar Thiyam leikai (Thiyam Sanatomba's residence)	93°45´41″E	24°37´34″N	43
S-7 (Tube well)	Bishnupur Bazar Thiyam leikai (Athuipau Gonmei's residence)	93°45´41″E	24°37´36″N	45
S-8 (Tube well)	Bishnupur Bazar (Koijam Tezmani Singh's residence)	93°45´42″E	24°37´37″N	47
S-9 (Tube well)	Bishnupur Bazar (R.K. Gyane Singh's residence)	93°45´42″E	24°37´35″N	48
S-10 (dug well)	Bishnupur Bazar ward no. 8 (public dug well)	93°45´48″E	24°37´35″N	19
S-11 (Tube well)	Bishnupur Bazar (Laishram Muhindro Singh's residence)	93°45´49″E	24°37´32″N	52
S-12 (Tube well)	Bishnupur Bazar (Khangembam Kumarjit's residence)	93°45´47″E	24°37´31″N	45
S-13 (dug well)	Bishnupur Thiyam Leikai (public dug well)	93°45´53″E	24°37´35″N	15
S-14 (Hand pump)	Kwatham (front of Thanga Chingningthou)	93°49´55″E	24°31´46″N	53
S-15 (Hand pump)	Thanga Meisnam (1) (Mandop Makha)	93°50´12″E	24°31´50″N	57
S-16 (Hand pump)	Thanga Meisnam (2) (Leihao Makhong)	93°50´7″E	24°32´3″N	56
S-17 (Hand pump)	Thanga Chingyang Bazar	93°49´59″E	24°32´5″N	51
S-18 (Hand pump)	Thanga Chingkha Mamang Leikai	93°49´58″E	24°32´4″N	54
S-19 (Hand pump)	Thanga Chingkha Bamon Mathak	93°49´52″E	24°32´5″N	51
S-20 (Hand pump)	Thanga Chingkha (Ibudhou Chairenlakpa)	93°49´43″E	24°32´6″N	49
S-21 (Hand pump)	Thanga Samukon	93°49´25″E	24°32´0″N	55
S-22 (Hand pump)	Thanga Khunjem Chengjing	93°49´0″E	24°31´32″N	53
S-23 (Hand pump)	Thanga Ngaram Church Makha (near foothill)	93°48´55″E	24°31´28″N	51
S-24 (Hand pump)	Thanga Ngaram Bamon Mathak	93°48´50″E	24°31´21″N	57
S-25 (Hand pump)	Thanga Ngaram Tongbram Machin	93°48´36″E	24°31´11″N	50
S-26 (Hand pump)	Chingmei Keina Bazar (near Keibul Lamjao National Park)	93°48´28″E	24°28´48″N	44
S-27 (Hand pump)	Chingmei Awang Leikai (near Keibul Lamjao National Park)	93°48´23″E	24°28´48″N	46

At the sampling locations, parameters like temp.(°C), total dissolved solids (TDS) and pH were detected. Other parameters viz., TH (total hardness), HCO_3^- (bicarbonate), NO_3^- (nitrate), TA (total alkalinity), Ca^{2+} (calcium), Cl^- (chloride), Mg^{2+} (magnesium), CO_3^{2-} (carbonate) and SO_4^{2-} (sulphate) were examined at the analytical laboratory, by following the standard guidelines and procedures of APHA, 1992. A digital thermometer and a TDS Meter (HANA, Romania) were used to detect temperature and TDS. pH Meter (HANNA Instrument for Romania) was used to measure the pH of the samples. Also, the parameters (TA, TH, Ca^{2+}) were analyzed using the 'titrimetric method'. The calculation method (from TA values) was employed to estimate CO_3^{2-} and HCO_3 concentrations. Mg^{2+} concentrations were also detected by the 'Calculation method' from the values of Ca^{2+} and TH. Concentrations of Na^+ and K^+ were estimated in the analytical laboratory by Flame photometer-128. Again, SO_4^{2-} and NO_3^- concentrations were estimated using UV/Visible spectrophotometer. Cl^- concentration was obtained by argentometric method. Heavy metals like As (total arsenic), Pb (lead) and Hg (mercury) were detected using AAS (Atomic Absorption Spectrophotometer) instrument.

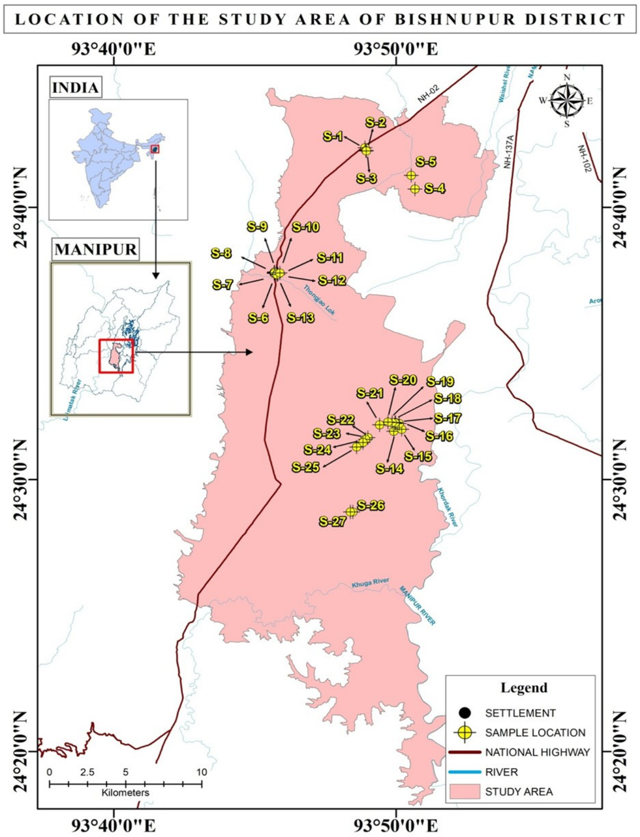

Fig.1. *Location map (sampling points: S-1 to S-27) of the study area of Bishnupur district*

Estimation of water quality index (WQI)

For ascertaining the appropriateness of groundwater for potability (drinking) purposes, WAWQI (Weighted Arithmetic Water Quality Index) was employed and evaluated from eq. (1) and is given below (Tyagi *et al*., 2013).

$$WQI = \frac{\sum Q_i W_i}{\sum W_i} \quad ......(1)$$

Where, Q_i and W_i represent quality rating scale and unit weight, respectively of an i^{th} parameter.

Q_i is obtained from eq. (2)

$$Q_i = \left[\frac{(V_i - V_o)}{(S_i - V_o)}\right] \times 100 \quad .....(2)$$

V_i, S_i, and V_o are termed as experimental value, standard value and ideal value, respectively of an i^{th} parameter, in which an ideal value for all analyzed parameters is taken as zero (0) except for pH = 7.00

Again, W_i is estimated from eq. (3)

$$W_i = \frac{K}{S_i} \quad ..... (3)$$

K denotes the proportionality constant, which is computed from eq. (4)

$$K = \frac{1}{\sum\left(\frac{1}{S_i}\right)} \quad ......(4)$$

In order to know the rating of water quality and its grading for drinking purposes, the estimated WQI values are described in five ways (Tyagi *et al*., 2013) i.e. (i) WQI values (0 to 25) is 'excellent' and its grading/ranking is given as 'A', (ii) WQI values (26 to 50) is 'good' and its grading is 'B', (iii) WQI values (51 to 75) is 'poor' and its grading is 'C', (iv) WQI values (76 to 100) is 'very poor' and its grading is 'D' and lastly, (v) WQI values of above 100 is 'unfit' and its grading is 'E'.

Evaluating of irrigation (agricultural) water quality

Five parameters (Table 2) were applied to understand the suitability of irrigation (agricultural) water qualities as these parameters were most commonly used for the evaluation of irrigation water quality and their required ionic concentrations were taken in meq/L (Wilcox, 1955; Todd, 1980; Doneen, 1964; Kelly, 1940).

RESULTS AND DISCUSSION

Tables 3a and 3b show the analyzed physicochemical parameters and concentration values of heavy metals in 27 groundwater samples. Table 4 presents the statistical summary of the groundwater samples' physicochemical parameters and heavy metals, and the estimated results are compared with both BIS (2012) and WHO (2011) standards for drinking water.

Table 2. Parameters taken for understanding the irrigation water quality

Sl. No.	Parameters	Formulae	Unit
1.	RSC (Residual Sodium Carbonate)	RSC = $(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$	meq/L
2.	SAR (Sodium Adsorption Ratio)	SAR = $\frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$	-
3.	%Na (Percent Sodium)	%Na = $\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$	-
4.	PI (Permeability Index)	PI = $\frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$	-
5.	KR (Kelly's Ratio)	KR = $\frac{Na^+}{Ca^{2+} + Mg^{2+}}$	-

Table 3a. Estimated values of physicochemical parameters (mg/L) except temp.(°C) and pH of water samples of Bishnupur district

Sample code	Temp.	pH	TDS	TA	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	NO_3^{-}	HCO_3^{-}	CO_3^{2-}
S-1	24.8	7.7	531	286.2	176	31.3	23.8	155.9	1.1	187.2	12.8	5.0	349.2	0
S-2	24.7	9.2	518	275.6	94	19.2	11.2	187.5	1.2	171.6	17.0	6.2	336.2	0
S-3	27.6	9.2	208	143.1	122	16.8	19.4	26.9	0.6	34.0	14.2	0.3	174.6	0
S-4	27.0	7.6	317	291.5	254	47.3	33.0	39.2	0.6	31.2	17.6	0.1	355.6	0
S-5	26.8	7.8	244	185.5	174	25.7	26.7	41.2	0.9	11.3	14.3	1.0	226.3	0
S-6	29.1	7.1	302	206.7	240	72.9	14.1	29.8	4.9	36.9	35.5	3.2	252.2	0
S-7	29.6	9.4	196	132.5	142	33.7	14.1	23.9	2.4	29.8	25.9	1.7	161.7	0
S-8	25.1	9.3	337	275.6	272	77.8	19.0	26.8	6.3	38.3	28.1	3.2	336.2	0
S-9	25.2	8.4	281	180.2	194	51.3	16.0	35.2	7.0	42.5	39.3	0.9	219.8	0
S-10	26.0	9.1	300	222.6	214	49.7	21.9	34.5	7.5	49.6	38.5	3.9	271.6	0
S-11	25.5	9.0	309	174.9	200	47.3	19.9	32.0	10.3	53.9	27.5	4.7	213.4	0
S-12	29.4	9.4	231	153.7	170	40.9	16.5	27.3	1.7	45.4	33.2	1.5	187.5	0
S-13	26.6	9.7	235	190.8	172	38.5	18.5	25.7	8.3	35.5	32.4	3.9	232.8	0
S-14	25.4	6.5	375	254.4	292	52.1	39.4	39.9	1.0	99.3	14.0	0.2	310.4	0
S-15	25.9	9.1	325	328.6	300	41.7	47.6	31.5	0.8	12.8	15.6	2.4	400.9	0
S-16	24.5	6.9	255	275.6	230	40.9	31.1	27.9	0.9	5.7	13.3	3.2	336.2	0
S-17	25.1	8.5	276	296.8	252	43.3	35.0	30.0	1.0	7.1	20.4	3.1	362.1	0
S-18	24.3	6.5	269	280.9	260	49.7	33.0	23.0	0.9	9.9	15.3	1.6	342.7	0
S-19	24.7	7.4	334	318.0	302	48.1	44.2	29.8	0.8	41.1	18.1	1.5	388.0	0
S-20	23.7	7.2	234	275.6	226	40.1	30.6	21.7	0.6	8.5	19.4	1.7	336.2	0
S-21	25.3	7.5	273	280.9	268	46.5	36.9	21.4	0.8	12.8	14.2	3.9	342.7	0
S-22	25.2	7.5	342	339.2	294	52.1	39.9	26.2	0.7	5.7	19.2	0.9	413.8	0
S-23	25.3	7.4	307	355.1	318	63.3	38.9	33.8	1.1	21.3	18.7	0.2	433.2	0
S-24	26.8	7.9	208	265.0	186	20.0	33.0	23.6	0.7	4.3	14.7	1.5	323.3	0
S-25	26.3	7.8	391	259.7	250	40.9	36.0	66.2	1.1	83.7	17.2	0.2	316.8	0
S-26	24.9	7.8	302	333.9	256	35.3	40.8	43.5	0.7	11.3	18.2	0.6	407.4	0
S-27	24.8	7.3	262	296.8	218	37.7	30.1	30.3	0.7	5.7	15.7	0.8	362.1	0

Physicochemical parameters

All the 27 groundwater samples (S-1 to S-27) were odourless and colourless. The temperature of samples ranged between 23.7°C and 29.6°C, with a mean of 25.91°C (Table 4). This may be due to the different depths of the sampling sites and, consequently, the variable absorption of heat from sunlight during the monsoon season of summer. S-20 (Thanga Chingkha, Ibudhou Chairenlakpa) and S-7 (Bishnupur bazar, Athuipau Gonmei's residence) possessed the minimum and maximum temperature of the analysed groundwater samples, respectively (Table 3a). High groundwater temperature may enhance the growth of microorganisms, harmful bacteria, and algae and may also affect taste.

pH value of the analysed samples was between 6.5 and 9.7, with a mean of 8.1 (Table 4). The lowest pH value was 6.5, observed at S-14 (Kwatham) and S-18 (Thanga Chingkha mamang leikai), whereas the highest pH value was 9.7, which was observed at S-13 (Bishnupur Thiyam leikai, public dug well), indicating 'alkaline' condition (Table 3a). 66.67% of samples (S-1, S-4 to S-6, S-9, S-14, S-16 to S-27) were observed within the desirable limit (6.5-8.5) of BIS (2012) and WHO (2011), whereas 33.33% of samples exceeded the standard limit of BIS (2012) and WHO (2011). High water pH may cause various issues like hair loss, skin diseases, stomach problems, etc. Water with a pH value greater than 8.5 or smaller than 6.5, may produce aesthetic effects like staining, etching and equipment scaling (Sunitha and Reddy, 2019).

The total dissolved solids (TDS) value of the groundwater samples was between 196 mg/L and 531 mg/L, having (mean = 302.30 mg/L) (Table 4). S-7 (Bishnupur bazar, Athuipau Gonmei's residence) and S-1 (Maibam Lotpa Chingning awang leikai-1) possessed the minimum and maximum TDS values, respectively (Table 3a). 92.59% of samples (S-3 to S-27) were reported below the standard limit of BIS (2012). Only 7.41% possessed the values of TDS above the standard limit of

Table 3b. Detected values (concentrations) of heavy metals in the water samples of Bishnupur district

Sample code	Total Arsenic (As) (mg/L)	Lead (Pb) (mg/L)	Mercury (Hg) (mg/L)
S-1	0.000	0.000	0.000
S-2	0.003	0.000	0.003
S-3	0.002	0.000	0.000
S-4	0.000	0.218	0.005
S-5	0.002	0.000	0.008
S-6	0.000	0.000	0.000
S-7	0.000	0.000	0.000
S-8	0.000	0.000	0.000
S-9	0.000	0.498	0.008
S-10	0.001	0.084	0.000
S-11	0.001	0.000	0.003
S-12	0.004	0.000	0.000
S-13	0.005	0.000	0.005
S-14	0.000	0.000	0.001
S-15	0.000	0.000	0.003
S-16	0.000	0.325	0.005
S-17	0.000	0.000	0.006
S-18	0.001	0.000	0.000
S-19	0.001	0.000	0.006
S-20	0.001	0.421	0.001
S-21	0.000	0.000	0.003
S-22	0.000	0.000	0.001
S-23	0.005	0.489	0.002
S-24	0.001	0.000	0.000
S-25	0.000	0.073	0.004
S-26	0.000	0.000	0.000
S-27	0.003	0.000	0.000

BIS (2012) but within the desirable limit of WHO (2011). All the samples come under the category of fresh water (Todd, 1980). Intake of high TDS water may cause a bitter taste and may have a chance of affecting the digestive system.

The samples' total alkalinity/TA (as $CaCO_3$) value varied from 132.5 mg/L to 355.1 mg/L, with a mean of 254.79 mg/L (Table 4). S-7 (Bishnupur Bazar, Athuipau Gonmei's residence) and S-23 (Thanga Ngaram Church makha) possessed the minimum and maximum TA values, respectively (Table 3a). Only 25.93% of groundwater samples (S-3, S-5, S-7, S-9, and S-11 to S-13) were recorded within its desirable limit of BIS (2012), whereas 74.07% of samples exceeded its desirable limit of BIS (2012). TA measured the acid-neutralizing capacity of the water, and its high value can increase pH value of the soil and consequently lower the various micro-nutrients present in the soil (Sreedevi *et al*., 2019).

Total hardness/TH (as $CaCO_3$) value of all the samples varied from 94 mg/L to 318 mg/L, having mean of 225.04 mg/L (Table 4). S-2 (Maibam Lotpa Chingning awang leikai-2) had the smallest TH value whereas S-23 (Thanga Ngaram Church makha) had the highest value (Table 3a). 37.04% of samples (S-1, S-2, S-3, S-5, S-7, S-9, S-11 to S-13 and S-24) were recorded within its desirable limit of BIS (2012). However, 62.96% of samples exceeded the desirable limit of BIS (2012). Table 5 elucidated that 81.48% of samples (hard water), 11.11% (moderately hard water) and 7.41% possessed very hard water (Sawyer and McCarty, 1967). Hard water can affect numerous things, such as water heaters, cooking utensils, well pumps, distribution pipes, and extra soap needed for washing our daily used clothing (Zohud *et al*., 2023).

Ca^{2+} concentration of all the samples ranged between 16.8 mg/L and 77.8 mg/L, having (mean = 43.11 mg/L) (Table 4). S-3 (Maibam Lotpa Chingning awang leikai-3) and S-8 (Bishnupur Bazar, Koijam Tezmani's residence) possessed the minimum and maximum concentration of $Ca^{2+,}$ respectively (Table 3a). 96.30% of samples (S-1 to S-7, S-9 to S-27) were observed within the desirable limit of BIS (2012), whereas 3.70% of samples exceeded its desirable limit of BIS (2012). Ca^{2+} was the dominant among cations (as indicated by mean value) (Table 4). For human beings mainly, intake of a greater amount of Ca^{2+} may cause multiple health issues like kidney problems (including kidney stones), constipation, digestive disorders etc. Rocks like dolomite, sandstone, limestone, gypsum and minerals such as pyroxene, amphiboles, plagioclase etc. are the sources of Ca^{2+} in groundwater (Rao, 2017). Ca^{2+} is very much needed in building strong teeth and bones, transmission, muscle contraction, blood clotting, regulating heartbeat, oocyte activation, nerve impulse and balancing fluid within cells (Pravina *et al*., 2013).

Mg^{2+} concentration of all the samples varied from 11.2 mg/L to 47.6 mg/L, having (mean = 28.54 mg/L) (Table 4). S-2 (Maibam Lotpa Chingning awang leikai-2) had the least concentration of Mg^{2+} and S-15 (Thanga Meisnam-1, Mandop makha) possessed the highest concentration of it (Table 3a). 44.44% of waters (S-1 to S-3, S-5 to S-13) were recorded below its desirable limit (30 mg/L) of BIS, whereas 55.56% of waters exceeded its desirable limit of BIS (2012). Mg^{2+} plays an important physiological role mainly in skeletal muscles, brain and heart (De Baaij *et al*., 2015). Mg^{2+} may also help to regulate blood sugar levels and blood pressure.

Na^{+} concentration of all the samples lies between 21.4 mg/L and 187.5 mg/L, with a mean of 42.03 mg/L (Table 4). S-21 (Thanga Samukon) and S-2 (Maibam Lotpa Chingning awang leikai-2) possessed the minimum and maximum concentrations of $Na^{+,}$ respectively (Table 3a). The concentration of Na^{+} for all the samples were observed below the threshold limit of WHO

Table 4. Statistical description of analysed seventeen parameters in the water samples of Bishnupur district

Studied Parameters	Min.	Max.	Mean	S.D.	Standard error	BIS - Acceptable limit	WHO - Desirable limit
Temp. (°C)	23.7	29.6	25.91	1.539	0.296	-	-
pH	6.5	9.7	8.1	0.966	0.186	6.5- 8.5	6.5 - 8.5
TDS (mg/L)	196.0	531.0	302.30	80.934	15.576	500	600
TA (mg/L)	132.5	355.1	254.79	63.190	12.161	200	-
TH (mg/L)	94.0	318.0	225.04	57.818	11.127	200	-
Ca^{2+} (mg/L)	16.8	77.8	43.11	14.347	2.761	75	-
Mg^{2+}(mg/L)	11.2	47.6	28.54	10.365	1.995	30	-
Na^{+} (mg/L)	21.4	187.5	42.03	38.708	7.449	-	200
K^{+} (mg/L)	0.6	10.3	2.39	2.859	0.55	-	-
Cl^{-} (mg/L)	4.3	187.2	40.61	46.507	8.950	250	250
SO_4^{2-} (mg/L)	12.8	39.3	21.12	8.224	1.583	200	250
NO_3^{-} (mg/L)	0.1	6.2	2.126	1.689	0.325	45	50
HCO_3^{-} (mg/L)	161.7	433.2	310.85	77.086	14.835	-	-
CO_3^{2-} (mg/L)	0.0	0.0	-	-	-	-	-
As (mg/L)	0.000	0.005	0.0011	0.0016	0.0003	0.01	0.01
Pb (mg/L)	0.000	0.498	0.0781	0.1600	0.0308	0.01	0.01
Hg (mg/L)	0.000	0.008	0.0024	0.0026	0.0005	0.001	0.006

(2011). In the human body, Na^{+} is one of the most essential minerals that can support muscles, nerve function, etc. The consumption of high Na^{+} concentrations in drinking water may cause different health issues, such as kidney disease, heart problems, elevated blood pressure, etc.

For potassium (K^{+}), its concentration varied from 0.6 mg/L to 10.3 mg/L, with (mean = 2.39 mg/L) (Table 4). Each of S-3 (Maibam Lotpa Chingning awang leikai-3), S-4 (Ishok Maning Chingya) and S-20 (Thanga Chingkha, Ibudhou Chairenlakpa) possessed the least concentration of K^{+} (0.6 mg/L), whereas S-11 (Bishnupur Bazar, Laishram Muhindro Singh's residence) possessed the highest (10.3 mg/L) (Table 3a). Using $KMnO_4$ (potassium permanganate) for water treatment is one of the main ways to enhance the level of K^{+} concentration in water (Banerjee and Prasad, 2020). Chemical fertilizer is also another source of it.

Chlorides (Cl^{-}) content of all the samples varied from 4.3 mg/L to 187.2 mg/L, with (mean = 40.61 mg/L) (Table 4). For chloride, S-24 (Thanga Ngaram Bamon mathak) possessed the least concentration, whereas S-1 (Maibam Lotpa Chingning awang leikai-1) had the highest one (Table 3a). As per BIS and WHO standards, all samples are observed below the standard limit (250 mg/L) of BIS (2012) and WHO (2011). In groundwater, chlorides are present in the form of NaCl, KCl, $MgCl_2$, $CaCl_2$, etc. and are readily soluble. The presence of high amounts of chlorine in drinking water can also affect the taste and odour of the water.

SO_4^{2-} concentration of all the samples varied from 12.8 mg/L to 39.3 mg/L, having (mean = 21.12 mg/L) (Table 4). S-1 (Maibam Lotpa Chingning awang leikai-1) and S-9 (Bishnupur Bazar, R.K. Gyane Singh's residence) possessed the minimum and maximum concentrations of SO_4^{2-} respectively (Table 3a). The SO_4^{2-} concentrations of the samples were reported to be below the desirable limit of both BIS (2012) and WHO (2011). In groundwater, SO_4^{2-} may be due to the presence of gypsum in aquifer materials, sulphide-bearing minerals, utilizing sulphate-rich fertilizers and so on (Sridharan and Nathan, 2017).

NO_3^{-} concentration of all the samples ranged between 0.1 mg/L and 6.2 mg/L, with mean of 2.126 mg/L (Table 4). S-4 (Ishok Maning Chingya) and S-2 (Maibam Lotpa Chingning awang leikai-2) were recorded to have the lowest and highest concentrations of NO_3^{-} respectively (Table 3a). All samples were observed below the desirable BIS (2012) and WHO (2011) limits. NO_3^{-} contamination in the groundwater may be due to several anthropogenic factors such as inappropriate garbage disposal, utilizing various chemical fertilisers, poor sewage system along with water carrying pipes, leaking of septic tanks and so on (Chakraborty *et al.*, 2022).

The HCO_3^{-} concentration for all the samples varied from 161.7 mg/L to 433.2 mg/L, with a mean value of 310.85 mg/L (Table 4). S-7 (Bishnupur bazar, Athuipau Gonmei's residence) and S-23 (Thanga Ngaram Church makha) possessed the lowest and highest concentrations, respectively (Table 3a). In the groundwater, the presence of HCO_3^{-} is due to the reaction between CO_2 (present in the soil) and minerals (rock-forming type), which produces an alkaline environment (Ram *et al.*, 2021). HCO_3^{-} is the dominant among ani-

Table 5. Class of groundwater by TH values (Sawyer and McCarty, 1967)

Sl. No.	TH values (mg/L)	Class/category	Water samples of present study	No. of samples	%
1.	(0 to 75)	Soft	-	-	-
2.	(75 to 150)	Moderately hard	S-2, S-3, S-7	3	11.11
3.	(150 to 300)	Hard	S-1, S-4 to S-6, S-8 to S-18, S-20 to S-22, S-24 to S-27	22	81.48
4.	Above 300	Very hard	S-19, S-23	2	7.41

ons (as indicated by mean value) (Table 4). However, the concentrations of CO_3^{2-} for S-1 to S-27 are recorded as zero, i.e., 0.0 mg/L.

Heavy metals analysis

Total arsenic (As) concentrations for all the samples were in the range (0.000 – 0.005) mg/L, having (mean = 0.0011 mg/L) (Table 4). Each of S-1, S-4, S-6 to S-9, S-14 to S-17, S-21, S-22, S-25 and S-26 has a concentration of total arsenic equal to 0.000 (zero), i.e. As was absent in such groundwater samples (Table 3b). The highest arsenic concentration was observed in the case of S-13 (Bishnupur Thiyam leikai, public dug well) and S-23 (Thanga Ngaram Church makha) (0.005 mg/L each) (table-3b). Arsenic concentration for all the samples was recorded within the desirable limit (0.01 mg/L) of both BIS (2012) and WHO (2011). Excessive contamination of As in drinking water can cause skin cancer and, high risk of bladder, lung, liver, kidney, prostate cancer and so on (Gray, 2008). Geogenic process is responsible for more than 90% of As pollution and the main source of As, present in the groundwater samples, is from alluvial sediments (Shaji *et al*., 2021).

Pb (lead) concentration for all the samples varied in the range (0.000 – 0.498) mg/L, having a mean of 0.0781 mg/L (Table 4). Each of S-1 to S-3, S-5 to S-8, S-11 to S-15, S-17 to S-19, S-21, S-22, S-24, S-26 and S-27 had concentrations of lead equal to 0.000 (zero), i.e. Pb was absent in such groundwater samples (Table 3b). The highest concentration of Pb was recorded in case of S-9 (Bishnupur bazar, R.K. Gyane Singh's residence) (0.498 mg/L) (Table 3b). 25.93% of samples (S-4, S-9, S-10, S-16, S-20, S-23, S-25) exceeded the desirable limit (0.01 mg/L) of both BIS and WHO, whereas 74.07% of samples were recorded below its desirable limit (BIS, 2012 and WHO, 2011). Pb enters the water bodies from anthropogenic and natural activities and is a toxic environmental contaminant (Ren *et al*., 2022). In our body, a high amount of Pb can cause death or permanent injury to CNS (central nervous system), kidneys and brain (Mebrahtu and Zerabruk, 2011). The main sources of Pb contamination in

Table 6a. S_i (Standards), Agency's name and W_i (Unit Weight) for estimating water quality index (WQI) values

Parameters studied (mg/L)	S_i	Agency's Name	$1/S_i$	W_i
pH	8.5	WHO/BIS	0.11765	0.55354
TDS	500	BIS	0.002	0.00941
TA	200	BIS	0.005	0.02353
TH	200	BIS	0.005	0.02353
Ca^{2+}	75	BIS	0.01333	0.06273
Mg^{2+}	30	BIS	0.03333	0.15684
Na^{+}	200	WHO	0.005	0.02353
Cl^{-}	250	BIS/WHO	0.004	0.01882
SO_4^{2-}	200	BIS	0.005	0.02353
NO_3^{-}	45	BIS	0.02222	0.10456
Total			$\sum W_i = 1.0000$	

Table 6b. Estimated values of water quality index (WQI)

Sample code	Values of WQI	Class/ Division	Ranking
S-1	51.88	Poor	C
S-2	99.11	Very poor	D
S-3	97.05	Very poor	D
S-4	51.29	Poor	C
S-5	51.29	Poor	C
S-6	24.77	Excellent	A
S-7	103.6	Unsuitable	E
S-8	110.1	Unsuitable	E
S-9	70.66	Poor	C
S-10	100.9	Unsuitable	E
S-11	95.35	Very poor	D
S-12	106.3	Unsuitable	E
S-13	119.1	Unsuitable	E
S-14	15.07	Excellent	A
S-15	115.1	Unsuitable	E
S-16	23.69	Excellent	A
S-17	85.61	Very poor	D
S-18	10.72	Excellent	A
S-19	51.03	Poor	C
S-20	34.02	Good	B
S-21	50.02	Good	B
S-22	52.55	Poor	C
S-23	49.71	Good	B
S-24	58.67	Poor	C
S-25	60.15	Poor	C
S-26	62.26	Poor	C
S-27	37.28	Good	B

A, B, C and D indicates the grading/ranking of the groundwater quality based on the computed WQI values

Table 6c. Water quality index (WQI) values categorization of the water samples

WQI ranges	Status of 'Water quality'	Sample code	Total	%
(0 to 25)	Excellent	S-6, S-14, S-16, S-18	4	14.815
(26 to 50)	Good	S-20, S-21, S-23, S-27	4	14.815
(51 to 75)	Poor	S-1, S-4, S-5, S-9, S-19, S-22, S-24, S-25, S-26	9	33.333
(76 to 100)	Very poor	S-2, S-3, S-11, S-17	4	14.815
> 100	Unsuitable	S-7, S-8, S-10, S-12, S-13, S-15	6	22.222

groundwaters are combustion of fossil fuels, gasoline, lead-based paint, cosmetics, industrial soil pollution and soldering (Asim *et al*., 2024).

Mercury (Hg) concentration for all the samples varied from 0.000 mg/L to 0.008 mg/L, having (mean = 0.0024 mg/L) (Table 4). Hg was absent in the groundwater, viz. S-1, S-3, S-6 to S-8, S-10, S-12, S-18, S-24, S-26 and S-27 (Table 3b). The maximum concentration of Hg was reported in the case of S-5 (Ishok Chengphu, Terapokpi) and S-9 (Bishnupur bazar, R.K. Gyane Singh's residence) (0.008 mg/L each) (table-3b). 51.85% of samples (S-1, S-3, S-6, S-7, S-8, S-10, S-12, S-14, S-18, S-20, S-22, S-24, S-26, S-27) were observed below the acceptable limit (0.001 mg/L) of BIS, whereas others 48.15% of samples exceeded the acceptable limit of BIS (2012). However, as per WHO standard, 92.59% of samples (S-1 to S-4, S-6 to S-8 and S-10 to S-27) were recorded below the desirable limit (0.006 mg/L), whereas 7.41% of samples exceeded the desirable limit of WHO (2011). The toxicity of Hg includes central nervous system (neurological dysfunction, memory loss, insomnia, nerve sensing etc.), digestive system (gastrointestinal dysfunction, diarrhoea, abdominal cramps, etc.), urinary system (renal dysfunction), genotoxicity (chromosomal aberrations and disorders) and others toxicity of Hg are chest pain, corrosive to eyes and skin, elevating blood pressure and so on (Al-Sulaiti *et al*., 2022). MeHg (methyl mercury) is one of the most toxic substances, mainly from ingesting contaminated fish (Al-Sulaiti *et al*., 2022).

Water Quality Index (WQI)

Ten physicochemical parameters have been considered, to examine the WQI values presented in Table 6a. WQI value varied from 10.72 for S-18 to 119.1 for S -13 (Table 6b). Table 6c explains that 14.815% of water comes under the class of 'excellent', another 14.815% (good water), 33.333% (poor water), another 14.815% (very poor water) and 22.222% of water fall under the class of 'unsuitable' for drinking purpose.

Irrigation (agricultural) water quality

Groundwater samples are usually more mineralised by dissolved salts that influence permeability, texture, structure, pH of the soil, the absorption of minerals and nutrients, etc. The low quality irrigation water directly influences crop yield. For this current work, based on Cl^- concentration for different groundwater (Table 3a), it can be clarified that S-3 to S-13, S-15 to S-24, S-26 and S-27 are normally 'safe' for all types of plants because these mentioned samples have Cl^- concentration less than 70 mg/L, i.e. they do not have major effects on crops (Zaman *et al*., 2018). Again, (from Table 3a), S-14 and S-25 fall under the Cl^- concentration (70 – 140) mg/L and it reveals that the sensitive plants showed 'slight' to 'moderate injury' whereas S-1 and S-2 fall under the Cl^- concentration (141 – 350) mg/L and it indicates that moderately tolerant plants showed slight to substantial injury (Zaman *et al*., 2018). Table

Table 7a. Computed values of Residual sodium carbonate (RSC), Sodium adsorption ratio (SAR), Percent sodium (% Na), Permeability index (PI), Kelly's ratio (KR)

Sample code	RSC	SAR	%Na	PI	KR
S-1	2.20	5.11	65.92	89.06	1.93
S-2	3.63	8.41	81.32	104.67	4.34
S-3	0.43	1.06	32.74	79.41	0.48
S-4	0.75	1.07	25.31	60.76	0.34
S-5	0.23	1.36	34.28	70.54	0.52
S-6	-0.66	0.84	22.85	54.63	0.27
S-7	-0.19	0.87	27.92	68.74	0.37
S-8	0.07	0.71	19.59	53.14	0.21
S-9	-0.27	1.10	30.61	63.42	0.39
S-10	0.17	1.03	28.33	62.44	0.35
S-11	-0.50	0.98	29.28	60.53	0.35
S-12	-0.32	0.91	26.59	64.13	0.35
S-13	0.37	0.85	27.86	67.34	0.32
S-14	-0.75	1.02	23.16	52.68	0.30
S-15	0.58	0.79	18.82	53.40	0.23
S-16	0.91	0.80	21.19	61.27	0.26
S-17	0.90	0.82	20.88	58.97	0.26
S-18	0.42	0.62	16.46	54.41	0.19
S-19	0.32	0.75	17.90	52.08	0.21
S-20	0.99	0.63	17.51	60.26	0.21
S-21	0.26	0.57	15.08	52.51	0.17
S-22	0.90	0.66	16.44	53.32	0.19
S-23	0.74	0.82	19.07	52.82	0.23
S-24	1.59	0.75	21.95	70.24	0.28
S-25	0.19	1.82	36.75	65.45	0.58
S-26	1.56	1.18	27.17	63.86	0.37
S-27	1.58	0.89	23.46	66.15	0.30
Min.	-0.75	0.57	15.08	52.08	0.17
Max.	3.63	8.41	81.32	104.67	4.34
Mean	0.596	1.349	27.72	63.564	0.519
S.D.	0.941	1.645	14.572	12.025	0.830
Standard error	0.181	0.317	2.804	2.314	0.160

Table 7b. Irrigational groundwater quality categorization

Sl. No.	Parameters studied	Values/ ranges	Category/ Class	Sample code	Total	%
1.	RSC	< 1.25	Good	S-3 to S-23 and S-25	22	81.4815
		(1.25 – 2.50)	Marginal	S-1, S-24, S-26 and S-27	4	14.8148
		> 2.50	Unfit	S-2	1	3.7037
2.	SAR	< 10	Excellent	S-1 to S-27	27	100.00
		10 to 18	Good water	-	-	-
		18 to 26	doubtful	-	-	-
		above 26	Unfit	-	-	-
3.	%Na	< 20 %	Excellent	S-8, S-15 and S-18 to S -23	8	29.6296
		(20 – 40) %	Good	S-3 to S-7, S-9 to S-14, S-16, S-17 and S-24 to S-27	17	62.9630
		(40 – 60) %	Permissible	-	-	-
		(60 – 80) %	Doubtful	S-1	1	3.7037
		> 80%	Unfit	S-2	1	3.7037
4.	PI	> 75%	Suitable	S-1 to S-3	3	11.11
		(25 – 75) %	Good	S-4 to S-27	24	88.89
		< 25 %	Unfit	-	-	-
5.	KR	≤ 1	Suitable	S-3 to S-27	25	92.59
		≥ 1	Unfit	S-1 and S-2	2	7.41

RSC (Residual sodium carbonate), SAR (Sodium adsorption ratio), %Na (Percent sodium), PI (Permeability index), KR (Kelly's ratio)

7a presents the calculated values of RSC, KR, SAR, PI, %Na, whereas Table 7b presents its categorization for examining the appropriateness of groundwater for irrigation.

The RSC value of all the samples varied in the range of -0.75 meq/L for S-14 to 3.63 meq/L for S-2, with a mean value of 0.596 meq/L (Table 7a). 81.4815% of water possessed 'good' water quality, 14.8148% (marginal) and 3.7037% (unfit) for irrigation (Table 7b). Except S-2 (Maibam Lotpa Chingning awang leikai-2), other samples were recorded as 'fit' for irrigation (Wilcox, 1955). Prolonged utilization of water with high RSC value leads to more chance of affecting the yield of crops.

The SAR value of all the samples varied between 0.57 for S-21 and 8.41 for S-2, having mean=1.349 (Table 7a). 100% of water falls under the class of 'excellent water' because the SAR values for all the samples were observed to be less than 10 (Table 7b). Therefore, all samples were recorded as 'suitable' for irrigation (Todd, 1980). Continuously using water having a greater amount of SAR value leads to the breakdown of soil's physical structure, which results in the dispersion of soil clay, which causes the soil to become compact and hard when dry (Zaman *et al*., 2018).

%Na value of all the samples ranged from 15.08% for S -21 to 81.32% for S-2, having mean=27.72% (Table 7a). 29.6296% of water falls under the group of 'excellent' class, 62.9630% (good), 3.7037% (doubtful) and 3.7037% (unfit) for irrigation purposes (Table 7b). In this case, also, only S-2 was recorded as 'unfit' whereas other samples were recorded as 'fit' for irrigation (Todd, 1980) (Table 7b). In groundwater, an excess amount of Na^+ concentration produces the unwanted effects since sodium reacts with soil to decrease its permeability and there is no support for the growth of plants (Singh *et al*., 2015).

PI value of all the samples varied in the range of 52.08% for S-19 to 104.67% for S-2, having mean=63.564% (Table 7a). 11.11% of water belongs to the category of 'suitable', whereas 88.89% of water possessed 'good' water quality (Table 7b). Hence, all samples were observed to be 'fit' for agricultural or irrigation purposes (Doneen, 1964). If the permeability is found in a low amount in the soil zone, it does not support the growth of plants.

The KR value of all the samples ranged from 0.17 for S -21 to 4.34 for S-2, with a mean=0.519 (Table 7a). 92.59% of water come under the 'suitable' category whereas, 7.41% of groundwater belongs to 'unfit' category for irrigation (Table 7b). Except S-1 and S-2, other groundwater samples were recorded under the class of 'suitable' for irrigation or agricultural activities (Kelly, 1940). It is suggested to use pure gypsum for reducing Na^+ ion effect if the K.R value is observed as high (Rawat *et al*., 2018).

From Table 7b, it can be summarized that based on RSC (except S-2), SAR, %Na (except S-2), PI, KR (except S-1 and S-2), all the samples were recorded as 'fit/suitable' for irrigation purposes.

Statistical analysis by Pearson's correlation coefficient (r) value

From Table 8, it is clarified that TA exhibited strong

Table 8. Correlation Coefficient (r) values of different parameters for different groundwater

	Temp.	pH	TDS	TA	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	NO_3^{-}	HCO_3^{-}	As	Pb	Hg
Temp.	1.000															
pH	0.405	1.000														
TDS	-0.375	-0.092	1.000													
TA	-0.667	-0.499	0.400	1.000												
TH	-0.374	-0.535	0.058	0.701	1.000											
Ca^{2+}	-0.068	-0.220	0.054	0.224	0.677	1.000										
Mg^{2+}	-0.450	-0.539	0.034	0.762	0.788	0.080	1.000									
Na^{+}	-0.210	0.104	0.847	0.132	-0.422	-0.363	-0.267	1.000								
K^{+}	0.121	0.493	-0.069	-0.477	-0.179	0.372	-0.554	-0.133	1.000							
Cl^{-}	-0.074	0.141	0.843	-0.074	-0.373	-0.188	-0.347	0.889	0.070	1.000						
SO_4^{2-}	0.387	0.485	-0.203	-0.506	-0.167	0.441	-0.596	-0.221	0.793	-0.042	1.000					
NO_3^{-}	-0.156	0.364	0.405	-0.085	-0.348	-0.039	-0.439	0.506	0.426	0.467	0.199	1.000				
HCO_3^{-}	-0.667	-0.499	0.400	1.000	0.701	0.224	0.762	0.132	-0.477	-0.074	-0.506	-0.085	1.000			
As	0.128	0.284	-0.162	-0.150	-0.297	-0.187	-0.246	0.063	0.098	0.019	0.128	0.018	-0.150	1.000		
Pb	-0.276	-0.241	-0.128	0.126	0.163	0.222	0.034	-0.125	0.031	-0.163	0.146	-0.259	0.126	0.093	1.000	
Hg	-0.177	0.006	-0.009	-0.024	0.045	-0.064	0.114	-0.007	0.092	-0.085	0.011	-0.014	-0.024	-0.010	0.308	1.000

+ve correlation with TH (r=0.701) but very strong +ve correlation with HCO_3^- (r=1.000). Again, TA shows a strong +ve correlation with Mg^{2+} (r=0.762), but a weak +ve correlation with Ca^{2+} and Na^+ (r=0.224 and 0.132 successively). Hence, it can be stated that TA of the different groundwater was mostly due to dissolved Mg $(HCO_3)_2$ but also by the presence of dissolved Ca $(HCO_3)_2$ and $NaHCO_3$ to a smaller extent. However, TH exhibits strong +ve correlation with Ca^{2+}, Mg^{2+} and HCO_3^- (r=0.677, 0.788 and 0.701 successively), but -ve correlation with Cl^- and SO_4^{2-} (r=-0.373 and -0.167 successively). From this, it can be confirmed that the TH of the analysed waters was mostly due to the dissolved $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$, exhibiting the temporary hardness of water predominantly.

From the above discussion, based on various experimental data of the different groundwater samples, most of samples were found to be fit mainly for drinking and irrigation purposes. However, for those fewer water samples, which were unfit for drinking and irrigation purposes, other treatments are suggestive to improve their quality. The slightly degrading quality of some of the groundwater samples may be due to inappropriate disposal of domestic waste products and extensive use of various fertilizers, pesticides, herbicides, etc. This study will be very beneficial to the inhabitants of the study areas mainly because most of them are below the poverty line. They cannot purchase well-treated water and do not have other alternate water sources for their daily needs.

Conclusion

The groundwater quality in certain regions of Bishnupur district, Manipur, India was of 'freshwater' type, slightly 'alkaline' and categorised as 'moderately hard' to 'very hard' water. Ca^{2+} and HCO_3^- were recorded as the dominant ion among cations and anions, respectively. For fewer samples, parameters like pH, Pb, TDS, Ca^{2+}, TA, Hg, Mg^{2+} and TH were reported above the desirable limit of BIS and WHO, and some suitable treatments were necessary for them. However, for most of the water samples, parameters were within/below the desirable limit of BIS and WHO for drinking purposes. From the estimated values of WQI also, it can be concluded that 14.815% of water possessed 'excellent water', 14.815% (good water), 33.333% (poor water), 14.815% (very poor water) and 22.222% of water were not suitable for drinking purpose. For irrigation purposes, the indices, viz. RSC, PI, SAR, KR, %Na elucidated that all analyzed samples were recorded as 'fit/safe'. The correlation coefficient (r) value confirmed that TH of the water samples was mostly on account of temporary hardness and TA was mostly as a result of dissolved $Mg(HCO_3)_2$ to a large extent but also by having dissolved $Ca(HCO_3)_2$ and $NaHCO_3$ to a smaller extent.

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Conflict of interest

The authors declare that they have no any conflict of interest.

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