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Comparative Study of Groundwater Quality for Drinking and Irrigation Purposes in Selected Villages of Manipur, India

NGANGBAM PREMALA DEVI[2] and LAISHRAM NANDABABU SINGH[1]*

[1]Department of Chemistry, D.M. College of Science, Dhanamanjuri University, Imphal, Manipur, India.
[2]Department of Chemistry, Manipur University, Canchipur, Manipur, India.

Abstract
A comparative study was done to monitor the groundwater qualities, both for drinking as well as irrigation purposes in some villages of Imphal East district, Manipur, in the period of pre-monsoon and monsoon of 2021. Totally, fifteen (15) groundwater samples were collected and examined for some important parameters like temperature, pH, TDS, TH, TA, Mg^{2+}, K^+, HCO_3^-, Ca^{2+}, CO_3^{2-}, Na^+, Cl^-, NO_3^- and SO_4^{2-}. The results revealed that all the groundwaters were slightly alkaline in nature and fall under freshwater category. In both the seasons, majority of the parameters for various groundwaters have found their values/ concentrations below its acceptable limits, as given by BIS and WHO. In pre-monsoon, 73.33% of groundwaters were found as 'moderately hard water' and 26.67% (hard water) whereas in monsoon, 60% (moderately hard water) and 40% (hard water). Dominant ions in both seasons were Na^+ (sodium) and HCO_3^- (bicarbonate) for cations and anions respectively. In most of the samples of monsoon, values and concentrations of the studied parameters were observed to be greater/higher as compared to that of pre-monsoon. It was mainly due to the leaching out of the soluble salts in the earth's crust by rainwaters and finally mingled with the groundwater bodies in the aquifers in monsoon season. WQI values showed that in pre-monsoon, 26.67% of groundwaters were found as excellent water, 66.67% (good) and 6.66% (poor) while in monsoon, 60% (good) and 40% (poor). For irrigation water qualities, the indices (RSC, SAR, %Na, PI and KR) were examined. In the overall, all the samples can be utilized for irrigation (agriculture) purposes in both seasons. Correlation co-efficient (r) values showed that in both the seasons, the TH of various groundwaters was mainly because of dissolved sulphates of Ca^{2+} along with Mg^{2+}.

CONTACT Laishram Nandababu Singh ✉ l.nandababu@yahoo.com ⦿ Department of Chemistry, D.M. College of Science, Dhanamanjuri University, Imphal, Manipur, India.

Introduction

Life on the earth will not be possible without water. Water (H_2O) is available in various forms like groundwater and surface water. However, many surface water bodies are diminishing continuously because of the increasing rate of urbanization and expansion of urban areas.[1] Not only this, the pollution load of many ground water bodies and surface water increases due to anthropogenic activities of the increasing population growth all over the world. Because of the diminishing of many surface waters in many areas of the world, it is needed to explore more groundwater. From the global water resources, groundwater is around 0.6% and out of these resources, around 0.3% is extracted economically.[2] Unmethodical, quick and unexpected urbanization damage the sustainability of many development processes by changing different environmental factors such as temperature, levels of groundwater and rainfall adversely.[3] By the consumption of contaminated drinking water continuously, many serious health problems and issues occur to human.[4] It is highly necessary to comprehend the qualities of groundwater for the effective planning and administration of ground-water resources to determine its use for drinking along with irrigation purposes.[5] For drinking as well as irrigation (agricultural) purposes, several researchers or scientists reported about quality of groundwaters whether they can be usable or not, in many countries of the world.[6-9] Similarly in India also, many researchers or scientists had

reported about groundwater qualities for drinking as well as irrigation/agricultural purposes.[10-13] Many researchers have also computed WQI for examining the suitability of different groundwaters for drinking purposes.[14-17]

In Imphal East district, Manipur, India, many of the villagers are very much dependent on the ground-waters for their livelihood as they do not have the facilities of treated water supply, tap-water system etc. for drinking purposes mainly. Therefore, this work attempts to execute a comparative study of groundwaters in some villages of Imphal East district, Manipur, India for drinking as well as irrigation/agricultural purposes during pre-monsoon and monsoon (2021).

Study Areas

Imphal East district is located at Manipur, India. As per 2011 census,[18] the total area of this district is nearly 709 Km^2 and it has a population of 4,56,113 including both males and females and also the district lies between latitudes 24°39'49.09"N and 25°4'5.45"N and longitudes 93°55'30"E and 94°8'42"E approximately. The location of study areas (longitudes and latitudes) along with depth of the tube wells (meter) are listed in table-1. The geographical positions of different sampling sites were measured by GPS instrument. The location map (sampling points) of the study areas of Imphal East District, Manipur, India is shown in fig.1.

Table 1: Locations of study areas with geographical positions

Sample no.	Sampling Sites	Longitudes	Latitudes	Depth of the tube wells (m)
S-1	Sangshabi mayai leikai (1) (near waiting shed and main road)	94°1'15.9"E	24°49'41.6"N	47
S-2	Sangshabi mayai leikai (2) (near foothill)	94°1'15.4"E	24°51'20.6"N	56
S-3	Sanjembam khullen awang leikai	94°1'34"E	24°49'9.1"N	50
S-4	Takhel youngdong (near foothill and paddy field)	94°2'41.2"E	24°49'6.2"N	56
S-5	Kangba chingjil khunou (1) (near club and house gate)	94°3'18.9"E	24°49'56.4"N	51
S-6	Kangba chingjil khunou (2) (near foothill)	94°2'17.1"E	24°49'42.9"N	55

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S-7	Kangba chingjil khullen (near community hall and anganwadi centre)	94°3'41"E	24°52'9.9"N	53
S-8	Kangba chingjil (near foothill and temple)	94°3'27.9"E	24°50'38.8"N	49
S-9	Kharason awang leikai (near banyan tree)	94°1'48.1"E	24°50'56.3"N	52
S-10	Kharason makha leikai (near foothill)	94°1'50.7"E	24°50'43.2"N	55
S-11	Pukhao Terapur (near foothill)	94°1'47.7"E	25°0'14.6"N	56
S-12	Poumai colony (near church)	93°56'40.73"E	24°50'5.15"N	59
S-13	Heingang mayai leikai (1) (near footpath)	93°56'39.59"E	24°51'31.83"N	60
S-14	Heingang mayai leikai (2) (near rice mill of N. Mangoljao)	93°56'41.88"E	24°51'32.71"N	52
S-15	Heingang awang leikai (3) (near community hall and foothill)	93°56'7.47"E	24°52'14.00"N	58
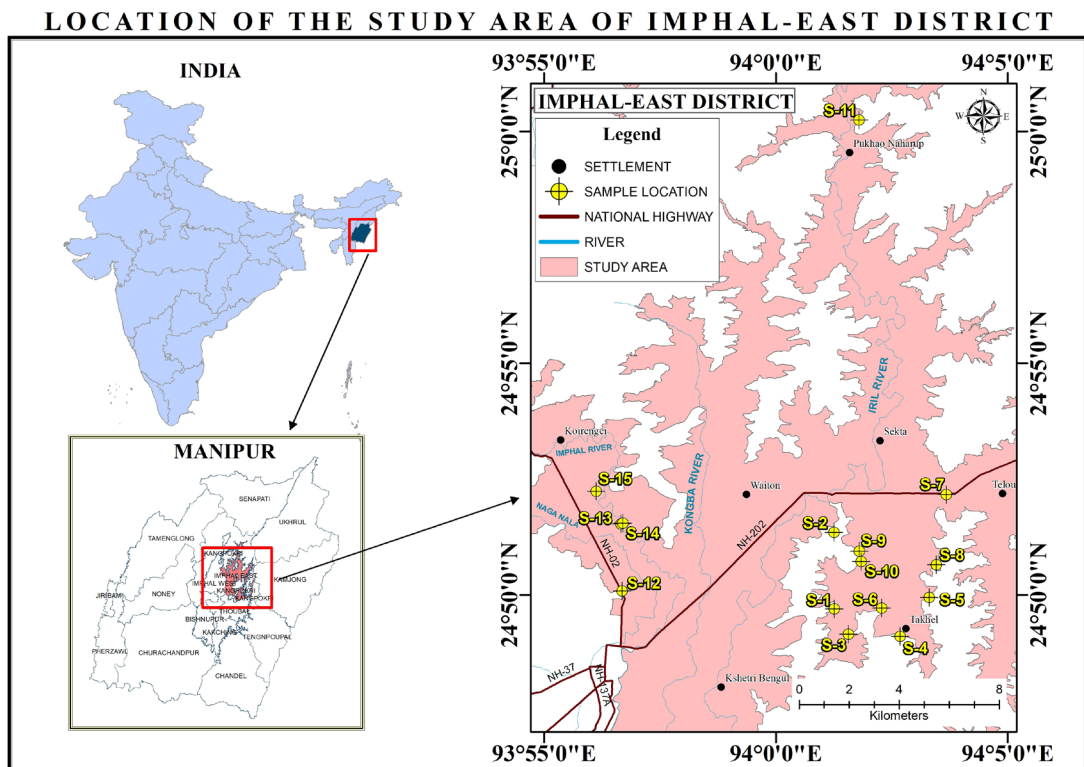
Fig.1: Sampling points of study area of Imphal East district of Manipur, India

Material and Methods

Altogether fifteen (15) groundwaters were selected from different hand pumps (tube wells) of some villages of Imphal East district, Manipur, located mainly near the foothills and agricultural areas during the time of pre-monsoon and monsoon seasons of 2021. The selected groundwater samples are extensively used by the local inhabitants for drinking, other domestic and irrigation purposes. Each sample was collected in a well sterilized polythene bottle in the morning session starting from around 8.00 a.m. Before sampling, all the sterilized bottles were rinsed with the groundwater, which is to be collected. Sampling and preservation of groundwater samples were done as per guidelines of APHA.[19] Temperature (°C), pH and TDS were examined at the sampling locations whereas TH, Na^+, TA, Mg^{2+}, K^+, CO_3^{2-}, Cl-, SO_4^{2-}, HCO_3^-, Ca^{2+} and NO_3^- were analysed at research lab by following the protocols and standard methods, as given by APHA.[19] The chemical reagents such as HCl, NH_4OH, methyl orange indicator, disodium salt of EDTA, N/50 $AgNO_3$ solution, NaOH, NH_4OH, NH_4Cl, $MgSO_4.2H_2O$, NaCl, KCl, phenolphthalein indicator, HNO_3, H_2SO_4, conditioning reagent, $BaCl_2$, arsenite solution and brucine-sulphanilic acid were used. Detailed methods and instruments which are utilized for determining the different parameters are listed as follows (table-2).

Table 2: Detailed methods and instruments for determining the different parameters

Sl. No.	Studied parameters	Instruments and detailed method
1	Temp. (°C) and TDS	TDS Meter - (TDS/Temp.) from (HIMEDIA by India) was utilized for measuring temp. (°C) along with TDS.
2	pH	pH Meter – (HI98107) was used for determining pH values.
3	TH	TH was obtained by EDTA titrimetric, in which EBT indicator was used.
4	TA	TA was determined by titration with standard HCl solution. Here, methyl orange indicators as well as phenolphthalein were used.
5	Ca^{2+}	'EDTA - titrimetric method' in which murexide indicator was utilized.
6	(a) Mg^{2+} (b) CO_3^{2-} and HCO_3^-	'calculation method' (a) Mg^{2+} is calculated from the values of TH and Ca^{2+} and (b) CO_3^{2-} and HCO_3^- are calculated from TA values.
7	Na^+ and K^+	'Flame Photometer-128' of Systronics, India was utilized.
8	Cl-	Argentometric titration was used.
9	SO_4^{2-} and NO_3^-	UV/ Visible spectrophotometer was used.

Computing of "Water Quality Index"

WAWQI/Weighted Arithmetic Water Quality Index is utilized. 5 (five) types of WQI values/ranges are divided in which WQI value of less than 25 is entitled as 'excellent', (26 upto 50) is termed as 'good', (51 upto 75) is treated as 'poor', (76 upto 100) is called as 'very poor' and greater than 100 is termed as 'unfit' for drinking purposes.[20]

Mathematically, WQI is calculated from eq.-(1).

a) $\mathrm{WQI} = \frac{\sum \mathrm{Qi\,Wi}}{\sum \mathrm{Wi}}$ ...(1)

Here, Qi is quality rating scale and Wi is called as Unit weight of an ith parameter.

Again, Qi is expressed using eq.-(2).

b) $\mathrm{Qi} = \left[\frac{(Vi-Vo)}{(Si-Vo)}\right] \times 100$ ...(2)

Here, Vi is experimental value of an ith parameter, Vo is Zero (0) except for the pH value of 7.0 and lastly, Si is known as recommended values of an ith parameter.

Also, Wi is derived using eq.-(3).

c) $\mathrm{Wi} = \frac{K}{Si}$ ...(3)

Here, K is termed as proportionality constant, obtained from eq.-(4).

d) $K = \dfrac{1}{\sum(\frac{1}{Si})}$ ...(4)

Irrigation Water Quality Assessment

The following parameters were evaluated for determining the suitability of irrigation water qualities for the present research work. The ionic concentration, which were required for computing RSC, SAR, %Na, PI and KI are taken as 'meq/L'.

RSC/Residual Sodium Carbonate

RSC values are calculated from eq.-(1) and its value/range is divided into 3 (three) classes.[21]

(a) RSC value which is less than 1.25 falls under good water quality,
(b) RSC ranges (1.25 - 2.50) falls under marginal or doubtful water quality and
(c) RSC value which is greater than 2.50 falls under unsuitable for irrigation purposes.

$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ ...(1)

Sodium Adsorption Ratio or SAR

By using eq.-(2), SAR value is obtained and also its value is classified into 4 (four) classes.[22]
(a) SAR < 10 - excellent water quality,
(b) SAR of 10 upto 18 - termed as good water quality,
(c) SAR of 18 upto 26 - doubtful,
(d) SAR > 26 - named as unfit for irrigation purposes.

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

Percent Sodium/%Na

The %Na is evaluated from eq.-(3) and also %Na value is divided into 5 (five) classes.[22]

(a) %Na < 20% - excellent water quality,
(b) %Na ranges (20 – 40)% as good water quality,
(c) %Na ranges (40 – 60)% fall under permissible,
(d) %Na values (60 – 80)% fall under doubtful,
(e) %Na values > 80% is named as unfit/unsuitable for irrigation purposes.

$\%Na = (Na^+ + K^+)/(Ca^{2+}+Mg^{2+}+Na^+ + K^+) \times 100$ …(3)

Permeability index or PI

The formula of PI is given in eq.-(4) and PI value range is classified into 3 (three) types[23]

(a) PI values > 75% - suitable,
(b) PI ranges (25 – 75)% - good water quality
(c) PI values < 25% is termed as unfit/unsuitable for irrigation purposes.

$PI = (Na^+ + \sqrt{HCO_3^-})/(Ca^{2+} + Mg^{2+}) + Na^+ \times 100$ ...(4)

Kelly's ratio or KR

KR is obtained from eq.-(5) for which KR ≤1 (suitable) and KR ≥1 (unsuitable) for irrigation[24]

$KR = Na^+/(Ca^{2+}+ Mg^{2+})$ ...(5)

Results and Discussion

Table-3a (pre-monsoon) and table-3b (monsoon) showed the values or concentrations of different physico-chemical parameters for fifteen (15) groundwater samples. Table-3c showed the descriptive summary along with BIS[25] and WHO[26] standards value. All the studied groundwaters were observed to be colourless as well as odourless.

Temperature (°C)

During pre-monsoon, the temperatures of the groundwaters are in the range (21.50°C - 24.6°C) and (mean value = 23.21°C) whereas in monsoon, they are in the ranges (23.6°C - 27.4°C) and (mean value = 25.19°C) (table-3c). Temperature affects the groundwater qualities in various ways, both in biological as well as physical process. The increase in temperature during the monsoon season is due to the prevailing of the summer season which gets more heating effect during this period and more disposals of organic waste products as compared to that of pre-monsoon.

pH

During pre-monsoon, 7.1 (each of S-1, S-2 and S-13) and 7.9 (each of the S-7, S-11, S-9) are the smallest and greatest pH values respectively in which (mean value = 7.51) whereas in monsoon, 7.4 (S-12) and 8.3 (each of S-9, S-11) are the smallest and maximal pH values respectively and (mean value = 7.79) (table-3c). Due to more leaching of alkaline substances by heavy rainfall into groundwaters during the time of monsoon, pH value of groundwaters becomes higher as compared to that of pre-monsoon. pH values for S-1 to S-15 in both seasons are found within its acceptable limit, as given by BIS and WHO for drinking water.[25-26]

**Table 3a: Values of physico-chemical parameters (mg/L), except pH and temp.
(°C) for pre-monsoon**

Sample no.	Temp.	pH	TDS	TH-Ca CO_3	TA-Ca CO_3	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-
S-1	23.8	7.1	187	128	212	17.6	20.4	24.7	0.9	5.7	11.8	0.3	258.6
S-2	22.8	7.1	170	152	185.5	20.8	24.3	18.4	0.7	7.1	12.4	0.3	226.3
S-3	23.4	7.3	480	86	477	13.6	12.6	194.0	1.5	32.6	14.5	2.2	581.9
S-4	22.5	7.6	288	210	323.3	32.1	31.6	52.9	1.3	5.7	11.1	0.1	394.4
S-5	23.4	7.8	323	94	328.6	14.4	14.1	106.2	1.4	8.5	16.8	0.6	400.9
S-6	24.2	7.7	310	180	307.4	32.9	23.8	59.9	1.7	17.0	27.7	1.4	375.0
S-7	24.6	7.9	381	116	275.6	23.2	14.1	104.2	1.7	82.2	13.7	0.6	336.2
S-8	23.6	7.6	289	104	302.1	16.8	15.1	85.0	1.3	8.5	13.4	0.4	368.6
S-9	21.5	7.9	281	90	275.6	23.2	7.8	79.1	1.3	19.9	13.1	0.7	336.2
S-10	21.7	7.6	309	122	302.1	24.0	15.1	81.3	1.0	26.9	12.0	1.7	368.6
S-11	24.3	7.9	193	158	201.4	26.5	22.4	16.0	0.9	4.3	11.8	0.5	245.7
S-12	22.9	7.2	397	128	413.4	29.7	13.1	105.6	1.2	9.9	12.4	6.3	504.3
S-13	22.9	7.1	277	100	275.6	17.6	13.6	60.6	1.5	15.6	11.0	6.6	336.2
S-14	23.3	7.2	291	112	296.8	18.4	16.0	76.7	1.6	19.9	11.1	4.1	362.1
S-15	23.2	7.6	215	150	227.9	26.5	20.4	30.2	0.9	5.7	11.0	0.3	278.0

TDS/Total dissolved solids (mg/L)

In pre-monsoon, TDS values for all the fifteen (15) groundwaters varies from 170.0 mg/L of S-2 to 480.0 mg/L of S-3 with (mean value = 292.73 mg/L) whereas during monsoon, its value are in the ranges (141.0 – 489.0) mg/L with (mean value = 287.33 mg/L) (table-3c). S-11 and S-3 are the smallest and maximal TDS values respectively in monsoon (table-3b). All the values of TDS are found within its acceptable limit, as given by BIS and WHO standard[25-26] in both the seasons (table-3c). S-3 (monsoon) has the highest TDS value (489 mg/L). All the studied samples belong to the category of 'fresh water' since the TDS values is less than 1000 mg/L.[22] Because of the dissolution of more soluble substance from earth's crust by the heavy rain, TDS values during the time of monsoon becomes higher as compared to that of pre-monsoon. Consumption of water having high TDS value may cause kidney stones and heart diseases to the person.

Total hardness/TH (mg/L)

In pre-monsoon, values of TH are in the range (86 – 210) mg/L and (mean = 128.67 mg/L) while in monsoon, its values are in the range (84 – 200) mg/L and (mean = 136.93 mg/L) (table-3c). S-3 and S-4 are the minimal and greatest TH values in pre-monsoon whereas S-3 and S-6 are the lowest and maximal in monsoon respectively. In S-4 (pre-monsoon), TH value is found below its permissible limit (600 mg/L) but above its acceptable limit of BIS.[25] But, the TH values of other groundwater samples have found within its acceptable limit, as given by BIS.[25] According to Sawyer and McCarty[27] (groundwaters classification by TH values), it is found that in pre-monsoon, 73.33% of groundwaters falls under 'moderately hard water' and 26.67% belongs to 'hard water category' (table-3a) whereas in monsoon, 60% of samples fall under moderately hard water and remaining 40% belongs to hard water category (table-3b). Hard water is not suggested for home usages as it may cause metal dissolution and also leads to abrasive coatings under pipelines, heaters and drums.[28]

Total alkalinity/TA (mg/L)

In pre-monsoon, total alkalinity values are in the range (185.50 – 477.0) mg/L in which (mean = 293.620 mg/L) whereas for monsoon, they are in the range (159.0 - 503.5) mg/L in which (mean value = 303.16 mg/L) (table-3c). For pre-monsoon, S-2 and S-3 have the smallest and maximal TA values respectively whereas in monsoon, S-11 and S-3 possess the minimal and greatest TA values

respectively. Except S-2 (pre-monsoon) and S-11 (monsoon), all other remaining samples have their total alkalinity values greater than its desirable limit of BIS,[25] however, they are observed below 600 mg/L (permissible limit) of BIS.[25] For both seasons, most of the groundwaters of Imphal East district have high values of TA which is mainly due to the leaching of

certain minerals and salts in the soil. In water (H_2O), alkalinity occurs because of the presence of CO_3^{2-}, HCO_3^- and OH- (hydroxide) components in a raw or treated water supply and among these, HCO_3^- is the major one which is due to the CO_2 action on basic materials of soil.[29]

Table-3b: Values of physico-chemical parameters (mg/L), except pH and temp.
(°C) for monsoon

Sample no.	Temp.	pH	TDS	TH-Ca CO_3	TA-Ca CO_3	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-
S-1	25.3	7.6	191	158	212	19.2	26.7	25.7	0.7	4.3	12.2	4.0	258.6
S-2	25.7	8.0	185	162	201.4	20.0	27.2	20.4	0.7	5.7	17.3	3.9	245.7
S-3	25.5	7.5	489	84	503.5	10.4	14.1	190.8	1.5	29.8	13.3	6.4	614.3
S-4	25.6	7.8	279	180	312.7	24.8	28.7	59.9	1.2	7.1	13.6	0.1	381.5
S-5	27.4	7.8	321	108	344.5	16.0	16.5	102.2	1.3	7.1	16.3	8.2	420.3
S-6	26.7	7.9	313	200	318	32.1	29.2	66.2	1.5	4.3	30.9	6.2	388.0
S-7	24.4	7.8	362	136	291.5	24.8	18.0	102.9	1.4	65.2	15.8	5.8	355.6
S-8	24.6	7.8	287	110	318	16.0	17.0	89.1	1.2	7.1	15.3	4.7	388.0
S-9	23.6	8.3	283	112	318	20.8	14.6	90.8	2.0	18.4	15.9	6.7	388.0
S-10	25.1	8.0	284	130	307.4	20.0	19.4	92.5	0.8	24.1	12.1	6.7	375.0
S-11	25.2	8.3	141	126	159	15.2	21.4	16.8	1.0	4.3	13.1	10.7	194.0
S-12	25.4	7.4	396	170	429.3	26.5	25.3	104.8	1.1	8.5	14.7	9.9	523.7
S-13	23.7	7.7	278	106	286.2	16.8	15.6	75.0	1.4	9.9	13.2	12.7	349.2
S-14	23.8	7.5	289	112	302.1	15.2	18.0	77.5	1.4	11.3	16.6	13.0	368.6
S-15	25.8	7.5	212	160	243.8	21.6	25.8	33.4	0.8	5.7	27.9	3.7	297.4

Ca^{2+}/Calcium (mg/L)
In pre-monsoon, concentrations of Ca^{2+} for the fifteen groundwaters varies from 13.60 mg/L (S-3) to 32.90 mg/L (S-6) and (mean = 22.49 mg/L) whereas in monsoon, its concentration ranges from 10.40 mg/L (S-3) to 32.10 mg/L (S-6) with (mean value = 19.96 mg/L) (table-3c). For both the seasons, concentrations of Ca^{2+} are observed within its desirable limit as suggested by BIS[25]. In groundwaters, Ca^{2+} is found to be very common due to its abundance in most of the rocks and higher solubility and also it is one of the important elements for developing proper bone growth[30]

Mg^{2+}/Magnesium (mg/L)
In pre-monsoon, concentrations for Mg^{2+} of the studied groundwaters varies between 7.80 mg/L of S-9 and 31.60 mg/L of S-4 having (mean value =

17.63 mg/L) whereas in monsoon, its concentration are in the range (14.1 - 29.2) mg/L having (mean value = 21.17 mg/L) (table-3c). In case of S-4 (pre-monsoon) (table-3a), the concentration of Mg^{2+} is observed above 30 mg/L (acceptable limit) of BIS25, however, its concentration is observed within 100 mg/L (permissible limit). But, all other groundwaters have found below its acceptable limit of BIS[25] in both the seasons.

Na^+/Sodium (mg/L)
It is one of the alkali metals which usually found in all the groundwaters. In pre-monsoon, concentrations of Na^+ in the groundwaters are in the range (16.0 - 194.0) mg/L having (mean = 72.99) (table-3c) while, in monsoon, its concentration are in the range (16.8 - 190.8) mg/L having (mean = 76.53) (table-3c). There is no huge difference in the variation of Na^+

concentration among the two seasons. Main source of Na^+ present in the groundwaters of Imphal East district comes from the agricultural by-products, municipal waste waters, industrial effluents etc. Concentrations of Na^+ of all the samples, for both the seasons are found below its threshold limit of WHO.[26] For cations group, sodium is observed as the dominant ion in both seasons, as is evident from mean abundance values (table-3c).

Table 3c: Descriptive summary along with BIS (acceptable limit) and WHO (standard)

Para meters	Pre-monsoon				Monsoon				BIS	WHO
	Ranges/ values	Mean values	S.D values	Stan -dard Error	Ranges/ values	Mean values	S.D values	Stan -dard Error		
Temp. (°C)	21.5 - 24.6	23.21	0.88	0.23	23.6 - 27.4	25.19	1.06	0.27	-	-
pH	7.1 - 7.9	7.51	0.31	0.08	7.4 - 8.3	7.79	0.28	0.07	6.5 - 8.5	6.5 - 8.5
TDS (mg/L)	170 - 480	292.73	83.61	21.59	141 - 489	287.33	87.37	22.56	500	600
TH (mg/L)	86 - 210	128.67	35.40	9.14	84 - 200	136.93	33.02	8.53	200	-
TA (mg/L)	185.5 - 477	293.62	76.80	19.83	159 - 503.5	303.16	85.32	22.03	200	-
Ca^{2+} (mg/L)	13.6 - 32.9	22.49	6.17	1.59	10.4 - 32.1	19.96	5.47	1.41	75	-
Mg^{2+} (mg/L	7.8 - 31.6	17.63	6.06	1.57	14.1 - 29.2	21.17	5.43	1.40	30	-
Na^+ (mg/L)	16 - 194	72.99	45.64	11.79	16.8 - 190.8	76.53	44.22	11.42	-	200
K^+ (mg/L)	0.70 - 1.70	1.26	0.32	0.08	0.7 - 2.0	1.2	0.36	0.09	-	-
Cl^- (mg/L)	4.3 - 82.2	17.97	19.70	5.09	4.3 - 65.2	14.19	16.06	4.15	250	250
SO_4^{2-} (mg/L)	11 - 27.7	13.59	4.21	1.09	12.1 -30.9	16.55	5.49	1.42	200	250
NO_3^- (mg/L)	0.1 - 6.6	1.74	2.18	0.56	0.1 - 13.0	6.847	3.55	0.92	45	50
HCO_3^- (mg/L)	226.3 - 581.9	358.2	93.69	24.19	194 - 614.3	369.86	104.1	26.88	-	-

K^+/Potassium (mg/L)
In pre-monsoon, concentrations of K^+ of the groundwaters are in the range, 0.70 – 1.70 mg/L in which (mean = 1.26) whereas they are in the range (0.70 – 2.0) mg/L in which (mean = 1.20) in monsoon (table-3c). Among fifteen groundwater samples, the highest value of the concentration of K^+ (2.0 mg/L) is found in case of S-9 during monsoon (table-3b). The concentrations of K^+ are found very low in both the seasons as compared to other ions.

Cl^-/Chloride (mg/L)
For pre-monsoon, concentrations of Cl- varies from 4.30 upto 82.20 mg/L and (mean = 17.97) whereas in monsoon, its concentrations varies from 4.30 upto 65.20 mg/L and (mean = 14.19) (table-3c). The concentrations of Cl- for all the studied samples have found below its acceptable limit as per BIS and WHO standard for drinking water.[25-26] In this study, the main sources of Cl- contamination in groundwater is may be due to domestic wastes products.

SO_4^{2-}/Sulphate (mg/L)
In pre-monsoon, SO_4^{2-} concentrations (S-1 to S-15) varies from 11.0 upto 27.70 mg/L and (mean = 13.59) while in monsoon period, its concentrations are in the range (12.1 - 30.9) mg/L in which (mean = 16.55) (table-3c). For both the two seasons, concentrations of SO_4^{2-} are observed within the desirable limits of both BIS and WHO standard value.[25-26] There is no drastic difference in the concentrations of SO_4^{2-} during pre-monsoon and monsoon season. In human and animal bodies, levels of both metha-emoglobin and sulphaemoglobin are altered when SO_4^{2-} is taken in larger contents through the dietary absorption.[31]

NO$_3^-$/Nitrate (mg/L)

For pre-monsoon, NO$_3^-$ concentrations range from 0.10 upto 6.60 mg/L and (mean of 1.74) whereas its concentration varies from 0.10 upto 13.0 mg/L and mean of 6.847mg/L in monsoon (table-3c). In this study area, NO$_3^-$ concentrations (S-1 to S-15) were observed within the desirable limit of BIS and WHO standard value[25-26] (table-3c). There is higher concentration of NO$_3^-$ in the groundwaters of monsoon than in pre-monsoon which may be caused by the contamination of more chemical fertilizers, animal wastes and industrial wastes. Consumption of drinking water which has high concentrations of NO$_3^-$ can cause various diseases like methemoglobinemia (MetHb), enlargement of thyroid gland, cancer and diabetes mellitus.[32]

CO$_3^{2-}$/ Carbonate and HCO$_3^-$/ Bicarbonate (mg/L)

Concentrations of CO$_3^{2-}$ for S-1 to S-15 are found as 0 (zero) in both the two seasons. But, the concentrations of HCO$_3^-$ are in the range (226.30 - 581.90) mg/L and (mean = 358.20 mg/L) in pre-monsoon whereas they are in the range (194 - 614.3) mg/L and (mean value = 369.86 mg/L) in monsoon.

Values and concentrations of studied parameters are observed to be greater during the time of monsoon as compared to that of pre-monsoon (tables-3a and 3b). This shows that the groundwaters of monsoon season are more polluted than pre-monsoon. It is mainly due to the leaching out of the soluble salts/minerals from the earth's crust by rainwater and finally mingled with the groundwater bodies in the aquifers during the monsoon season.

Computing of WQI values

In order to calculate the WQI values, ten (10) parameters were considered and its standards (Si), unit weight (Wi) and recommended agency are shown below in table-4a. In pre-monsoon, WQI value ranges from 19.705 (S-13) to 52.206 (S-11) while in monsoon, its value ranges from 38.636 (S-3) to 66.920 (S-11) (table-4b). Further, in pre-monsoon, 26.67% of groundwaters belongs to excellent water quality, 66.67% (good water) and other 6.66% have poor water while in monsoon, 60% (good water quality) and 40% (poor water quality) (table-4c). As compared to that of pre-monsoon, there is a significant increase in the values of WQI of all the groundwaters during monsoon except (S-7), which is due to its higher values/concentrations of the various studied parameters during monsoon. Finally, from table-4c, it can be said that all studied groundwaters are regarded as 'appropriate' for drinking purposes.

Table 4a: Standards (Si) and Unit Weight (Wi) for computing WQI values

Sl. no.	Parameters (mg/L)	Standards (Si)	1/SI	Unit Weight (Wi)	Approved agencies
1	pH	6.5-8.5	0.11765	0.55354	BIS/WHO
2	TDS	500	0.002	0.00941	BIS
3	TH	200	0.005	0.02353	BIS
4	TA	200	0.005	0.02353	BIS
5	Ca^{2+}	75	0.01333	0.06273	BIS
6	Mg^{2+}	30	0.03333	0.15684	BIS
7	Na$^+$	200	0.005	0.02353	WHO
8	Cl$^-$	250	0.004	0.01882	BIS
9	SO$_4^{2-}$	200	0.005	0.02353	BIS
10	NO$_3^-$	45	0.02222	0.10456	BIS
		Total		$\sum Wi = 1$	

Table 4b: WQI values (S-1 to S-15) for both seasons

Sl. no.	Sample no.	Pre-monsoon			Monsoon		
		WQI values	rank of quality of water	grading	WQI values	rank of quality of water	grading
1	S-1	20.721	Excellent	A	43.825	Good	B
2	S-2	22.909	Excellent	A	58.811	Poor	C
3	S-3	29.53	Good	B	38.636	Good	B
4	S-4	48.981	Good	B	53.862	Poor	C
5	S-5	45.327	Good	B	48.766	Good	B
6	S-6	48.826	Good	B	60.46	Poor	C
7	S-7	49.993	Good	B	49.951	Good	B
8	S-8	38.076	Good	B	47.696	Good	B
9	S-9	45.457	Good	B	65.887	Poor	C
10	S-10	39.308	Good	B	57.366	Poor	C
11	S-11	52.206	Poor	C	66.92	Poor	C
12	S-12	26.755	Good	B	41.769	Good	B
13	S-13	19.705	Excellent	A	44.592	Good	B
14	S-14	24.776	Excellent	A	38.76	Good	B
15	S-15	40.47	Good	B	40.518	Good	B

Table 4c: Summary classification of WQI values for both seasons

WQI value range	Water quality status	Pre-monsoon			Monsoon		
		Groundwater code no.	Total samples	%	Groundwater code no.	Total samples	%
(0 – 25)	Excellent	S-1, S-2, S-13, S-14	4	26.67	0	0	0
(26 – 50)	Good	S-3, S-4, S-5, S-6, S-7, S-8, S-9, S-10, S-12, S-15	10	66.67	S-1, S-3, S-5, S-7, S-8, S-12, S-13, S-14, S-15	9	60
(51 – 75)	Poor	S-11	1	6.66	S-2, S-4, S-6, S-9, S-10, S-11	6	40
(76 – 100)	Very poor	0	0	0	0	0	0
> 100	Unsuitable	0	0	0	0	0	0

Evaluation of Irrigation water quality

Table-5a shows the evaluated values of studied parameters for monitoring the suitability of different groundwaters for irrigation whereas table-5b shows its water quality classification.

Residual Sodium Carbonate Or RSC

The RSC values range from 0.67 meq/L to 7.82 meq/L and (mean value = 3.298 meq/L) in pre-monsoon whereas its values are in the range (0.66 - 8.39) meq/L and (mean value = 3.325 meq/L) in monsoon

(table-5a). In case of RSC values, majority of the studied groundwaters are found very high (RSC > 2.50 meq/L) in both the seasons and therefore they cannot be granted/suitable for irrigation (agricultural) purposes[21] (table-5b).

Sodium adsorption ratio or SAR

In pre-monsoon, values of SAR are in the range (0.55 - 9.11) and (mean value = 3.009) whereas during monsoon, its value ranges from 0.65 to 9.06 and (mean value = 3.023) (table-5a). In both seasons, all the values of SAR falls under 'excellent water quality' (SAR < 10) (table-5b) for irrigation purposes and hence all of them can be used for irrigation (agricultural) purposes.[22]

Percent sodium/%Na

For pre-monsoon, %Na varies from 18.51% to 83.17% and (mean value = 51.375%) whereas in monsoon, %Na are in the range (21.86% - 83.24%) and (mean value = 51.208%) (table-5a). For both the seasons, the %Na value of S-3 is found greater than 80% while all other remaining samples have their values of %Na below 80% (table-5b). Thus, except

S-3, all the remaining groundwaters can be used for irrigation (agricultural) purposes.[22]

Permeability index/PI

In pre-monsoon, the PI in the fifteen groundwaters ranges from 70.01% to 113.5% having mean value of 94.745% while during monsoon, it ranges from 70.21% to 115% having mean value of 92.701% (table-5a). The result indicates that the studied groundwaters for both seasons, can be used for irrigation purposes.[23]

Kelly's ratio/KR

In case of KR for the fifteen samples, its lowest values are found to be 0.2 (S-11) and 0.3 (each of S-2 and S-11) in pre-monsoon and monsoon respectively (table-5a). However, S-3 has the highest values of KR in both the seasons (4.9 each) (table-5a). The groundwaters (S-1, S-2, S-4, S-6, S-11 and S-15) are observed to be granted for irrigation (KR ≤1) while other groundwaters (S-3, S-5, S-7 to S-10, S-12, S-13 and S-14) are taken as unsuitable for irrigation/agricultural purposes (KR ≥1) of both the two seasons[24] (table-5b).

Table 5a: RSC, SAR, % Na, PI and KR values for different groundwater samples

Sample no.	Pre-monsoon					Monsoon				
	RSC	SAR	%Na	PI	KR	RSC	SAR	%Na	PI	KR
S-1	1.68	0.95	30.03	86.31	0.4	1.08	0.89	26.47	74.36	0.4
S-2	0.67	0.65	21.22	71.06	0.3	0.79	0.70	21.86	70.21	0.3
S-3	7.82	9.11	83.17	113.5	4.9	8.39	9.06	83.24	115.0	4.9
S-4	2.26	1.59	35.71	74.50	0.5	2.66	1.94	42.28	82.31	0.7
S-5	4.69	4.76	71.24	110.6	2.5	4.73	4.28	67.50	107.1	2.1
S-6	2.55	1.94	42.39	81.95	0.7	2.36	2.03	42.15	78.47	0.7
S-7	3.19	4.21	66.37	100.4	2.0	3.11	3.84	62.40	95.78	1.6
S-8	3.96	3.62	64.19	106.5	1.8	4.16	3.70	64.00	105.4	1.8
S-9	3.71	3.63	65.87	110.5	1.9	4.12	3.73	64.11	104.6	1.8
S-10	3.60	3.20	59.34	100.3	1.4	3.55	3.53	60.92	98.27	1.6
S-11	0.86	0.55	18.51	70.01	0.2	0.66	0.65	23.09	77.37	0.3
S-12	5.71	4.06	64.36	104.4	1.8	5.18	3.49	57.40	94.06	1.3
S-13	3.51	2.64	57.24	107.6	1.3	3.60	3.17	60.85	105.0	1.5
S-14	3.70	3.16	60.18	103.6	1.5	3.80	3.18	60.33	103.9	1.5
S-15	1.56	1.07	30.81	79.94	0.4	1.68	1.15	31.52	78.68	0.5
Mean	3.298	3.009	51.375	94.745	1.44	3.325	3.023	51.208	92.701	1.4
S.D.	1.876	2.18	19.898	15.643	1.205	1.99	2.094	18.649	14.419	1.146
Min.	0.67	0.55	18.51	70.01	0.2	0.66	0.65	21.86	70.21	0.3
Max.	7.82	9.11	83.17	113.5	4.9	8.39	9.06	83.24	115	4.9

Table 5b: Water quality classification for the irrigation purposes in both seasons

Parameters	Values/ranges	Class	Groundwater samples	
			Pre-monsoon	Monsoon
RSC (meq/L)	< 1.25	Good	S-2, S-11	S-1, S-2, S-11
	(1.25 – 2.50)	Marginal	S-1, S-4, S-15	S-6, S-15
	> 2.50	Unsuitable	S-3, S-5, S-6 to S-10, S-12, S-13, S-14	S-3, S-4, S-5, S-7 to S-10, S-12, S-13, S-14
SAR	< 10	Excellent	S-1 to S-15	S-1 to S-15
	10 to 18	Good water	0	0
	18 to 26	doubtful	0	0
	above 26	Unfit/Unsuitable	0	0
% Na	< 20 %	Excellent	S-11	0
	(20 – 40) %	Good	S-1, S-2, S-4, S-15	S-1, S-2, S-11, S-15
	(40 – 60) %	Permissible	S-6, S-10, S-13	S-4, S-6, S-12
	(60 – 80) %	Doubtful	S-5, S-7, S-8, S-9, S-12, S-14	S-5, S-7 to S-10, S-13, S-14
	> 80%	Unsuitable	S-3	S-3
PI	> 75%	Suitable	S-1, S-3, S-5 to S-10, S-12 to S-15	S-3 to S-15
	(25 – 75) %	Good	S-2, S-4, S-11	S-1, S-2
	< 25 %	Unsuitable	0	0
KR	KR≤1	Suitable	S-1, S-2, S-4, S-6, S-11, S-15	S-1, S-2, S-4, S-6, S-11, S-15
	KR ≥1	Unsuitable	S-3, S-5, S-7 to S-10, S-12, S-13, S-14	S-3, S-5, S-7 to S-10, S-12, S-13, S-14

From table-5b, it is seen that all the groundwaters are fit/granted for irrigation/agricultural uses, based on SAR, %Na (except S-3) and PI in both the two seasons. But, some groundwater samples are found unsuitable, based on RSC and KR values in both the seasons. However, in the overall, all the groundwaters can be utilized for irrigation.

Pearson's Correlation Coefficient (r) Value
Correlation coefficient (r) value for different parameters for both seasons is shown below (tables-6a and 6b).

For both the seasons (tables-6a and 6b), a very strong positive correlation between TA and HCO_3^- (r = 1.000 each) is obtained. Again, TA shows strong positive correlation with Na^+ both in pre-monsoon and monsoon (r = 0.899, r = 0.926). K+ exhibits moderately +ve correlation with the bicarbonate (HCO_3^-) both in pre-monsoon and monsoon (r = 0.532 and 0.486 respectively). Further, for both the two seasons, TDS also exhibits strong +ve correlation with total alkalinity (TA) (r = 0.925, r = 0.956). Again, in both pre-monsoon and monsoon, total hardness (TH) exhibits strong +ve correlation with Ca^{2+} having (r) value of 0.798 and 0.863 respectively. Similarly, for both seasons, TH also exhibits strong +ve correlation with magnesium (Mg^{2+}) having (r) value of 0.929 and 0.952. However, regarding the parameters between TH and SO_4^{2-} in pre-monsoon, there is weak positive correlation (r=0.185) whereas in case of monsoon, there is moderately +ve correlation of TH with SO_4^{2-} with (r) = 0.515. Besides, in case of pre-monsoon, TH shows negative correlation

with Cl- and HCO_3^- having (r) value of -0.300 and -0.301 respectively. Similarly, for monsoon also, TH shows negative correlation with both Cl^- and HCO_3^- having (r) value of -0.279 and -0.274 respectively. Thus, in both the two seasons, by the presence of dissolved sulphates of Ca^{2+} and Mg^{2+}, the TH of different groundwaters leads to mildly permanent hardness of water but there is no indication of temporary hardness of water.

Table 6a: Correlation coefficient (r) values of studied parameters (pre-monsoon)

Param-eters	Temp.	pH	TDS	TH	TA	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-
Temp.	1												
pH	0.121	1											
TDS	0.030	0.071	1										
TH	0.131	0.093	-0.391	1									
TA	-0.111	-0.091	0.925	-0.301	1								
Ca^{2+}	-0.045	0.306	-0.115	0.798	-0.099	1							
Mg^{2+}	0.213	-0.053	-0.485	0.929	-0.367	0.519	1						
Na^+	-0.032	0.031	0.949	-0.582	0.899	-0.379	-0.594	1					
K^+	0.265	0.191	0.673	-0.249	0.532	-0.064	-0.315	0.589	1				
Cl^-	0.262	0.287	0.540	-0.300	0.194	-0.087	-0.373	0.473	0.539	1			
SO_4^{2-}	0.354	0.294	0.233	0.185	0.198	0.261	0.102	0.154	0.464	0.082	1		
NO^{3-}	-0.145	-0.548	0.365	-0.301	0.414	-0.053	-0.396	0.269	0.324	-0.001	-0.132	1	
HCO_3^-	-0.111	-0.091	0.925	-0.301	1	-0.099	-0.367	0.899	0.532	0.194	0.198	0.413	1

Table 6b: Correlation coefficient (r) values of studied parameters (monsoon)

Param-eters	Temp.	pH	TDS	TH	TA	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-
Temp.	1												
pH	-0.090	1											
TDS	0.035	-0.460	1										
TH	0.420	-0.046	-0.278	1									
TA	0.087	-0.470	0.956	-0.273	1								
Ca^{2+}	0.238	0.044	-0.008	0.863	-0.064	1							
Mg^{2+}	0.475	-0.097	-0.403	0.952	-0.363	0.668	1						
Na^+	-0.056	-0.318	0.949	-0.531	0.926	-0.258	-0.626	1					
K^+	-0.332	0.172	0.523	-0.371	0.486	0.015	-0.554	0.555	1				
Cl^-	-0.309	-0.002	0.499	-0.279	0.265	0.027	-0.430	0.511	0.300	1			
SO_4^{2-}	0.404	-0.087	-0.072	0.515	-0.083	0.545	0.431	-0.219	0.068	-0.200	1		
NO_3^-	-0.358	-0.061	0.105	-0.466	0.080	-0.322	-0.490	0.156	0.280	-0.026	-0.175	1	
HCO_3^-	0.087	-0.470	0.956	-0.274	1	-0.064	-0.363	0.926	0.486	0.265	-0.083	0.080	1

Conclusion

1. In both seasons, all groundwaters fall under the category of fresh water. Majority of the parameters for various groundwaters have found their values/concentrations below the acceptable limits of BIS and WHO. In pre-monsoon, 73.33% of water samples belongs to moderately hard water and 26.67% (hard water) whereas in monsoon, 60% (moderately hard water) and 40% (hard water). The TH and Mg^{2+} values of S-4 (pre-monsoon) are

found beyond their acceptable limits but below the permissible limits. Again, the TA values for all the groundwater samples except S-2 (pre-monsoon) and S-11 (monsoon) have found their values beyond its acceptable limit but below its permissible limit. Therefore, treatments are required in order to maintain the TH values and Mg^{2+} concentration in case of S-4 and the TA for all the samples (except S-2 and S-11) below their corresponding acceptable limits. The study data also indicate that the values or concentrations of parameters in most of the samples of monsoon season are observed to be higher than that of pre-monsoon.

2. With special reference to mean abundance values (table-3c), in pre-monsoon, the order of cations is given by "$Na^+ > Ca^{2+} > Mg^{2+} > K^+$" whereas for monsoon, its order is given - "$Na^+ > Mg^{2+} > Ca^{2+} > K^+$". Again, for pre-monsoon, an anion series is given - "$HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$" whereas for monsoon, its order - "$HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$.

3. From WQI data analysis, it is seen that in pre-monsoon, 26.67% of samples have excellent type of water quality, 66.67% (good) and 6.66% (poor) while in monsoon, 60% (good) and 40% (poor). The WQI data shows that all the samples (S-1 to S-15) can be taken as granted (suitable) for human consumption.

4. In the overall, the samples from S-1 to S-15 can be used for irrigation (agricultural) purposes.

5. For both the two seasons, the TH of the various samples is mainly due to dissolved sulphates of Ca^{2+} and Mg^{2+} leading to weakly permanent hardness of water but there is no sign of temporary hardness of water.

Conflict of Interest
The authors declare that they have no conflict of interest.

Data Availability Statement
Not applicable.

Ethics Approval Statement
Not applicable.

Authors' Contribution
Both the authors have contributed equally in this article.

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