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Hydrochemistry of groundwater and quality assessment of Manipur Valley, Manipur, India

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Abstract

The present study aims to understand the hydrogeochemical characteristics and groundwater quality of Manipur Valley, Manipur, India. A total of 145 groundwater samples were collected and analyzed for different physico-chemical parameters such as pH, electrical conductivity, turbidity, dissolved oxygen, phosphate, nitrate, total hardness, chloride, total dissolved solids, total alkalinity, sodium, potassium, calcium and magnesium, following the standard procedures. The analytical results were compared with drinking water guideline values of the Bureau of Indian Standards (BIS) and the World Health Organization (WHO). The concentrations of several variables like conductivity, total dissolved solids, turbidity, chloride, phosphate and sodium were beyond their desirable limits for drinking water in a number of sites. To determine the suitability of groundwater for agricultural use, chemical indices like percent sodium (Na %), sodium adsorption ratio (SAR), magnesium ratio (MR)/magnesium hazard (MH), permeability index (PI) and Kelley's ratio (KR) were calculated. Based on the analytical results, majority of water sources of the area are unsuitable for irrigation purposes. Gibb's ratio was also calculated to understand the mechanisms controlling groundwater chemistry of the study area.

Keywords: Groundwater quality, Hydrochemistry, Drinking water, Irrigation water, Manipur Valley, India.

Introduction

Groundwater forms the major source of water supply for drinking purposes in most parts of India. India is by far, the largest and fastest growing consumer of groundwater in the world, with around 80% of the rural population and 50% of the urban population use groundwater for domestic purposes. Groundwater also plays a significant role in the ecological functions of various ecosystems. However, as a consequence of population growth, urbanization, industrialization, irrigation, mining and waste disposal practices, a large number of anthropogenic contaminants have emerged as a serious threat to groundwater resources. At the same time, groundwater contamination by arsenic, fluoride and others in many parts of the world also causes a great impact to human health[1,2]. Millions of people in the Ganga–Brahmaputra–Meghna Basin are at risk from drinking arsenic contaminated water. The problems of high salinity (electrical conductivity), nitrate, chloride, iron and microbial contaminants were also encountered in different groundwater sources of the country[3-5]. In our country, 70% of the water sources are seriously polluted and 75% of illness and 80% of child mortality are attributed to water pollution[6]. Therefore, the assessment of water quality and its management options is very significant in India and other developing countries to meet the growing demands in their domestic, agricultural, and industrial sectors[7,8]. The Manipur Valley is endowed with plenty of surface water sources which include lakes, rivers and numerous other lentic water bodies[9]. However, with rapid increase in population and growth of urbanization, the available water resources are getting depleted and deteriorated by disposal of urban and industrial solid wastes. Open dumping is the most common way to dispose municipal and industrial wastes. Subsequent leaching of toxic contaminants through the dumping site also leads to extensive contamination of ground water at many places. Available literature shows the presence of excess fluoride, arsenic, iron, chloride, nitrate, sodium along with other trace metals in groundwater sources of northeast States particularly Assam and Manipur[10]. Previous workers have already been reported that besides arsenic and iron, high concentrations of other variables like phosphate, chloride, sodium, total dissolved solids, conductivity and turbidity were also present in groundwater sources of Manipur[11-13]. The objectives of this paper are i. to assess the hydrochemical characteristics and groundwater quality of the four districts of Manipur Valley, Manipur, India to ascertain the suitability of groundwater for drinking, and agricultural use; ii. to study correlations among the groundwater variables; and iii. to study the seasonal and spatial variations of groundwater variables.

Materials and methods

Study area: The Manipur (Imphal) Valley, an intermontane valley, is selected as the study area. It is located in the central part of Manipur, between 24°28′ N to 24°59′ N and 93°46′ E to 94°07′E. The valley has four districts (Imphal West, Imphal

East, Thoubal, and Bishnupur) (Figure-1), which is surrounded by the high slope hills on all sides**.** The total area of the valley is about 2000 km^2, with an average altitude of 780 msl. Physiographically, the valley has hills, plains, marshes and Rivers like Imphal, Nambul, Thoubal and their tributaries. The valley areas were once full of swamps and marshes, a large number of which were reclaimed for agriculture and urban settlements. The average annual rainfall during the last 24 years is 1400 mm.

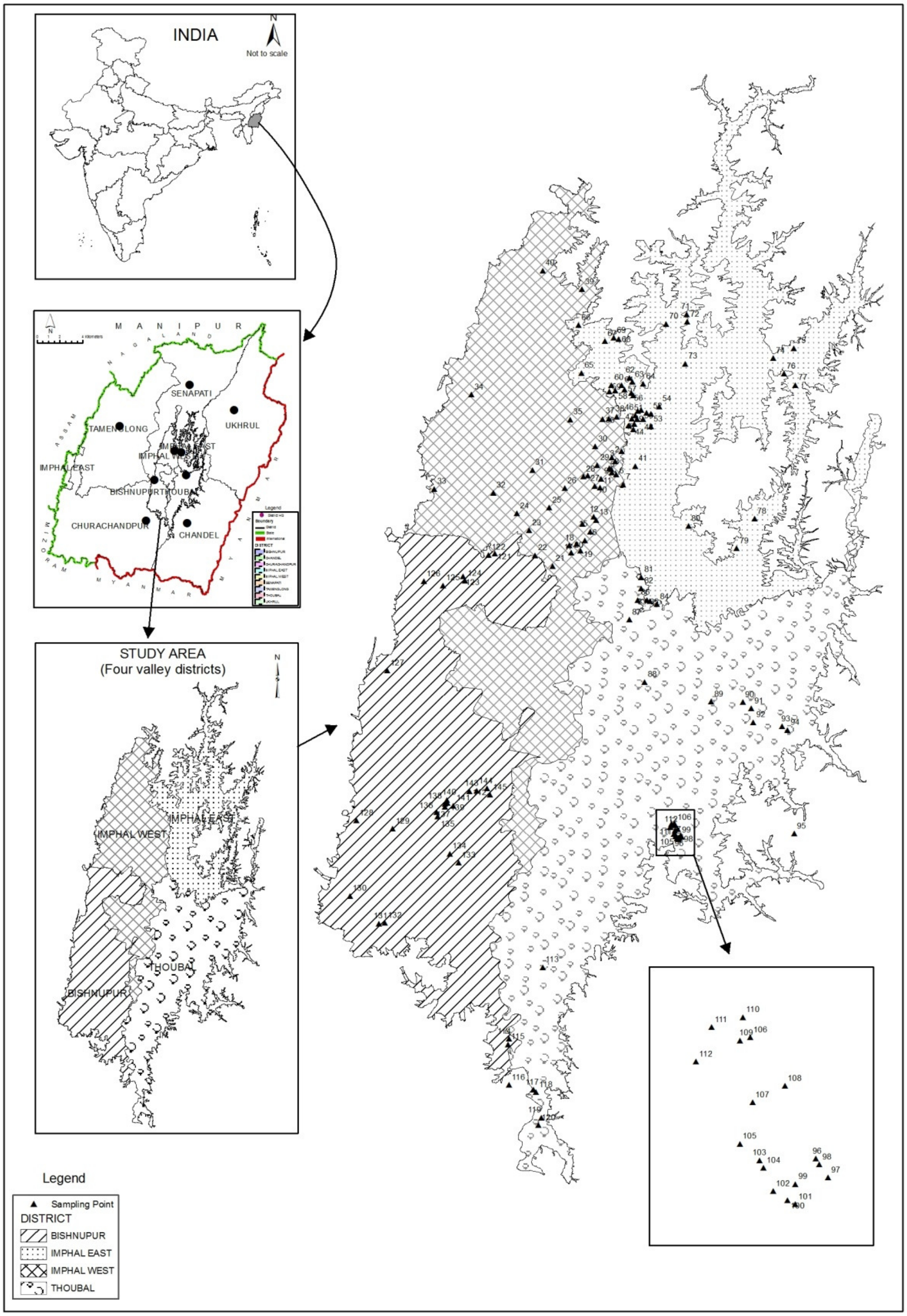

Figure-1: Location map of the study area showing the sampling points.

Hydrogeology: The major parts of Manipur Valley were found to be underlain by Quaternary formation comprising of recent alluvium followed by Tertiary formation. Hydrogeologically, groundwater occurs mostly in unconfined and semi-confined aquifers within a depth of c. 100 m in unconsolidated recent alluvium formations of quaternary age having a lithology of sand, gravel, pebble, silt, and clay. The water yielding properties are highly variable depending upon the nature of the weathered material and surface cover. Large alluvial plains form the potential source of ground water[5].

Sample collection and analysis: A total of 145 groundwater samples were collected from different sites of the four districts of Manipur Valley during pre (March–May) and post-monsoon (November–January) seasons of 2009 to 2012 (Figure-1). GPS readings were recorded to identify the sampling locations. The physico-chemical parameters like temperature (T^0C), pH, electrical conductivity (EC), turbidity (Turb), and dissolved oxygen (DO) were determined on the spot by using portable field kits like pH meter, Conductivity meter, Turbidity meter, and DO meter. Parameters, viz., phosphate (PO_4^{3-}), nitrate (NO_3^-), total hardness (TH), chloride (Cl^-), total alkalinity (TA), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+) were estimated as per standard procedures[14]. These parameters were compared with the standard guideline values of BIS and WHO to recognize their suitability for domestic use. Suitability of groundwater for irrigation was determined using various parameters like salinity, percent sodium (Na%), sodium absorption ratio (SAR), magnesium ratio (MR)/ magnesium hazard (MH) and kelley's ratio (KR)[15]. The irrigation indices were estimated using the following formulae:

Percent sodium (Na%): Percent sodium in water is a parameter computed to evaluate the suitability of water quality for irrigation[16]. It can be calculated as:

$$Na^+ \% = (Na^+ + K^+) \text{ X } 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+) \ (meqL^{-1}).$$

Sodium absorption ratio (SAR): SAR is another important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops[17]. SAR can be expressed as:

$$SAR = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+}/2)} \ (meqL^{-1}).$$

Permeability index (PI): The permeability index (PI) is an important factor which influences quality of irrigation water. It is expressed as:

$$PI = [\{Na + \sqrt{(HCO_3)}\} / (Ca + Mg + Na)] \text{ X } 100 \ (meqL^{-1}).$$

Doneen[18] classified the groundwater as class I, class II and class III to find out suitability of groundwater for irrigation purpose. Soil permeability is affected by long term use of irrigation water with high salt content.

Magnesium hazard (MH): The magnesium hazard (MH) of irrigation water was proposed by Szabolcs and Darab[19] and redefined by Raghunath[20]. MH is expressed as;

$$MH = Mg^{2+} / (Ca^{2+} + Mg^{2+}) \text{ x } 100 \ (meqL^{-1}).$$

The MH values exceeding 50 is considered harmful and unsuitable for irrigation use[21].

Kelly's ratio (KR): Based on Kelly's ratios, ground water was classified for irrigation with KR> 1 indicating an excess level of sodium in water; therefore water with Kelly's ratio of less than 1 was suitable for irrigation[22].

$$KR = Na/ Ca + Mg \ (meqL^{-1}).$$

Results and discussion

Mechanisms controlling groundwater quality: The sources of dissolved chemical constituents like precipitation-dominance, rock-dominance and evaporation-dominance were assessed using Gibb's diagrams, which can be represented by the ratios 1($Cl/Cl + HCO_3$) and 2 (Na + K/Na + K+ Ca) against the values of TDS[23]. In different samples of the study area, the ratio 1 and 2 ranged from 0.82 to 0.98 and 0.94 to 0.03, with averages of 0.18 and 0.94, respectively. The values were plotted separately against the respective TDS values of 202.67 to 780.67 mgL^{-1} with an average of 448 mgL^{-1} and it was found that most of the samples were in the rock-dominance domain. This suggests that the groundwater quality of the area is largely governed by the chemical weathering of rock-forming minerals.

Seasonal and spatial variations: Statistical comparisons between each variable of pre- and post-monsoon seasons by non-parametric Mann-Whitney tests revealed significant temporal variations in temperature, pH, conductivity, potassium, and magnesium in groundwater samples of the area. The lowering of temperature from an average of 29.83^0C in pre-monsoon to 18.91^0C in post-monsoon can be attributed to the subtropical latitude and elevation of 780 msl of the study area. pH also lowers from an average of 7.64 (pre-monsoon) to 7.45 (post-monsoon). Similarly, the average values of conductivity, potassium, and magnesium were lowered from 609.22 to 770.12μScm^{-1}, 3.22 to 2.18mgL^{-1}, and 17.95 to 15.66mgL^{-1}, respectively. Seasonal variations in all other variables were not statistically significant. The present study reveals that the values of all the measured variables in pre-monsoon were comparatively higher than that of post-monsoon season. This is mainly because of monsoon flushing and dilution effect. Further, results from one-way ANOVA showed insignificant spatial variability (p=1.00) at 145 sampling sites which indicates that sampling sites have insignificant contributions to groundwater contamination of the area.

Groundwater chemistry: The statistical summary and hydrochemical data of groundwater in Manipur Valley (4 districts), during 2009- 2012 are presented in Table-1 (A and B) and Table-2. Temperature (T^0C) is an important biologically significant factor, which plays an important role in the metabolic activities of an organism. The groundwater temperature varied from 22.78 to 25.72^0C with an average of 24.41^0C. The variation in water temperature may be due to different timings of collection and influence of season[24]. The pH is a measure of the intensity of acidity or alkalinity conditions of a solution. The values of groundwater pH varied from 6.60 to 8.73 with an average of 7.54 and showed a slightly alkaline character of groundwater[25]. pH of most samples were within the prescribed limit (6.5 - 8.5) of WHO and BIS.

The alkalinity of groundwater is due to the presence of carbonates and bicarbonates produced from the interaction of groundwater with the aquifer materials[26]. Electrical conductivity (EC) signifies the amount of total dissolved salts in groundwater. The EC was in the range of 220.50 to 3309.33 μScm^{-1} with an average of 785.22 μScm^{-1}. EC of most samples were within the maximum permissible limit of 1500 μScm^{-1} (WHO), except 8 (5.52%) of the samples. High values of EC in few samples are due to intense chemical weathering and long residence time of groundwater within the local lithology (saline peat and alluvium) in the region. This may also be due to ion exchange and solubilisation in the aquifer, in addition to the leaching of agricultural runoff[27, 28]. Turbidity (Turb) values were in the range of 0.03 to 231.45 NTU with an average of 12.77 NTU. Turbidity values exceeded the permissible limit of 25 NTU (WHO) in 19 (13.10%) of the samples. High turbidity may be due to the presence of particulate matters such as clay, silt, finely divided organic matter, plankton or other microscopic organisms in groundwater of the area. High turbidity values are therefore, associated with poor water quality[29]. Dissolved oxygen (DO) is an important parameter in water quality assessment and reflects the physical and biological processes prevailing in the water.

The DO values indicate the degree of pollution in water bodies. Concentrations of dissolved oxygen (DO) in unpolluted waters are usually about 8-10 mgL^{-1} [30]. The recommended value of DO for drinking water is 4-6 mgL^{-1} (WHO 2004) and above 5 mgL^{-1} for irrigational and fisheries purposes. DO values varied from 6.25 to 9.84 mgL^{-1} with an average of 7.44 mgL^{-1}. High D.O in groundwater indicates high aerobic condition, which is suitable for drinking, irrigation and fisheries purposes, but very low DO will result in anaerobic conditions that cause bad odours. Phosphate (PO_4^{3-}) was in the range of 0.04 to 7.31 mgL^{-1} with an average of 0.98 mgL^{-1}. Phosphate concentrations exceeded the permissible limit of WHO (0.4 mgL^{-1}) in 105 (72.41%) of the samples. High phosphate in the area may be derived from fertilizers (used in agricultural practices by the local farmers) and decay of natural organic matter. High phosphate could also be due to effluents induced by agriculture or domestic wastes entering the alluvial aquifers[31,32]. Nitrate (NO_3^-) was in the range of 0.03 to 46.33 mgL^{-1} with an average of 2.70 mgL^{-1}. No samples of the area exceeded the permissible limit of WHO (45 mgL^{-1}). Low nitrate in the area indicates low nitrate content in the waste effluents, percolating or, leaching into groundwater. Excessive intake of nitrate causes a disease in infants known as methenoglobinemia or baby syndrome in which blood loses its ability to carry sufficient oxygen[33,34]. Being loosely bound to soils, nitrate is expected to be more in runoff and hence its concentration increases during rainy seasons[35]. Total hardness (TH) is caused by the presence of cations such as calcium and magnesium and anions such as carbonate, chloride and sulphate in water.

The dissolution of salts and minerals present in soil and nearby agricultural fields due to rise in water table particularly during rainy season enhances its concentration in groundwater[36]. Hardness values varied from 26.73 to 263.67 mgL^{-1} with an average of 136 mgL^{-1} and about 19 (13.10%) of the samples were found to be above the WHO limits of 200 mgL^{-1}. High concentrations of hardness indicate the presence of Ca^{2+} and Mg^{2+} rich carbonate rocks like khondalites in the aquifer materials and there is lack of agricultural activities in and around the sampling sites. Small concentration of chloride (Cl^-) in drinking water is not harmful to humans. However, above a concentration of 250 mg L^{-1} chloride, the water may taste salty and sometimes lead to hypertension, risk for stroke, left ventricular hypertension, osteoporosis, renal stones and asthma in human beings[37].

The concentrations of chloride varied from 18.31 to 630.94 mgL^{-1} with an average of 98.21 mgL^{-1} and were found within the WHO limit of 250 mgL^{-1}, except 14 (9.66%) samples. Salt springs, which are of common occurrence in many places in Manipur and discharge of sewage and domestic effluents in the sampling sites, may contribute towards elevated chloride in groundwater[38]. Total dissolved solids (TDS) indicate the salinity behaviour of groundwater. TDS in water samples were in the range of 133.50 to 1542.17 mgL^{-1} with an average of 472.20 mgL^{-1}, indicating high TDS in the study area. TDS values in 51 (31.17%) samples exceeded the desirable limit of WHO (500 mgL^{-1}). High values of TDS in these samples may be due to leaching of various salts/ ions from the soils, rocks, organic matter, other particles, and also from agricultural practices[39, 40]. Water containing TDS more than 500 mgL^{-1} is not desirable for drinking but in unavoidable cases 1500 mgL^{-1} is also allowed and consumers of such water containing TDS more than 500 mgL^{-1} is known to cause gastrointestinal irritation[41,42]. Total alkalinity (TA) of water is its capacity to neutralize a strong acid and it is normally due to the presence of bicarbonate, carbonate and hydroxide compound of calcium, sodium and potassium[43]. Alkalinity values range between 99.08 to 641.33 mgL^{-1} with an average of 338.93 mgL^{-1}, indicating high TA values in the study area. Alkalinity exceeds the WHO limit of 100-200 mgL^{-1} in 137 (94.48%) of the samples.

The probable reasons for high alkalinity in the area is because of the presence of carbonates, bicarbonates and hydroxide compound of calcium, sodium and potassium in aquifers materials. Large amount of alkalinity imparts a bitter taste to water. Excess alkalinity in water is harmful for irrigation, which leads to soil damage and reduce crop yields. Sodium (Na^+) occurs as a major cation in water samples. The primary source of sodium in natural water is from the release of soluble products during the weathering of plagioclase feldspars. The concentrations of sodium varied from 24.33 to 357.67 mgL^{-1} with an average of 123.50 mgL^{-1} and sodium exceeded the WHO guideline value of 200 mgL^{-1} in 21 (14.48%) of the samples.

The sodium concentrations more than 50 mg L^{-1} makes the water unsuitable for domestic use because it causes severe health problems like hypertension. Potassium (K^+) is commonly present in minerals of orthoclase, feldspar, microline, leucite, and biotite. The concentration of K^+ is less than 10 mg L^{-1} in drinking water. It maintains fluids in balance stage in the human body. In the present study, potassium concentrations ranged from 1 to 5.33 mg L^{-1} with an average of 2.75 mg L^{-1}. The permissible limit of potassium is 10 mg L^{-1} and about 13 (8.97%) of the samples exceeded the permissible limit. Thus, the excess amount of potassium present in the water sample may lead to nervous and digestive disorder. High potassium in the area may be attributed to the effluent discharged by industries and domestic sewages. However, excessive fertilizer usage may also increase its concentration in groundwater[34]. Calcium (Ca^{2+}) is directly related to hardness. Calcium concentration was very low and ranged between 1.73 to 24.07 mg L^{-1} with an average of 5.62 mgL^{-1}.

The permissible limit of calcium in drinking water is 75 mgL^{-1}. No samples of the area exceeded the permissible limit of WHO (75 mgL^{-1}). Low calcium content showed the absence of carbonate rocks and minerals like limestone and calcite in groundwater aquifers of the study area. An inadequate intake of calcium is usually associated with Hypocalcemia. Symptoms include weakness, muscle spasms, and heart rhythm disturbance[44]. Magnesium (Mg^{2+}) is also directly related to hardness.

Magnesium is an essential ion for functioning of cells in enzyme activation, but at higher concentration, it is considered as laxative agent, while deficiency may cause structural and functional changes in human beings[45]. Magnesium varied from 4.40 to 33.41 mgL^{-1} with an average of 16.66 mgL^{-1}. No samples of the area exceeded the permissible limit of WHO (50 mgL^{-1}). Low magnesium may be attributed to the absence of carbonate rocks and minerals like dolomite and magnetite in shallow aquifers of the area.

Drinking water quality: The study reveals that a large proportion of groundwater sources of the area have exceeded the WHO limits for several physico-chemical variables such as total alkalinity, phosphate, total dissolved solids (TDS), total hardness (TH), turbidity (Turb), and chloride (Cl^-), in 100% (40), 80% (32), 30% (12), 15% (6), 7.5% (3), 5% (2), respectively (Table-2). Thus, groundwater with high concentrations of these chemical parameters rendered unsuitable for drinking purposes.

Irrigation water quality: Table-3 presents the status of groundwater in Manipur Valley, Manipur, for irrigation based on TDS, EC, %Na, TH, SAR, MH, PI and KR during 2009-2012. It was observed that the salinity hazard (EC) values ranged from 220.50 to 3309.33 μScm^{-1}. The water quality is good based on EC. About 56.55% (82) of the samples belong to 'Good' with only 4.18% (6) and 0.69% (1) in 'Doubtful' and 'unsuitable' category for irrigation use.

The groundwater of the area is hard with 40% (58) of samples exceeding the hardness values of 150 -300 mgL^{-1} and slightly saline as TDS of most samples were below 1000 mgL^{-1}. The percent sodium (% Na^+) in the area is high with about 29.66% (43) and 66.90 % (97) of the samples belong to 'doubtful' and 'unsuitable' category followed by only 2.07% (3) in 'permissible' category. As per the Indian standards, a maximum Na^+ content of 60% is recommended for irrigation water[46]. The agricultural yields are generally low in lands irrigated with waters belonging to doubtful to unsuitable category. This is probably due to the presence of excess sodium salts, which causes osmotic effects on soil-plant system. The sodium absorption ratio (SAR) is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkalinity/ sodium hazard to crops. The irrigation water will cause permeability problems on shrinking and swelling in clayed soils if the values of SAR is more than 9. The higher the SAR values in water, the higher the concentration of salt in water which leads to the formation of saline soil[47, 48].

The values of sodium absorption ratio (SAR) exceeded the SAR value of 26 (unsuitable water category) in 69.66% (101) of the samples, which comprises another constraint for adopting groundwater irrigation in the area. Another factor affecting irrigation water is magnesium ratio/ magnesium hazard (MH). MH values >50 are considered harmful and unsuitable for irrigation use. The values of magnesium ratio ranged from 18.22 to 91.75 with an average of 76.5, and about 93.79% (136) of the samples exceeded the magnesium ratio of 50.

This would adversely affect the crop yield, as soils become more alkaline. Doneen classified water quality for irrigation as Class I, Class II, and Class III based on PI values. Class I and Class II represent good waters for irrigation with 25–75% or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability.

The PI values varied from 76.18 to 110.18 with an average of 96.64, and belong to class II and this reveals that groundwater of the area is suitable for irrigation purposes. In the present study KR values were in the range of 1.03 to 17.61 with an average of 5.92 indicating that water is not suitable for irrigation purpose as the average value is greater than 1.

Correlation analysis: Table-4 shows the Pearson's correlation coefficient (r) among the overall mean values of groundwater variables in Manipur Valley, Manipur, India (2009-2012). Significant positive or negative correlations were observed among the variables. Positive correlations were observed in temperature with total hardness; conductivity with total dissolved solids and alkalinity; phosphate with nitrate, hardness, chloride, alkalinity, and magnesium; nitrate with hardness, alkalinity, and magnesium; hardness with alkalinity, potassium, and magnesium; chloride with alkalinity, total dissolved solids, and alkalinity; alkalinity with magnesium; and sodium with potassium. And negative correlations were observed in that of temperature with pH; turbidity with dissolved oxygen; dissolved oxygen with total dissolved solids, alkalinity, sodium, potassium and magnesium, respectively.

Table-1A: Statistical summary of the chemical characteristics of groundwater in Manipur Valley (4 districts), Manipur, India (2009- 2012).

Statistics	T	pH	EC	Turb	DO	PO_4	NO_3	TH
Mean	24.41	7.54	785.22	12.77	7.44	0.98	2.7	136.66
S.E. of mean	0.04	0.03	36.43	2.65	0.04	0.09	0.55	4.53
S.D.	0.51	0.36	438.73	31.95	0.51	1.03	6.66	54.55
Variance	0.26	0.13	192500	1021	0.26	1.07	44.36	2975
Skew-ness	-0.24	0.3	2.52	4.85	0.45	3.21	4.22	0.29
Kurtosis	0.59	1.1	9.75	27.48	2.42	15.15	20.59	-61
Mini-mum	22.78	6.6	220.5	0.03	6.25	0.04	0.03	26.73
Maxi-mum	25.73	8.73	3309.33	231.45	9.84	7.31	46.33	263.67

Table-1B: Statistical summary of the chemical characteristics of groundwater in Manipur Valley (4 districts), Manipur, India (2009- 2012).

Statistics	Cl	TDS	TA	Na	K	Ca	Mg
Mean	98.21	472.2	338.93	123.5	2.75	5.62	16.66
S.E. of mean	8.11	19.18	9.77	5.16	0.08	0.38	0.33
S.D.	97.67	230.91	117.67	62.11	0.92	4.6	4
Variance	9538	53320	13850	3858	0.85	21.15	16.02
Skew-ness	2.79	1.69	0.64	0.75	0.3	2.3	0.06
Kurtosis	10.41	4.77	-0.26	0.56	-37	4.73	2.28
Mini-mum	18.31	133.5	99.08	24.33	1	1.73	4.4
Maxi-mum	630.94	1542.17	641.33	357.67	5.33	24.07	33.41

S.E. Standard error; S.D. Standard deviation.

Table-2: Hydrochemical data of groundwater (mean ± SD with range in parenthesis) in Manipur Valley (4 districts), Manipur, India (2009- 2012)

Parameters	Imphal West	Imphal East	Thoubal	Bishnupur	Manipur Valley
T (^{0}C)	24.23 ± 0.47 (23.17 - 25.15)	24.66 ± 0.27 (24.17- 25.20)	24.66 ± 0.46 (23.78- 25.72)	23.88 ± 0.40 (22.78- 24.57)	24.41 ± 0.51 (22.78- 25.72)
pH	7.67 ± 0.31 (7.07 - 8.33)	7.28 ± 0.35 (6.60- 8.73)	7.41 ± 0.35 (6.97- 8.60)	7.40 ± 0.21 (7.03 - 7.89)	7.54 ± 0.36 (6.60 - 8.73)
EC (µs Cm^{-1})	878.04 ± 671.58 (220.50 - 3309.33)	872.45 ± 374.89 (292.33- 2425)	706.77 ± 223.62 (401.50 - 1498.83)	607.10 ± 218.04 (431.33- 1255)	785.22 ± 438.73 (220.50- 3309.33)
Turb (mgL^{-1})	15.80 ± 28.78 (0.26 - 131.50)	23.63 ± 50.80 (0.37 - 231.45)	6.46 ± 9.69 (0.12 - 41.43)	0.61 ± 0.63 (0.03 - 2.08)	12.77 ± 31.95 (0.03 - 231.45)
DO (mgL^{-1})	7.16 ± 0.52 (6.25- 8.23)	7.27 ± 0.54 (6.62- 9.84)	7.49 ± 0.22 (7.28- 8.23)	7.79 ± 0.44 (7.13- 8.45)	7.44 ± 0.51 (6.25- 9.84)
PO_4 (mgL^{-1})	0.95 ± 0.54 (0.06- 2.23)	0.91 ± 0.61 (0.06- 2.34)	1.30 ± 1.56 (0.04- 7.31)	0.65 ± 1.03 (0.04- 5.11)	0.98 ± 1.03 (0.04- 7.31)
NO_3 (mgL^{-1})	0.85 ± 0.69 (0.10 - 3.08)	0.54 ± 0.58 (0.03- 2.46)	8.26 ± 10.96 (0.04 - 46.33)	0.30 ± 0.21 (0.04 - 0.99)	2.70 ± 6.66 (0.03 - 46.33)
TH (mgL^{-1})	114.56 ± 55.46 (26.73 - 239)	157.32 ± 51.45 (73.83- 263.67)	149.96 ± 49.88 (68.33 - 259)	117.71 ± 48.11 (54.67- 205.33)	136.66 ± 54.55 (26.73- 263.37)
Cl (mgL^{-1})	137.32 ± 127.87 (20.04 - 630.94)	82.70 ± 101.77 (18.31- 612.61)	80.76 ± 68.43 (26.82- 327.17)	86.47 ± 51.65 (34.21- 225.24)	98.21 ± 97.67 (18.31- 263.67)
TDS (mgL^{-1})	469.40 ± 322.96 (133.50 - 1542.17)	539.99 ± 224.89 (457.67- 1357.83)	448 ± 156.49 (202.67- 780.67)	371.82 ± 100.31 (233.33- 605.33)	472.20 ± 230.91 (133.50- 1542.17)
TA (mgL^{-1})	364.44 ± 134.60 (99.08 - 621.33)	348.56 ± 105.35 (105.35- 619)	353.89 ± 112.50 (214- 641.33)	249.02 ± 68.85 (143.17- 473.17)	338.93 ± 117.67 (99.08- 641.33)
Na (mgL^{-1})	154.63 ± 74.31 (24.33 - 357.67)	126.64 ± 55.74 (41- 0.254)	104.08 ± 43.99 (44.17- 243.83)	95.25 ± 54.37 (32.17- 180.33)	123.50 ± 62.11 (24.33- 357.67)
K (mgL^{-1})	2.78 ± 0.98 (1.00- 5.00)	2.94 ± 1.09 (1.09- 5.33)	2.63 ± 0.71 (1.33 - 4.00)	2.51 ± 0.79 (1.50 - 4.17)	2.57 ± 0.92 (1.00 - 5.33)
Ca (mgL^{-1})	6.42 ± 5.34 (2.11 - 22.44)	4.54 ± 3.82 (1.73- 20.19)	6.34 ± 4.87 (2.16- 24.07)	4.80 ± 3.71 (2.33- 18.55)	5.62 ± 4.60 (1.73- 24.07)
Mg (mgL^{-1})	16.86 ± 3.32 (4.40- 21.62)	17.01 ± 2.99 (2.99- 21.14)	17.65 ± 5.02 (8.09- 33.41)	13.58 ± 3.32 (7.26- 19.54)	16.66 ± 4.00 (4.40- 33.41)

Conclusion

The present study reveals that the groundwater quality of Manipur Valley, Manipur is characterized by high concentrations of hydrochemical variables like conductivity, dissolved solids, alkalinity, hardness, chloride, and phosphate. This restricts the water from being used for drinking purposes. The high values of percent sodium (%Na), sodium absorption ratio (SAR), magnesium hazard (MH), permeability index (PI) and kelley's ratio (KR) comprise another constraint for adopting groundwater irrigation in the study area. The mean values of all the measured variables were found to be comparatively higher in pre-monsoon (PRM) season than that of post-monsoon (POM) season during the study period (2009-2012), which may be due to the effects of dilution by monsoon rains. Gibb's plots suggest that the chemical weathering of rock-forming minerals largely governed the groundwater quality of the study area, while evaporation and precipitation were not among the major factors affecting groundwater variables. This calls for effective management of surface water resources with people's participation for reduced dependency on groundwater.

Table-3: Classification of groundwater based on the basis of EC, TH, TDS, Na%, SAR, PI, MH and KR.

Parameters	Range	Water Class	% samples (sample) > PL
EC	< 250	Excellent	1.38% (2)
	250 -750	Good	56.55% (82)
	750 -2000	Permissible	40% (58)
	2000 -3000	Doubtful	4.18% (6)
	> 3000	Unsuitable	0.69% (1)
TH	< 75	Soft	14.48% (21)
	75 - 150	Moderately	47.58% (69)
	150- 300	Hard	40% (58)
	> 300	Very hard	0
TDS	< 1000	Fresh	2.78% (4)
	1000 -3000	Saline	0
	3000 -10000	Moderately Saline	0
	> 10000	Highly Saline	0
Na%	< 20	Excellent	0.68% (1)
	20 -40	Good	0.00 % (0)
	40 -60	Permissible	2.07% (3)
	60 -80	Doubtful	29.66% (43)
	> 80	Unsuitable	66.90% (97)
SAR	< 10	Excellent	1.38% (2)
	43026	Good	16.55% (24)
	18 -26	Doubtful	14.48% (21)
	> 26	Unsuitable	69.66% (101)
MH	< 50	Suitable	6.21 % (9)
	> 50	Unsuitable	93.79% (136)
PI	CI & C II (25- 75% or >)	Suitable	100% (145)
	C III (25% or <)	Unsuitable	0.00 % (0)
KR	< 1	Suitable	0.00 % (0)
	> 1	Unsuitable	100% (145)

Table-4: Pearson correlation among the overall mean values of groundwater variables in Manipur Valley, Manipur (2009-2012).

	T	pH	EC	Turb	DO	PO4	NO3	TH	Cl	TDS	TA	Na	K	Ca	Mg
T	1														
pH	**-.280****	1													
EC	-0.021	0.096	1												
Turb	0.112	-0.082	-0.024	1											
DO	-0.063	0.056	-.181*	**-.293****	1										
PO4	0.064	-0.021	0.131	0.092	-0.146	1									
NO3	0.152	0.117	0.041	0.015	0.054	**.724****	1								
TH	**.223****	-.194*	0.08	0.059	-.206*	**.374****	**.321****	1							
Cl	-0.058	.187*	.190*	.193*	-0.101	**.229****	.187*	0.035	1						
TDS	0.094	-0.102	**.736****	0.136	**-.292****	0.147	0.148	.201*	0.023	1					
TA	0.159	-0.034	**.213****	0.068	**-.259****	**.390****	**.371****	**.293****	**.280****	**.326****	1				
Na	-0.034	-0.122	0.073	0.119	**-.235****	.173*	-0.07	0.042	0.068	0.107	.201*	1			
K	0.085	-0.086	0.104	0.162	**-.272****	.172*	-0.014	**.349****	0.044	.205*	0.156	**.287****	1		
Ca	0.005	.165*	0.096	-0.024	-0.08	.171*	0.162	0.056	0.049	0.02	0.073	-0.067	-.203*	1	
Mg	.195*	0.007	0.04	0.128	**-.246****	**.310****	**.271****	**.527****	0.043	0.152	**.427****	0.092	0.162	0.131	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

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