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# PHYSICO-CHEMICAL PARAMETERS OF GROUNDWATER IN A PART OF IMPHAL EAST DISTRICT, MANIPUR (INDIA)

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**Abstract**

The groundwater quality of a part of Imphal East District of Manipur Valley has been assessed to determine its suitability for drinking and domestic purposes. Thirty four (34) groundwater samples were collected for pre-monsoon (PRM) and post-monsoon (POM) seasons during 2019-2020 and analysed for physico-chemical parameters like temperature (T), pH, electrical conductivity (EC), turbidity (Turb), dissolved oxygen (DO), phosphate ($PO_4^{3-}$), nitrate ($NO_3^-$), total hardness (TH), chloride ($Cl^-$), total dissolved solids (TDS), total alkalinity (TA), calcium ($Ca^{2+}$), and magnesium ($Mg^{2+}$). Analysis results were compared with the WHO (2004) guideline for drinking water. Seasonal variation of parameters is observed in the study area. The physico-chemical parameters like pH, EC, $Cl^-$, $Ca^{2+}$, $Mg^{2+}$, TH, and $NO_3^-$ were well within the WHO guideline values for drinking water except pH in 2.94% (1), EC in 2.94% (1) PRM & 5.88 % (2) POM, $Cl^-$ in 5.88% (2) samples. Whereas parameters like Turbidity (Turb) in 26.47% (9) PRM and 23.53% (8) POM, $PO_4^{3-}$ in 23 (67.64%) PRM and 19 (55.88%) POM, TDS in 22 (64.70%) samples and TA in all samples (34) exceed the WHO limit. This study reveals that the overall groundwater quality of the study area is not fairly good, being contaminated with turbidity, $PO_4^{3-}$, TDS, TA, but can be used for drinking and domestic purposes after proper treatment. Present study recommends for regular water quality monitoring and surveillance, encourage water harvesting practice, use of surface water for drinking after proper treatment such as chlorination, defluoridation and desalination.

**Keywords:** Physico-chemical parameters. Groundwater quality.

## Introduction

Groundwater is an essential and vital component of our life support system. The groundwater resources are being utilized for drinking, irrigation and industrial purposes. It is estimated that approximately one third of the world's population uses groundwater for drinking purposes (Nickson et al. 2005). The quality of groundwater depends on various chemical constituents and their concentration. There has been a growing concern on groundwater contamination by domestic, industrial effluents and agricultural activity in developing countries. The indiscriminate discharge of industrial waste water, sewage sludge and solid waste materials into the environment, results in pollution of subsurface aquifers, irrigation and drinking water resources (Forstner et al. 1981). Several authors have reported about the presence of contaminants in groundwater and surface waters in various part of the globe (Qishlaqi et al. 2007; Elango et al. 2003; Srinivasa Rao et al. 1997; Subba Rao et al. 1998). Studies regarding the groundwater quality analysis have been made by many authors like Gupta et al. 1999; Rajasekara et al. 2005; Thakare et al. 2005; Shikha Bisht et al. 2007. Contamination of water resources available for household and drinking purposes harmful is becoming one of the serious major health problems (Palanisamy et al. 2007 Kamal et al. 2002). Except Singh (2004) and Chakraborti's (2008) preliminary report on groundwater arsenic contamination in Imphal East district, no other published data are available on groundwater quality in Imphal East region with reference to physico-chemical properties. Moreover, most of the population of the area is not well aware about the drinking water quality and uses the available water only, which could endanger their life from water borne diseases like cholera, ulcer and gastrointestinal troubles, etc. Keeping this in focus, a preliminary study on groundwater quality of Imphal East district in Manipur Valley, Manipur (India) was undertaken to provide safe potable drinking water to the inhabitants of the study area. The main objectives of the present study are; to evaluate some of the important physico-chemical parameters Temperature, pH, Electrical Conductivity, Turbidity, Dissolved Oxygen, Phosphate, Nitrate, Total Hardness and Chloride; to compare the analysis results with the WHO (2004) Standards; to examine the seasonal variation of the ground water quality parameters under consideration; to highlight the possible water management measures that would enhance good quality of these water resources; and to dispose-off the outcome of this study to general public, State Governments to help in policy formulation, implementation, monitoring and evaluation, especially on issues relating to water and sanitation management.

## Materials and Methods

### Study Area

The study area is a part of Imphal East District, one of the nine districts of Manipur state. The total area of the district is 710km$^2$. The geographical co-ordinates are 24$^0$48'N and 93$^0$57'E. The study area is crossed by three main rivers; the rivers are Imphal River, Iril River and Kongba River. The climate of this region is salubrious and Monsoon is tropical. The average annual rainfall for last 24 years is 1400mm. The maximum rainfall is observed in the month of June and minimum is in the month of January. The minimum annual temperature is 3$^0$C and maximum annual temperature is about 34$^0$C. Agriculture is the main occupation of the people of the area. Basically, the area is made up of thick alluvium of fluvio-lacustrine origin, which is sub-divided in the older (Pleistocene) and Newer Alluvium due to change in lithology (Soibam 1998). The average thickness of the alluvium is about 100-150 m. The alluviums are mainly dark grey to black carbonaceous clay, silt and sand of which clay form the sediments while silt and sand are subordinate. Based on lithology and structure, the region is divided into two types of aquifers – weathered rock aquifer and alluvium aquifer

### Sampling Procedures and Analytical Method

As a preliminary work, thirty-four (34) groundwater samples (tube wells water) were collected in acid pre-washed (1L) polythene bottles after continuously pumping off at least 4-5 minutes, from different locations of Imphal East District in Manipur Valley, Manipur (India) for pre-monsoon (PRM) and post- monsoon (POM) during 2019-2020 (Fig. 1). GPS readings were recorded to indentify the sampling locations exactly (Table 1). The collected groundwater samples were filtered using 0.45µ Millipore filters. For estimation of dissolved anions unacidified water samples will be used. Physico-chemical parameters like Temperature (T), pH, Electrical Conductivity (EC), Turbidity (TRB), and Dissolved Oxygen (DO) were determined on the spot by using portable field kits like pH meter, Conductivity meter, Turbidity meter, and DO meter. Phosphate ($PO_4^{3-}$) and Nitrate ($NO_3^-$) was estimated by UV- spectrophotometer. Total Hardness (TH) was determined by ethylenediaminetetraacetic acid (EDTA) titrimetric method, Chloride ($Cl^-$) by standard $AgNO_3$ titration, total alkalinity (TA), calcium ($Cl^{2+}$), magnesium ($Mg^{2+}$), sodium ($Na^+$), and potassium ($K^+$) were measured following standard methods (APHA 2005), and the results obtained were compared with Standards (WHO 2004).

## Results and Discussion

### Physico-chemical Parameters

Table 2 represents physico-chemical parameters of groundwater samples of the study area with mean ± SD and concentration ranges for pre- and post-monsoon (PRM &POM) seasons in parenthesis seasons. What follows is a brief description of the physico-chemical parameters of groundwater samples.

**Temperature (T) in $^0$C**: Temperature is an important biologically significant factor, which plays an important role in the metabolic activities of an organism. The temperature in the study area varied from 27.7 to 32$^0$C (mean: 30.01$^0$C; SD ± 1.55) and 19.1 to 19.8$^0$C (mean: 19.3$^0$C; SD ± 0.14) for Pre-monsoon (POM) & Post-monsoon (POM) seasons, respectively. The variation in the water temperature may be due to different timings of collection and influence of season (Jayaraman et al., 2003).

**pH:** The pH of a water body is very important in determination of water quality since it affects other chemical reactions such as solubility and metal toxicity (Fakayode, 2005). pH values in the study area varied from 6.52 to 9.35 (mean: 7.4 $mgL^{-1}$; SD ± 0.5) and 6.53 to 9.08 $mgL^{-1}$ (mean: 7.38; SD ± 0.47) for PRM & POM seasons, respectively. The pH of the water samples under study in both seasons is within the WHO standard of 6.5- 9.2, except 2.94% (1) sample (GW-32). Most of the water samples are alkaline due to the presence of carbonates and bicarbonates produced from the interaction of groundwater with the aquifer material.

**Electrical Conductivity (EC) in $\mu Scm^{-1}$**: Electrical conductivity (EC) is a measure of water capacity to convey electric current. It signifies the amount of total dissolved salts (Sudhir and Amarjeet, 1999). EC values were in the range of 482 to 2480 $\mu Scm^{-1}$ (mean: 894.48 $\mu Scm^{-1}$ ; SD ± 358.78 and mean: 911.63 $\mu Scm^{-1}$; SD ± 394.78 ) for PRM & POM seasons, respectively and the values were found to be within the limit of 1500 $\mu Scm^{-1}$ prescribed by WHO. EC in 2 (5.88%) PRM &POM samples (GW-31 and GW-17) exceed the prescribed limit. The reason for higher EC in these samples may be due to the presence of high amount of dissolved inorganic substances in ionized form. Mishra (1993) reported that use of fertilizers for nutrient enrichment may enhance TDS, which in turn increases the EC since these two parameters are directly related to each other.

**Turbidity (Turb) in NTU:** The turbidity values varied from 0.06 to 270 NTU for PRM, with a mean of 28.16 NTU and 0.01 to 234.5 NTU POM, with a mean of 24.07 NTU ; SD ± 49.05. Turbidity values in 26.47% (9) PRM samples (GW-2, GW-7, GW-9, GW-10, GW-20, GW-22, GW-29, GW-30, and GW-34), 23.53% (8) POM samples (GW-7, GW-9, GW-10, GW-20, GW-22, GW-29, GW-30, and GW-34) were above the permissible limit of 25 NTU. High turbidity in the study area may be due to presence of particulate matters such as clay, silt, finely divided organic matter, plankton or other microscopic organisms in groundwater of the study area. High turbidity levels are therefore associated with poor water quality (Adekunle et al., 2007).

**Dissolved oxygen (DO) in $mgL^{-1}$:** 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 $mgL^{-1}$ (Joseph and Jacob, 2010). 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 in the study area varied from 6.55 to 10.63 $mgL^{-1}$ (mean: 7.63 $mgL^{-1}$**;** SD ± 1.07) and 7.53 to 10.63 $mgL^{-1}$(mean: 8.55 $mgL^{-1}$; SD ± 0.80) for PRM & POM seasons showing high DO values. The higher range of D.O values in the study area indicates high aerobic groundwater condition, which is suitable for drinking, irrigation and fisheries purposes, but very low DO will result in anaerobic conditions that cause bad odours.

**Phosphate ($PO_4^{3-}$) in $mgL^{-1}$:** Traces of phosphates increase the tendency of troublesome algae to grow in the water and their presence in the study area may be traced to agricultural activities (Punmia et al. 1998). High phosphate content in groundwater is indicative of nutrient pollution which could enhance nuisance growth of algae and accelerate the process of eutrofication, but has no direct impact on human health (Trivedy and Goel, 1986). Phosphate in natural water mostly ranges between 0.005 and 0.020 $mgL^{-1}$ (Chapman et al. 1992). Phosphate content in the study area was in the range of 0.02 to 2.38 $mgL^{-1}$ (mean: 0.97 $mgL^{-1}$ ; SD ± 0.73) and 0.02 to 2.78 $mgL^{-1}$ (mean: 0.76 $mgL^{-1}$; SD ±0.68) for PRM & POM seasons and found to be mostly beyond the prescribed limit of WHO. 23 (67.64%) sampling points in PRM namely GW-1, GW-2, GW-3, GW-4, GW-5, GW-9, GW-10, GW-12, GW-13, GW-14, GW-15, GW-16, GW-17, GW-18, GW-19, GW-20, GW-21, GW-22, GW-23, GW-29, GW-31, GW-32, GW-33 and 19 (55.88%) sampling points in POM namely GW-1, GW-8, GW-9, GW-10, GW-14, GW-16, GW-17, GW-18, GW-20, GW-21, GW-22, GW-23, GW-24, GW-26, GW-29, GW-31, GW-32, GW-33, and GW-34 showed phosphate values higher than the prescribed WHO limit of 0.4 $mgL^{-1}$. High value of phosphate in groundwater samples may be due to widespread use of phosphatic fertilizers in agriculture practices.

**Nitrate ($NO_3^-$) in $mgL^{-1}$**: Groundwater is contaminated by nitrate from leaching of nitrate rich sewage and other wastes with percolating water. **$NO_3^-$** in the study area is found to be comparatively low and was in the range of 0.02 to 1.41 $mgL^{-1}$ (mean: 0.32 $mgL^{-1}$; SD ± 0.3) and 0.04 to 0.52 $mgL^{-1}$ (mean: 0.17 $mgL^{-1}$; SD ± 0.11) for PRM & POM seasons. The results revealed that none of the samples exceed the permissible limit of WHO (45$mgL^{-1}$). Low nitrate in the study area indicates that the percolating or, leaching water and waste effluents contains low nitrate. Nitrate in drinking water above the WHO recommended value is highly deleterious to babies less than three to six months of age because of its ability to cause methaemoglobinaemia or baby syndrome in which blood loses its ability to carry sufficient oxygen (Fecham et al. 1986; Burkart et al. 1993; Groen et al. 1988). Being loosely bound to soils, nitrate is expected to be more in runoff and hence its concentration increases during rainy seasons (Rao et al. 2004).

**Total Hardness (TH) in $mgL^{-1}$:** Hardness is the property of water which prevents the lather formation with soap and increases the boiling points of water (Trivedy and Goel, 1986)**.** Hardness of water depends upon the amount of calcium or magnesium salts or both. 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 (Kotaiah et al. 2004). Hardness values varied from 40 to 260 $mgL^{-1}$ (mean: 156 $mgL^{-1}$; SD ±54.31 and 44 to 252 $mgL^{-1}$ (mean 155.85 $mgL^{-1}$; SD ± 52.03) for PRM & POM seasons, respectively. TH in 5 (14.70%) PRM samples (GW-23, GW-24, GW-31, GW-32, GW-34) and 4 (11.76%) POM samples (GW-23, GW-24, GW-31, and GW-34) were found to be above the WHO guideline value of 200 $mgL^{-1}$. The high values of TH in these samples indicate the presence of $Ca^{2+}$ & $Mg^{2+}$ rich carbonate rocks like khondalites in the aquifer materials and there is lack of agricultural activities in and around the sampling sites.

**Chloride ($Cl^-$) in $mgL^{-1}$: $Cl^-$** occurs naturally in all types of waters. In natural waters, the probable sources of chloride comprise the leaching of chloride-containing minerals (like apatite) and rocks with which the water comes in contact, inland salinity and the discharge of the agricultural, industrial and domestic waste waters (Abbasi et al. 1998; CGWB 2005). Agricultural application of $K^+$ as a plant nutrient commonly results in chloride contamination of recharging shallow groundwater (Bohlke et al. 2002).The values of $Cl^-$ for PRM ranged between 14.2 to 700 $mgL^{-1}$ (mean: 75.14 $mgL^{-1}$; SD ±123.40) and 14.2 to 700 $mgL^{-1}$ (mean: 75 $mgL^{-1}$; SD ±123.40) for PRM & POM seasons, respectively and the values were within the WHO limit of 250$mgL^{-1}$ except 5.88% (2) PRM & POM samples (GW-16 and GW-18). High $Cl^-$ values these two samples (GW-16 &GW-18) may be due to big discharge of sewage and domestic effluents in the sampling sites.

**Total Dissolved Solids (TDS) in $mgL^{-1}$:** Total dissolved solids indicates the salinity behaviour of groundwater. TDS content in the study water sample was ranging from 215 to 1360 $mgL^{-1}$ (mean: 585.44 $mgL^{-1}$; SD ± 213.32) and 220 to 1357 $mgL^{-1}$ (mean: 587.17 $mgL^{-1}$; SD ± 213.37) for PRM & POM seasons, indicating high TDS in the study area. TDS values in 22 (64.70%) PRM & POM samples namely GW-1, GW-2, GW-3, GW-4, GW-5, GW-7, GW-8, GW-11, GW-12, GW-13, GW-14, GW-17, GW-20, GW-22, GW-23, GW-24, GW-25, GW- 26, GW-29, GW-30, GW-32, and GW-34 were found to be above the WHO guideline value of 500 $mgL^{-1}$. High 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 (Garg, 2003; Subha Rao, 2006). Water containing TDS more than 500 $mgL^{-1}$ not desirable for drinking but in unavoidable cases 1500 $mgL^{-1}$ is also allowed (Srinivasa and Venkateswaralu, 2000) and consumers of such water containing TDS more than 500 $mgL^{-1}$ is known to cause gastrointestinal irritation (BIS 1991; WHO 2004).

**Total Alkalinity (TA) in $mgL^{-1}$:** Alkalinity 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. TA values for PRM samples ranged between 203 to 615 $mgL^{-1}$ (mean: 362.35 $mgL^{-1}$; SD ± 105.58) and 205 to 620 $mgL^{-1}$ (mean: 366.75 $mgL^{-1}$; SD ± 106.40) for POM, indicating high TA values in the study area. Results revealed that TA values in all the analysed PRM &POM samples i.e., 100 % (34) samples exceed WHO limit of 100-200 $mgL^{-1}$. The probable reasons behind this TA values is that the groundwater aquifers of the study area are rich in carbonates, bicarbonates and hydroxide compound of calcium, sodium and potassium as the aquifers are primarily controlled by carbonate reactions. 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.

**Calcium ($Ca^{2+}$) in $mgL^{-1}$:** $Ca^{2+}$ is directly related to hardness. $Ca^{2+}$ content in the studied samples was very low and the values ranged between 1.65 to 21.86 $mgL^{-1}$ (mean: 5.41 $mgL^{-1}$; SD ± 4.38) and 1.60 to 22.11 $mgL^{-1}$ (mean: 5.37 $mgL^{-1}$; SD ± 4.50) for PRM & POM seasons, respectively. The results showed that all samples (34) were found to be within the WHO limit of 75 $mgL^{-1}$. Low $Ca^{2+}$ content in water samples indicates that the groundwater aquifers of the study area are mostly shallow aquifers and not controlled by carbonate reactions i.e., contain little or no carbonate rocks like limestone and minerals like calcite in groundwater aquifers of the area under study. Inadequate intakes of $Ca^{2+}$ have been associated with increased risked of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity.

**Magnesium ($Mg^{2+}$) in $mgL^{-1}$:** $Mg^{2+}$ is also directly related to hardness. $Mg^{2+}$ values from 15.4 to 20.4 $mgL^{-1}$ (mean: 18.53 $mgL^{-1}$ ; SD ± 1.06) and 14.8 to 19.8 $mgL^{-1}$ (mean: 18.0 $mgL^{-1}$; SD ± 0.93) for PRM & POM seasons, respectively and the values were all fall well within the WHO recommended limit of 150 $mgL^{-1}$. Low $Mg^{2+}$ values in the study area may also be mainly because of shallow aquifers made up with little or no carbonate rocks like dolomite and minerals like magnesite. Low Mg2+ status has been implicated in hypertension, coronary heart disease, type 2 diabetes mellitus and metabolic syndrome.

**Statistical Analysis**

Correlation analyses were performed for physico-chemical parameters like temperature (Temp), pH, electrical conductivity (EC), turbidity (Turb), dissolved oxygen (D.O), phosphate ($PO_4^{3-}$), nitrate ($NO_3^-$), total hardness (TH), chloride ($Cl^-$), total dissolved solids (TDS), total alkalinity (TA), calcium ($Ca^{2+}$), and magnesium ($Mg^{2+}$) in the groundwater collected from Imphal East district. The results are depicted in Table 2. Out of a total 78 correlations between water quality parameters, 13 were found to have significant (r>0.127). The negative (inverse) correlations were found in 37 cases between Turb and pH (r = -0.179), between turbidity and EC (r = -0.277), between DO and temp (r = -0.325), between DO and pH (-0.266), between DO and EC (r = -0.241), between DO and Turb (r= -0.175), between $PO_4^{3-}$ and Turb (r = -0.061), between $PO_4^{3-}$ and DO (r = -0.335), between $NO_3^-$ and Turb (r = -0.289), between $NO_3^-$ and DO (r = -0.253), between $NO_3^-$ and $PO_4^{3-}$ (r = -0.001), between TH and DO (r = -0.162), between TH and $PO_4^{3-}$ (r = -0.016), between TH and $NO_3^-$ (r = -0.15), between $Cl^-$ and Temp (r = -0.01), between $Cl^-$ and Turb (r = -0.125), between $Cl^-$ and DO (r = -0.138), between TDS and Ph (r = -0.217), between TDS and EC (r = -0.216), between TDS and $PO_4^{3-}$ (r = -0.107), between TDS and $NO_3^-$ ( r = -0.22), between TDS and TH (r = -0.036), between TDS and $Cl^-$ ( r = -0.16), between TA and Temp (r = -0.337), between TA and Ph (r = -0.239), between TA and EC (r = -0.296), TA and Turb (r = -0.048), between TA and $NO_3^-$(r = -0.27), between TA and $Cl^-$ (r = -0.16), between $Ca^{2+}$ and Turb (r = -0.138), between $Ca^{2+}$ and DO ( r = -0.300), between $Ca^{2+}$ and $PO_4^{3-}$ ( r = -0.110), between $Ca^{2+}$ and TDS (r = -0.246), between $Ca^{2+}$ and TA (r = -0.341), between $Mg^{2+}$ and Turb (r = -0.201), between $Mg^{2+}$ and DO (r = -0.244), between $Mg^{2+}$ and TA (r = -0.406). No strong correlation was observed between different physico-chemical parameters of groundwater samples.

**Recommendations**

Development activities should not deplete or degrade the natural resources, including water on which present and future life depends.

The following recommendations are suggested to have a better groundwater quality in the study area:
Regular water quality monitoring and surveillance;
Use of surface water and adoption of water treatment technologies such as water softening, ion exchange, chlorination, defluoridation, desalination and demineralization of water;
Excess use of chemical fertilizers particularly phosphatic for higher crop yields should be avoided;
Encourage practices of rainwater harvesting techniques should be implemented to augment the groundwater resource;
Formulation of action plan for surface water management with people's participation for reduced dependency on groundwater.

**Conclusions**

On the basis of the above discussion, the following conclusions can be drawn:

The values of all the studied parameters in groundwater samples of the study area were relatively high in pre-monsoon (PRM) season, compared to the post-monsoon (POM) season during the period of investigation due to dilution effect. Ground waters in the study area were slightly alkaline in pre-and post-monsoon (PRM & POM) seasons due to the influence of semi-arid climate, gentle slope, lack of good drainage conditions, longer contact of groundwater with the aquifer material and anthropogenic activities. Physico-chemical parameters like pH, EC, $Cl^-$, $Ca^{2+}$, $Mg^{2+}$, TH and $NO_3^-$ were well within the WHO guideline values for drinking water except pH in 1 (2.94%) sample (GW-32), EC in 2 (5.88%) PRM &POM samples (GW-17 & GW-31), $Cl^-$ in 2 (5.88%) PRM &POM samples (GW-16 & GW-18), TH in 5 (14.70%) PRM samples (GW-23, GW-24, GW-31, GW-32, GW-34) and 4 (11.76%) POM samples (GW-23, GW-24, GW-31, and GW-34). Parameters like Turbidity (Turb) in 26.47% (9) PRM and 23.53% (8) POM samples, $PO_4^{3-}$ in 23 (67.64%) PRM, and 19 (55.88%) POM samples and TDS in 22 (64.70%) samples and TA in all samples (34) samples exceed WHO limit.The study reveals that the overall groundwater quality of the study area is not fairly good, contaminated with turbidity, $PO_4^{3-}$, TDS, TA, but can be used for drinking and domestic purposes after proper treatment.

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Table Captions:

Table 1 Locations of groundwater sampling sites in the study area

Table 2 Physico-chemical properties of groundwater (mean ± SD with range in parenthesis) of a part of Imphal East District in pre & post-monsoon seasons, 2019-2020

Table 3 Correlation between different physico-chemical parameters of groundwater samples

Figure Caption:

Fig 1 Groundwater sampling locations in the study are

Table 1 Location of groundwater sampling sites

| SAMPLE ID | LOCATION | LATITUDE | LONGITUDE |
|---|---|---|---|
| GW-1 | Dewlahland | 24049.403' | 93056.320' |
| GW-2 | Dewlahland | 24049.395' | 93056.839' |
| GW-3 | Dewlahland | 24049.400' | 93056.321' |
| GW-4 | Dewlahland | 24049.424' | 93056.911' |
| GW-5 | Dewlahland | 24049.390' | 93056.889' |
| GW-6 | Dewlahland | 24049.415' | 93056.918' |
| GW-7 | Dewlahland | 24049.344' | 93056.981' |
| GW-8 | Dewlahland | 24049.398' | 93056.835' |
| GW-9 | Tangkhul Avenue | 24049.697' | 93056.904' |
| GW-10 | Tangkhul Avenue | 24049.682' | 93056.391' |
| GW-11 | Tangkhul Avenue | 24053.414' | 93055.070' |
| GW-12 | Tangkhul Avenue | 24049.676' | 93056.883' |
| GW-13 | Tangkhul Avenue | 24049.670' | 93056.942' |
| GW-14 | Tangkhul Avenue | 24049.665' | 93056.920' |
| GW-15 | Tangkhul Avenue | 24049.663' | 93056.975' |

| | | | |
|---|---|---|---|
| GW-16 | Chingmeirong makha | 24049.754' | 93056.794' |
| GW-17 | Chingmeirong | 24049.852' | 93056.731' |
| GW-18 | Chingmeirong mamang | 24049.758' | 93056.884' |
| GW-19 | Chingmeirong | 24049.878' | 93056.886' |
| GW-20 | Chingmeirong | 24049.920' | 93056.790' |
| GW-21 | Chingmeirong | 24049.672' | 93056.594' |
| GW-22 | Chingmeirong | 24049.835' | 93056.641' |
| GW-23 | Chingmeirong | 24049.835' | 93056.641' |
| GW-24 | Chingmeirong | 24049.860' | 93056.662' |
| GW-25 | Chingmeirong | 24049.839' | 93056.618' |
| GW-26 | Chingmeirong | 24049.871' | 93056.688' |
| GW-27 | Chingmeirong | 24049.897' | 93056.665' |
| GW-28 | Chingmeirong | 24049.920' | 93056.792' |
| GW-29 | Sangakpham Bazar | 24049.980' | 93056.754' |
| GW-30 | Laipham khunou | 24050.045' | 93057.09' |
| GW-31 | Laipham khunou | 24050.057, | 93057.089' |
| GW-32 | Laipham khunou | 24050.103' | 93057.094' |
| GW-33 | Laipham khunou | 24050.123' | 93056.961' |
| GW-34 | Laipham khunou | 24049.996' | 93056.967' |

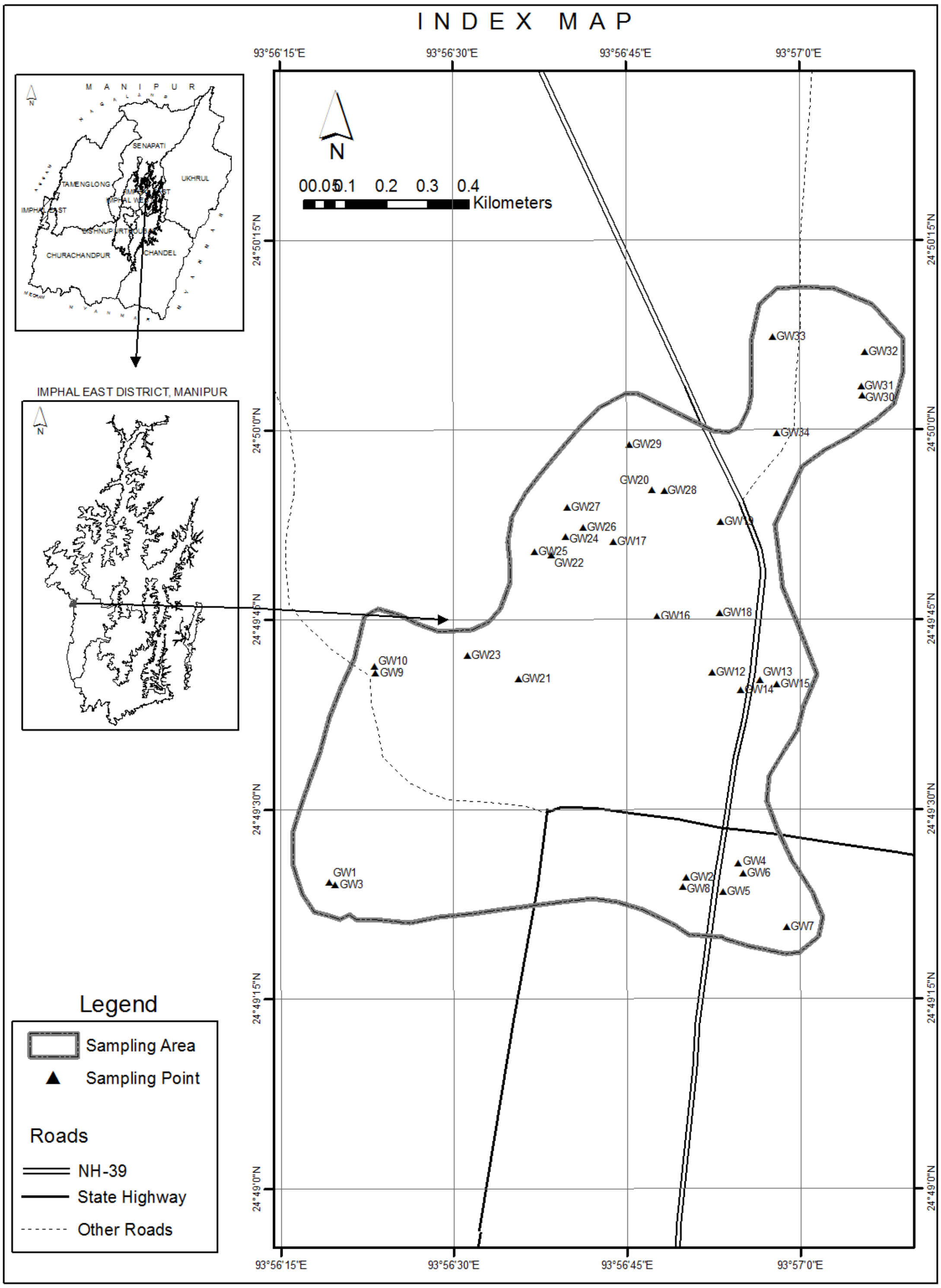


Fig1 Groundwater sampling locations in the study area

Table 2 Physico-chemical properties of groundwater (mean ± SD with range in parenthesis) of a part of Imphal East District in pre & post-monsoon seasons, 2019-2020

| Parameters | WHO Standards | Mean ± SD (Min –Max) | |
|---|---|---|---|
| | | PRM | POM |
| Temperature ($^0$C) | -------- | 30.01 ± 1.55 (27.7 -32) | 19.3 ± 0.14 (19.1- 19.8) |
| pH | 6.5 -9.2 | 7.4 ± 0.5 (6.52 - 9.35) | 7.38 ± 0.47 (6.53- 9.08) |
| EC ( µs) | 1400 | 894.48 ± 358.78 (482 - 2480) | 911.63± 394.78 (482- 2480) |
| Turbidity (NTU) | 25 | 28.16 ± 60.77 (0.06 - 270) | 24.07± 49.05 (0.01- 234.5) |
| D.O (mg $L^{-1}$) | 4 to 6 | 7.63 ± 1.07 (6.55 - 10.63) | 8.55± 0.80 (7.53- 10.63) |
| Phosphate(mg $L^{-1}$) | 0.4 | 0.97 ± 0.73(0.02 - 2.38) | 0.76 ± 0.68 (0.02- 2.78) |
| Nitrate (mg $L^{-1}$) | 45 | 0.32 ± 0.3 (0.02 - 1.41) | 0.17 ± 0.11(0.04- 0.52) |
| Total hardness (mg $L^{-1}$) | 200 | 156 ± 54.31(40 - 260) | 155.85 ± 52.03 (44- 252) |
| Chloride (mg $L^{-1}$) | 250 | 75.14 ± 123.41(14.2 - 700) | 75 ± 123.40 (14.2- 700) |
| TDS (mg $L^{-1}$) | 500 | 585.44 ± 213.32(215 - 1360) | 587.17 ± 213.37 (220- 1357) |
| Total alkalinity (mg $L^{-1}$) | 100 -200 | 362.35 ± 105.58 (203 - 615) | 366.75 ± 106.40 (205- 620) |
| $Ca^{2+}$ (mg $L^{-1}$) | 75 | 5.41 ± 4.38 (1.65- 21.86) | 5.37± 4.50(1.60- 22.11) |
| $Mg^{2+}$(mg $L^{-1}$) | 150 | 18.53 ± 1.06 (15.4 - 20.4) | 18.0 ± 0.93 (14.8- 19.8) |

Table 3 Correlation between different physico-chemical parameters of groundwater samples

| | Temp | pH | EC | Turbidity | DO | Phosphate | Nitrate | TH | Chloride | TDS | TA | $Ca^{2+}$ | $Mg^{2+}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1 | | | | | | | | | | | | |
| pH | 0.187 | 1 | | | | | | | | | | | |
| EC | 0.268 | 0.177 | 1 | | | | | | | | | | |
| Turbidity | 0.006 | -0.179 | -0.277 | 1 | | | | | | | | | |
| DO | -0.325 | -0.266 | -0.241 | -170 | 1 | | | | | | | | |
| Phosphate | 0.176 | 0.089 | 0.2 | -0.061 | -0.335 | 1 | | | | | | | |
| Nitrate | 0.266 | 0.314 | 0.284 | -0.289 | -0.253 | -0.001 | 1 | | | | | | |
| TH | 0.195 | 0.032 | 0.176 | 0.072 | -0.162 | -0.016 | -0.151 | 1 | | | | | |
| Chloride | -0.01 | 0.213 | 0.177 | -0.125 | -0.138 | 0.132 | 0.144 | 0.019 | 1 | | | | |
| TDS | 0.078 | -0.217 | -0.216 | 0.2 | 0.018 | -0.107 | -0.218 | -0.04 | -0.16 | 1 | | | |
| TA | -0.337 | -0.239 | -0.296 | -0.048 | 0.394 | 0.064 | -0.272 | 0.013 | -0.16 | 0.124 | | | |
| $Ca^{2+}$ | 0.122 | 0.167 | 0.168 | -0.138 | -0.3 | -0.11 | 0.342 | 0.237 | 0.533 | -0.246 | -0.341 | 1 | |
| $Mg^{2+}$ | 0.16 | 0.075 | 0.156 | -0.201 | -0.244 | 0.102 | 0.127 | 0.271 | 0.337 | 0.012 | -0.406 | 0.36 | 1 |

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