Geographical Assessment and Comparison of Some Physicochemical Parameter of Groundwater in Some Designated Tea Plantations of Lakhimpur District, Assam, India

Bistirna Saikia[1], Parmita Phukan[2], Bhabajit Bhuyan[3]

[1]Department of Geography, Gauhati University, Guwahati, Assam, India
Email: *sbistirna09[at]gmail.com*

[2, 3]Department of Chemistry, North Lakhimpur University, North Lakhimpur, Assam, India
Email: *bhabajitb[at]rediffmail.com*
Email: *parmitaphukan92[at]gmail.com*

Abstract: ***Water quality monitoring is indeed becoming increasingly crucial on a global scale due to intensifying water use. Contamination of groundwater has raised its ugly head recently in Assam. Results reported by various agencies have been alarming. The present research conducted in Lakhimpur district, Assam, focusing on studying some physico-chemical water quality parameters in and around some selected tea gardens. The primary objectives are to establish consistent records of water contamination, which may serve as indicators for short-term environmental changes. Twenty ground water samples were chemically analyzed by adopting standard procedures. The experimental values of physicochemical parameters were compared with the World Health Organization and ISI water quality standards. The observed variations in quality of water samples inside and outside tea gardens may be due to the high permeability of tea garden soils combined with the relatively short distance to the water table making these areas particularly sensitive to contamination. It was found that people use water for drinking purposes mostly from tubewells, borewells and supply water sources, which need purification before drinking. The present study, however, fulfilled the limited purpose of strengthening database which may help in implementing effective remedial policies and strategies to manage and mitigate water pollution.***

Keywords: groundwater quality, tea garden, water contamination, drinking water etc

1. Introduction

The need for water quality monitoring at a global level grows and increases exponentially as water use intensifies. The present research has been carried out to study some of the physic-chemical water quality parameters in and around some selected tea gardens of Lakhimpur district, Assam with a specific view to provide unfaltering records of contamination of water so that it is of value as an indicator of short-term improvement or deterioration in the environment, when implementing remedial policies as well as to help users at local level to establish which chemicals in a particular setting should be given priority in developing strategies for risk. The growth of literature and database on water chemistry has been really tremendous during the last several years. Current literature available on water quality tends to be conceptual, analytical, or prescriptive in terms of standard setting. An exhaustic literature survey is a near impossible task and, therefore, only a sample of the published literature, having relevance directly and indirectly to our research work is discussed here. Water is the most precious gift of the nature. It is indispensable for sustenance of life and is one of most important components which influences economic, agricultural and industrial growth of mankind. The effect of water on almost everything in our environment is far more significant than might be imagined. There is growing shortage of usable water resources and it is going to be one of the major issues of the twenty first century. Human use of fresh water has registered a 35-fold increase in the last 300 years. As a whole, 3500 km^3 of fresh water was withdrawn from different sources throughout the world for human use every year. Providing clean and safe drinking water to all people is still a far cry in many parts of India and as a result, this has remained at the top of the government agenda for last several years. Contamination of groundwater has raised its ugly head recently in Assam. Results reported by various agencies have been alarming. While some of the results may have been exaggerated and may have suffered from improper sample collection, lack of calibration of measuring instruments, use of non-standard methods and human errors, it is no longer possible to ignore the gradually accumulating data. The need is for a more systematic and careful study eliminating all possible sources of error and to build up a reliable database. Thus, every effort should be made to achieve a drinking-water quality as safe as practicable. This work will ensure whether safe and wholesome supply of drinking water is available or not. Moreover, the data set that will be developed during this research can be applied to more sites and the statistics can be examined more critically. In addition, the cost and practicality of the measure will also be considered. Developing regional database would allow inter-regional use of water chemistry data to increase national sampling efficiencies, increase local water chemistry knowledge and promote interaction and collaboration between GOs and NGOs. The present work has been undertaken with a specific view to further strengthen the water chemistry database as well as to educate and raise awareness so that concerted strategies can be adopted, at the planning level, to keep the chemical contamination of water at the minimum. Pollution of fresh water occurs due to three major reasonsexcess nutrients from sewage, wastes from industries, mining and agriculture (Malik et al. 2020, Mayback 1989). India is currently facing critical water supply and drinking water quality problems. Water supplies in India are no longer unlimited. In many parts of the country, water supplies are threatened by contamination and future water supplies are uncertain. There is evidence of prevailing contamination of water resources in many areas of India. Although information on drinking water quality of North Eastern India is very little, results reported by various agencies have been alarming. The discovery that arsenic contaminated groundwater is found in many tubewells in West Bengal has provided a major challenge to the efforts to provide safe drinking water (Ray et al. 2020). Available literature shows that groundwater in Assam is highly contaminated with iron (Dutta et al. 2022). High level of fluoride and iron distribution in ground water sources of certain districts of Assam has also been observed (Lahkar et al. 2019; Kumar et al. 2016). There is evidence of prevailing heavy metal contamination of groundwater in many areas of India Heavy metal contamination of groundwater more often than not goes unnoticed and remains hidden from the public view. Presently, it has raised wide spread concerns in different parts of the world and results reported by various agencies have been alarming (Bhuyan, R et al. 2023, Borah, K, K et. al. 2010, Bhuyan, B et al. 2010, Buragohain, M et.al. 2010, Bhuyan, J. et al. 2025, Hazarika, S, Bhuyan, B., 2013, Nath, B.K et. al. 2018, Bhuyan, B et. al. 2006, Bhuyan, B et al.2016, Bhattacharjee, K. G et al. 2007, CGWB, 2010, A. Gamar et. al 2020, A. A. Werhneh, 2015, Oko O. Jet. al. 2017). Thus, the monitoring of groundwater quality has been universally recognized as the quality of ground water cannot be restored once it is contaminated, by stopping the flow of pollutants from the source. The elevated metal level in groundwater is a new public concern in Assam. The standards set by the regulatory bodies should always be observed to ensure that the health of consumers is not compromised. In particular, the effects of contaminants should always be established before releasing the standards to suppliers and consumers. Testing of water quality on a regular basis is, therefore, an important part of maintaining a safe and reliable source. W.H.O has given a set of guideline values for drinking water quality (W.H.O 2009). These guideline values, along with tolerance limits prescribed by the Indian Standard Institute (Trivedy 1990) and EPA standards of USA are also important in determining water quality (Train 1979).

2. Study Area

The study area Lakhimpur district is situated in the eastern parts of India on the northeast corner of Assam. Located between mighty Brahmaputra River and Himalayan foothills of Arunachal Pradesh, the district is largely plain with some hills. The district lies between $26^0 48^/$ and $27^0 53^/$ northern latitude and $93^0 42^/$ and $94^0 20^/$ eastern longitude (approximately). The district covers an area of 2,977 sq. km out of which 2,957 sq. km is rural and 20 sq. km is urban. Lakhimpur District falls in the sub-tropical climatic region, and enjoys monsoon type of climate. The district experiences a dry and hot summer season when compared to the other parts of Assam. Autumns are dry, and warm. Winters extend from the month of October to February, and are cold and generally dry. There are nine large Tea gardens apart from several small tea gardens in the district of Lakhimpur, Assam. These gardens are situated near the banks of river Dikrong, Ranganadi and Subansiri respectively.

Physio graphically, the Lakhimpur district is more or less flat and can be divided into high-level plain of Brahmaputra River and flat flood plain area. The area bordering the north of the district is a hilly terrain. The main characteristic features of the area are high-level terraces or piedmont plains at altitude of 122 m and low-level terraces at altitude between 107 and 122 m above mean sea level. The piedmont zone extends up to 4–6 km from the foothills. Hydro geologically, the entire area under present study is occupied by alluvial sediments of Quaternary age. Groundwater in the area occurs under phreatic condition in the shallow aquifer zone and under semi-confined condition in the deeper aquifer. The flow of groundwater is from north to south. Rainfall is the main source of groundwater recharge although seepage from canal, return flow from applied irrigation, seepage from surface water body, etc. takes place (CGWB 2007).

The major tea producer of the district includes Ananda Tea Estate, Johing Tea Estate, Sirajuli Tea Estate, Dirzo Tea Estate, Harmuuty Tea Estate, Koilamari Tea Estate, Doloohat Tea Estate, Kakoi Tea Estate and Silanibari Tea Estate (Figure 1).

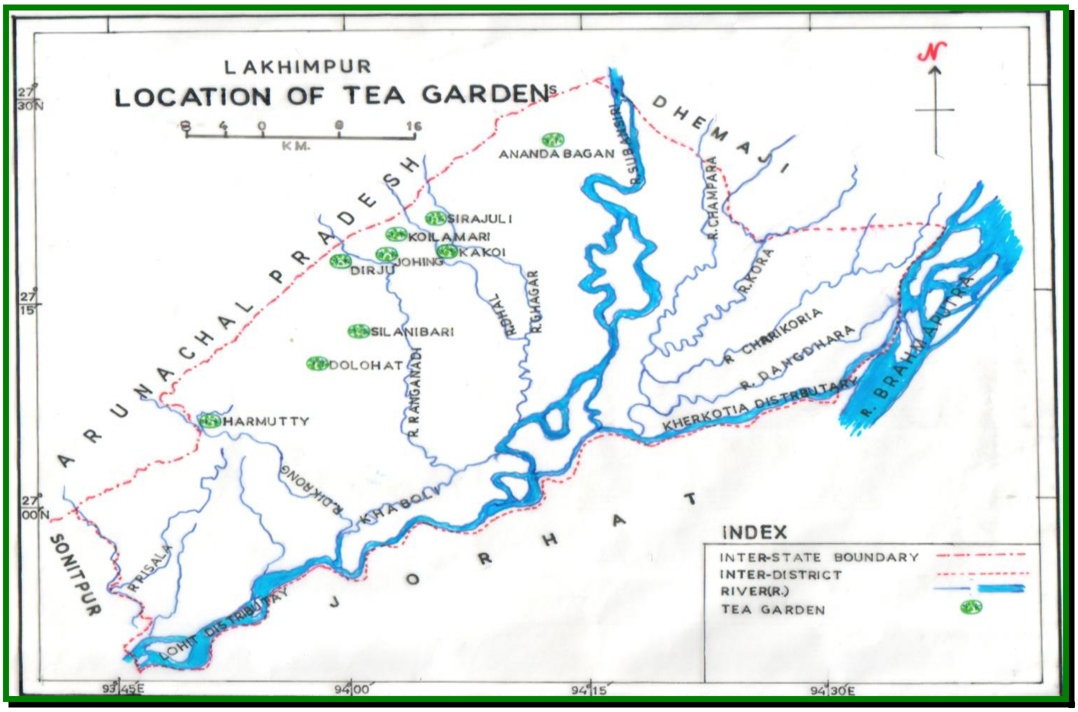

Figure 1: Distribution of tea estate in Lakhimpur district

3. Materials and Methodology

Separate water samples are selected by random selection and compiled together in plastic bottles to set a representative sample collected in and around five selected tea gardens of Lakhimpur district, Assam during June to November, 2023 (Table-1).

Table 1: Water sampling locations

Sample No	Source	Place	Sample No	Source	Place
A1	Supply Water	Tea Garden (Harmutty)	B5	Ring Well	Outside Tea Garden (Johing)
A2	Tube Well	Tea Garden (Harmutty)	B6	Tube Well	Outside Tea Garden (Johing)
B1	Supply Water	Outside Tea Garden (Harmutty)	A7	Supply Water	Tea Garden (Dirju)
B2	Tube Well	Outside Tea Garden (Harmutty)	A8	Tube Well	Tea Garden (Dirju)
A3	Supply Water	Tea Garden (Silonibari)	B7	Ring Well	Outside Tea Garden (Dirju)
A4	Tube Well	Tea Garden (Silonibari)	B8	Tube Well	Outside Tea Garden (Dirju)
B3	Tube Well	Outside Tea Garden (Silonibari)	A9	Supply Water	Tea Garden (Koilamari)
B4	Ring Well	Outside Tea Garden (Silonibari)	A10	Tube Well	Tea Garden (Koilamari)
A5	Supply Water	Tea Garden (Johing)	B9	Tube Well	Outside Tea Garden (Koilamari)
A6	Supply Water	Tea Garden (Johing)	B10	Tube Well	Outside Tea Garden (Koilamari)

Temperature, pH and conductivity were determined quickly after sampling. Samples were protected from direct sun light during transportation (Tata, 1987). The physical parameters studied are Temperature, Colour, Odour, Taste, Conductivity, Total Solid (TS), Total Dissolved Solid (TDS) and Total Suspended Solid (TSS). The chemical parameters studied are pH, Alkalinity, Chloride (Cl^-), Sulphate (SO_4^{--}), Nitrate (NO_3^-), Total Hardness, Calcium (Ca), Magnesium (Mg) and Iron (Fe). Analytical techniques as described in "Standard Methods for the Examination of Water and Wastewater" (APHA, 1995) are adopted for physico-chemical analysis of water samples.

4. Results

The test values of physico-chemical parameters of water samples are presented in Table 2 and 3. To look into the trend and distribution patterns investigated water quality parameters, data were also presented graphically (Figure 2).

Table 2: Water test values in and around tea gardens

Sample No	Temp. (^{0}C)	Conductivity (mmho/cm)	TS (mg/L)	TSS (mg/L)	TDS (mg/L)	Alkalinity (mg/L)	Hardness (mg/L)
A1	21	0.74	410	15	395	400	395.4
A2	20	0.28	196	16	180	316	40.3
A3	20	0.69	467	17	450	178	209.8
A4	21	1.0	543	08	535	110	141.2
A5	20	0.52	372	32	340	160	147.9
A6	19	0.36	321	21	300	336	398.1
A7	21	1.03	548	02	550	330	360.4
A8	22	0.84	392	12	380	92	425

A9	22	0.58	268	08	260	160	242.1
A10	20	0.71	478	18	460	198	269
B1	22	0.78	362	10	352	100	60
B2	23	0.34	141	8	133	115	55
B3	22	0.98	446	4	442	113	203
B4	21	0.68	368	6	362	105	192.2
B5	20	0.23	153	3	150	125	110
B6	23	0.34	134	1	133	142	280
B7	23	0.94	377	9	368	90	300
B8	23	0.86	346	9	337	91	340
B9	23	0.82	331	10	321	180	70
B10	22	0.77	356	8	348	175	165

Table 3: Water test values in and around tea gardens

Sample No	pH	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Chloride (mg/L)	Sulphate (mg/L)	Nitrate (mg/L)
A1	6.6	73.5	24.5	0.2	2.4	1.16	2.5
A2	8.0	7.5	2.5	0.4	6.3	1.71	2.4
A3	7.4	39	13	0.4	18.8	3.32	2.4
A4	6.8	26.3	8.8	1.8	28.1	8.42	4.5
A5	7.6	27.5	9.2	0.1	13.1	0.01	1.4
A6	7.9	74	24.7	1.2	16.4	9.63	4.6
A7	6.8	67	22.3	0.1	12.5	1.18	2.5
A8	6.5	79	26.3	5.2	27.4	17.86	4.8
A9	7.9	45	15	0.2	19.3	1.21	1.1
A10	8.2	50	16.7	4.1	22.1	7.83	4.9
B1	7.2	5	3.2	2	11.4	2.02	0.3
B2	6.9	4.3	2.3	1.4	7.1	1.81	1.2
B3	7.4	24.8	11.6	0.7	63.6	4.12	0.5
B4	7.3	19.8	9.4	0.5	68.1	2.10	0.4
B5	7.3	24.4	12.6	0.8	22.6	10.22	4.8
B6	7.2	31	11	0.7	22.7	1.14	1.8
B7	6.7	6.6	2.1	2.1	23.8	6.43	2.6
B8	7.0	6.8	2.6	4.2	12.1	16.08	4.9
B9	6.7	3.6	1	0.2	20.1	0.86	0.2
B10	6.9	4.1	1.5	3.6	21.3	10.01	4.7

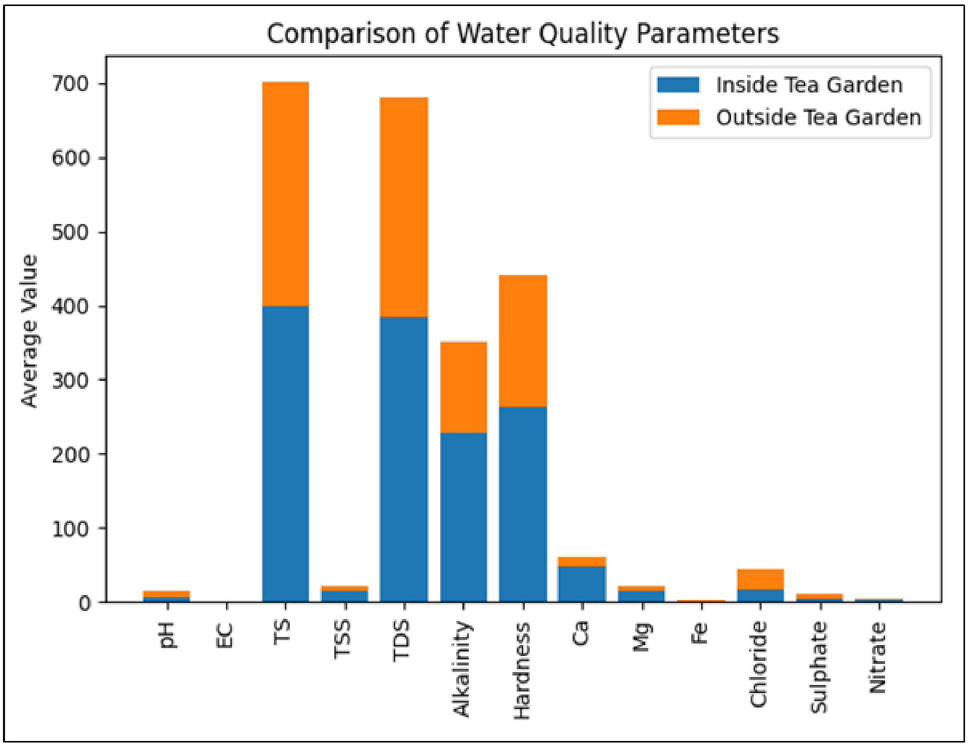

Figure 2: Distribution and Comparison of average physicochemical parameters of groundwater inside and outside tea gardens of some designated tea gardens

5. Discussion

Water is continually cycling. The water that we use has been used before. Producers and consumers, rural and urban people and the public and private sectors, are all responsible for using water wisely and ensuring that the resource be maintained for others. Human activities should not change water temperatures beyond natural seasonal fluctuations. To do so could disrupt aquatic ecosystems. Good temperatures are dependent on the type of stream. In general water temperatures should be between 20 °C to 32 °C. Temperature varies at different sampling stations in the study area. The variation is mainly due to the locations of the sampling stations and their exposure to sun. It ranges between 19^0C to 23^0C.

Colour is monitored through visual observation only. Colour of water may be indicative of large quantities of organic chemicals and inadequate treatment. While colour itself is not usually objectionable from the standpoint of health, its presence is aesthetically objectionable and suggests that the water samples in the present study may need additional treatment since seven samples have colours that are not suitable for drinking. It may be due to oxidation of dissolved iron particles in water that changes the iron to white, then yellow and finally to red-brown solid particles that settle out of the water. Iron that does not form particles large enough to settle out and that remains suspended (colloidal iron) leaves the water with a red tint. Seven samples of the present study have objectionable odour. It has been found that seven samples of the present research have unpleasant taste.

Total dissolved solids, consequently, (W.H.O limit: 500 mg/L) may have an influence on the acceptability of the water in general. In addition, high TDS value may be an indication of the presence of excessive concentration of some specific substance, not included in the Safe Drinking Water Act, which would make the water aesthetically objectionable to the consumer. Although there are no direct health concerns, the high concentration may be objectionable through taste. The variations are observed in TDS, TS and TSS among the sampling stations which need improvement of filtration techniques since most of the suspended solids can be removed by filtration. It is important to keep in mind that water with a very lower TDS concentration may be corrosive and corrosive waters may leak toxic metals. TSS constitutes particles of different sizes ranging from coarse to fine colloidal particles and impart turbidity of water. TSS of water samples from tea gardens ranged from 2 to 32 mg/L with an average of 14.9 mg/L: where as for outside tea gardens, it ranged from 0 to 10 mg/L with an average of 6.8 mg/L, indicating water samples inside tea gardens is more turbid. TSS concentrations in our study area exceed the maximum admissible limit (5 mg/L) of United States Public Health (USPH) Standard (De, A.K., 2000). The variation in TDS, TS and TSS are mainly due to ionic composition of water and the factors like rainfall and biota cause changes in their concentrations. The EC of water in the study area have values greater than the maximum permissible limit (300 µmho cm^{-1}) of USPH except for two samples (De, A.K. 200).

pH is a numerical expression that indicates the degree to which a water is acidic or alkaline and is an operational parameter. Corrosion effects may become significant at a pH below 6.5 and scaling may become a problem at a pH above 8.5. For this reason, an acceptable range for drinking water pH is from 6.5 to 8.5 (WHO, 2009). In all the sampling stations studied pH are within the W.H.O guide lines values for safe drinking water. In the study area the variation of pH is narrow and in general the pH is towards the alkaline side.

Total alkalinity of a water body refers to its ability to neutralise a strong acid, i.e. its buffering capacity. Alkalinity around 150 mg/L has been found to be conducive to higher productivity of water bodies (Ball, 1994). The aesthetic objective is set at a maximum of 500 mg/L. In the present study total alkalinity ranges from 90 mg/L to 400 mg/L.

The water hardness of the study area ranges from 40.3 mg/L to 425 mg/L. It is observed that the water is moderately hard for maximum part of the study and eight samples have crossed the maximum limit prescribed by W.H.O for potability purposes.

In the present study the calcium concentration does not exceed the ISI limit of 75 mg/L (Trivedy, 1990). Calcium concentration is 30.96 mg/L and magnesium is found to be 11.02 mg/L, which is also within the ISI limit of 30 mg/L.

Iron (W.H.O limit: 0.3 mg/L) at 1.0 mg/L can cause the bitter astringent taste of water. Also at this concentration iron will cause reddish-brown staining of laundry, porcelain, dishes, utensils and even glassware. Iron deposits build up in pipelines, pressure tanks, water heaters and water softeners. A problem that frequently results from iron in water is iron bacteria. These nonpathogenic (not health threatening) bacteria occur in soil, shallow aquifers and some surface waters. The bacteria feed on iron in water. These bacteria form red-brown (iron) slime in toilet tanks and can clog water systems. Since the pH of the investigated water samples are slightly towards the alkaline side, the solubility of iron, therefore, decreases which may be due to the formation of sulphide mineral or low solubility hydroxide and oxide minerals. The iron concentration is highest at source A8 that is 5.2 mg/L and minimum at source at A7 that is 0.1 mg/L. The higher concentration of iron in tube well waters with respect to supply waters may be due to soil origin and age-old iron pipes used. The data exceeds the WHO guide line value of 0.3 mg/L in most cases.

Nitrate (NO_3^-) (WHO Limit: 50 mg/L) is the most stable oxidized form of combined nitrogen in most environmental media. In excessive amounts it poses a health risk. The toxicity of nitrate in humans is due to the body's reduction of nitrate to nitrite. Although the nitrate contents of investigated samples is within the tolerance limit prescribed for potability, the gastric problems associated with the tea garden labourers may be due to the slow exposure of nitrate through waters over a long period of time.

Chloride content (WHO limit: 250 mg/L) above the permissible limit changes the taste of water which may become objectionable to the consumer. The salty taste imparted by chloride is variable and dependent on the chemical composition of the water. The slight salty taste of eight water samples may be due to the presence of chloride in small concentration; however, it is not harmful in moderate quantity. No fixed trend of variation of chloride among the sampling stations could be ascertained which may be due to precipitation, evaporation, human activity and waste disposal.

Sulphate occurs naturally in water and may be present in natural waters in concentrations ranging from a few to several thousand mg/L. Higher concentration of sulphate (W.H.O limit: 250 mg/L) in drinking waters can cause scale formation, taste effects and laxative effects with excessive intake. The sulphate concentrations of water under study are within the approved WHO guide line values for safe drinking water.

The experimental values of physicochemical parameters were compared with the World Health Organization, USPHS, European Standard and ISI water quality standards and are presented in Table 4 and 5.

Table 4: Analytical data of water inside tea garden with rating chart

Sl. No.	Parameters (Inside tea gardens)	Statistical Values			Maximum Permissible Limit (Hooda et.al.,2005)			
		Average	Maximum	Minimum	W.H.O	I. S. I	USPHS	European Standard
1	pH (Units)	7.37	8.2	6.5	6.5-8.5	6.5-8.5	6.0-8.5	5.0-9.0
2	Electrical conductance (mmhos/cm)	0.67	1.03	0.28	-	-	0.3	0.4
3	TS (mg/L)	399.5	548	196	-	-	-	-
4	TSS (mg/L)	14.9	32	2	-	-	5.0	-
5	TDS (mg/L)	385	550	180	1000	500	500	500
6	Alkalinity (mg/L)	228	400	92	-	-	-	-
7	Hardness (mg/L)	262.92	425	40.3	250	-	-	-
8	Ca (mg/L)	48.88	79	7.5	100	75	100	100
9	Mg (mg/L)	16.3	26.3	2.5	150	30	30	-
10	Fe (mg/L)	1.37	5.2	0.1	0.3	0.3	0.3	-
11	Chloride (mg/L)	16.64	28.1	2.4	250	250	250	25
12	Sulphate (mg/L)	5.23	17.86	0.01	400	150	250	-
13	Nitrate (mg/L)	3.11	4.9	1.1	50	-	10	-

Table 5: Analytical data of water outside tea garden with rating chart

S. No.	Parameters (Inside tea gardens)	Statistical Values			Maximum Permissible Limit (Hooda *et.al.,*2005)			
		Average	Maximum	Minimum	W.H.O	I. S. I	USPHS	European Standard
1	pH (Units)	7.06	7.4	6.7	6.5-8.5	6.5-8.5	6.0-8.5	5.0-9.0
2	Electrical conductance (µmho/cm)	0.67	0.98	0.23	-	-	0.3	0.4
3	TS (mg/L)	301.4	446	134	-	-	-	-
4	TSS (mg/L)	6.8	10	1	-	-	5.0	-
5	TDS (mg/L)	296.4	442	133	1000	500	500	500
6	Alkalinity (mg/L)	123.6	180	90	-	-	-	-
7	Hardness (mg/L)	177.52	340	55	250	-	-	-
8	Ca (mg/L)	13.04	31	3.6	100	75	100	100
9	Mg (mg/L)	5.73	12.6	1	150	30	30	-
10	Fe (mg/L)	1.62	4.2	0.2	0.3	0.3	0.3	-
11	Chloride (mg/L)	27.28	68.1	7.1	250	250	250	25
12	Sulphate (mg/L)	5.48	16.08	0.86	400	150	250	-
13	Nitrate (mg/L)	2.14	4.9	0.2	50	-	10	-

6. Conclusion

Safe water is a precondition for health and development and a basic human right, yet it is still denied to hundreds of millions of people throughout the developing world. Ground water quality and its impact on human health in and around the tea gardens of Lakhimpur district, Assam, India were assessed. Tea plantations can impact groundwater quality through the use of agrochemicals (fertilizers, pesticides) and potential leaching of these substances into the groundwater. The observed variations in quality of water samples inside tea gardens than from samples taken from outside may be due to the high permeability of tea garden soils combined with the relatively short distance to the water table make these areas particularly sensitive to contamination. Excessive rainfall or over-irrigation can cause downward movement of water through the soil profile. Chemicals which do not bind strongly to soil particles can be carried with the downward moving water and eventually can be leached to the groundwater. Activities near a well, particularly mixing or storing chemicals can potentially contaminate the water supply. The found values of physicochemical parameters were compared with the World Health Organisation and ISI water quality standards. Based on the analysis, it was found that people use water for drinking mostly from tubewells, rainwells and ponds and need purification for drinking purpose. As a result scarcity as well as chemical contamination of water affects a large number of people. Moreover, outbreak of waterborne diseases such as dysentery, malaria, skin diseases etc. are very common among the people of our study area. The problem accentuated much by the absence of proper medical facilities to fight the menace of unsafe and contaminated water. Keeping in view of the above discussion it is advisable to test the potability of groundwater of the area before using. The present study, however, fulfilled the limited purpose of strengthening database which may help in formulating strategy for future protection of environment in the study area. It is hoped that this study will encourage further work on monitoring with respect to other parameters.

Conflict of interest: There is no conflict of interest

References

[1] Adhena Ayaliew Werhneh, Belay Zimbelachew Medhanit, Angaw Kelemework Abay, Jemal Yimer Damte., 2015, Physico-Chemical Analysis of Drinking Water Quality at Jigjiga City, Ethiopia. American Journal of Environmental Protection,4(1), pp.29-32.

[2] A.P.H.A., 1998, Standard Methods for the Examination of Water and Wastewater, New York, 20th Edition (APHA, AWWA and WEF).

[3] Ball, R. C., 1994, Fertilization of lake, Good or Bad, Michigen, Conserv. p. 7-14.

[4] Bhattacharya, K. G., 2007, Contamination of Groundwater by Arsenic, Distribution, Health Effects and Treatment. in Silver Lining, pp. 32-53.

[5] Bhuyan, B., 2010, "A Study on Arsenic and Iron Contamination of Groundwater in Three Development Blocks of Lakhimpur District, Assam, India", Report and Opinion, Marsland Press, USA, 2(6), 2010, 82-87

[6] Bhuyan, B., Kakati, S., and Sarma, H. P., 2006, Chemical Quality of Water and Health Effects of Drinking water Contaminants in and around the Tea Gardens of Lakhimpur District, Assam', Pollution Research, 25(3): p. 571-575.

[7] Bhuyan, B. Barah, K and Misra A.K., 2016. "Seasonal Distribution of Arsenic and Iron In Ground Water of Lower Subansiri District, Arunachal Pradesh" International Journal of Pharmaceutical and Chemical Sciences, 5 (2). 132-136

[8] Borah, K. K., Bhuyan, B., & Sarma, H. P. (2010). Lead, arsenic, fluoride, and iron contamination of drinking water in the tea garden belt of Darrang district, Assam, India. Environmental monitoring and assessment, 169(1), 347-352.

[9] Bhuyan, J., Choudhury, S., & Choudhury, D. (2025). Assessing Heavy Metal Contents in Groundwater of South Kamrup Region (Assam), India and Its Impact on Human Health and Environment Using GIS. In *Groundwater Resource Management Planning Strategies: A Geospatial Approach: Volume 1* (pp. 405-419). Cham: Springer Nature Switzerland.

[10] Bhuyan, R., Brahma, P., Chabukdhara, M., Tyagi, N., Gupta, S. K., & Malik, T. (2023). Heavy metals contamination in sediments of Bharalu river, Guwahati, Assam, India: A tributary of river Brahmaputra. Plos one, 18(4), e0283665.

[11] Buragohain, M, Bhuyan, B., and Sarma, H. P., 2010, "Seasonal variations of lead, arsenic, cadmium and aluminium contamination of groundwater in Dhemaji district, Assam, India", Environmental Monitoring and Assessment, Springer, 170 (1-4), 2010, 345-351. DOI 10.1007/s10661-009-1237-6

[12] CGWB, 2010, Ministry of Water Resources, Govt. of India, Faridabad, 2010, Ground Water quality in shallow aquifers of India

[13] CGWB (2007). Ground water information booklet Dhemaji district, Assam, CGWB. North Eastern region, ministry of water resources, Govt. of India. Guwahati: Central Ground Water Board.

[14] De, A.K(2000). Environmental Chemistry 4th Edition, New Age International (P) limited publishers, New Delhi., P.239-240

[15] Dutta, S., Barman, R., Radhapyari, K., Datta, S., Lale, K., Ray, B., & Srivastava, S. K. (2022). Potentially toxic elements in groundwater of the upper Brahmaputra floodplains of Assam, India: water quality and health risk. Environmental Monitoring and Assessment, 194 (12), 923.

[16] Hazarika, S, Bhuyan, B., 2013, Assessment of groundwater quality with reference to fluoride, arsenic and iron in tea garden belt of Lakhimpur district, Assam, India, Advances in Applied Science Research, 2013, 4(2), 93-97

[17] Hooda, S and Kaur, S., 2005, Laboratory Manual for Environmental Chemistry, S. Chand Company, New Delhi, pp 94-95.

[18] Kumar, M., Das, A., Das, N., Goswami, R., & Singh, U. K. (2016). Co-occurrence perspective of arsenic and fluoride in the groundwater of Diphu, Assam, Northeastern India. Chemosphere, 150, 227-238.

[19] Lahkar, M., & Bhattacharyya, K. G. (2019). Heavy metal contamination of groundwater in Guwahati city, Assam, India. Int. Res. J. Eng. Technol, 6(6), 1520-1525

[20] Mayback, M., Chapman, D. V & Helmer, R (Eds.), Global Environment Monitoring System, Global Fresh Water Quality, Basil Blackwell Ltd., Oxford (1989), 107-163.

[21] Ray, B., Abedin, M. A., & Shaw, R. (2020). Safe drinking water solutions in parts of West Bengal, India: combating health issues through participatory water management. In Public health and disasters: health emergency and disaster risk management in Asia (185-200). Singapore: Springer Singapore.

[22] Nath, B. K., Chaliha, C., Bhuyan, B., Kalita, E., Baruah, D. C., & Bhagabati, A. K. (2018). GIS mapping-based impact assessment of groundwater contamination by arsenic and other heavy metal contaminants in the Brahmaputra River valley: a water quality assessment study. *Journal of Cleaner Production*, *201*, 1001-1011.

[23] Oko O.J., Aremu M.O., Andrew C. (2017). "Evaluation of the physicochemical and heavy metal content of ground water sources in Batgi and Rafin-Kada settlements of Wukari L.G.A., Taraba State, Nigeria". Journal of Environmental Chemistry and Ecotoxicology, 9(4). pp. 43 - 53.

[24] Train R E, 1979, 'Quality criteria for water USEPA', Washington DC.

[25] Trivedy R K., 1990, 'Quality Criteria of Drinking water Prescribed by Indian Standard Institute (ISI)', In: Environmental Directory of India, Enviro Media, Karad, (India), pp. 279- 281.

[26] USPH Standard, 1980, The official journal of the European Committees, L229, P. 16-21.

[27] WHO, 2009, World Health Organization guidelines for drinking water quality 3rd edition. WHO Geneva 140-144