NMHS-Himalayan Institutional Fellowship Grant

FINAL TECHNICAL REPORT (FTR)

NMHS Reference No.:	HSF 2017-18/I-23/11	Date of Submission:	1	2	1	2	2	0	2	2
			d	d	m	m	y	y	y	y

INVESTIGATION OF THE POSSIBLE HEALTH HAZARDS ASSOCIATED WITH DRINKING WATER IN SOUTH-WEST NAGALAND AND DEVELOPMENT OF EFFECTIVE WAYS FOR WATER RESOURCE MANAGEMENT

Sanctioned Fellowship Duration: *from* (**08.06.2018**) *to* (**31.03.2021**).

Extended Fellowship Duration: *from* (**01.04.2021**) *to* (**31.12.2021**).

***Submitted to*:**

Er. Kireet Kumar
Scientist 'G' and Nodal Officer, NMHS-PMU
National Mission on Himalayan Studies, GBP NIHE HQs
Ministry of Environment, Forest & Climate Change (MoEF&CC), New Delhi
E-mail: nmhspmu2016@gmail.com; kireet@gbpihed.nic.in; kodali.rk@gov.in

***Submitted by*:**

Dr, Amrit Puzari
National Institute of Technology Nagaland, Chumukedimar-Nagaland
Contact No.: +91-9435316819
E-mail: amrit09us@yahoo.com

GENERAL INSTRUCTIONS:

1. The Final Technical Report (FTR) has to be commenced from the date of start of the Institutional Fellowship (as per the Sanction Order issued at the start of the Fellowship) till its completion. Each detail has to comply with the NMHS Sanction Order.
2. The FTR should be neatly typed (in Arial with font size 11 with 1.5 spacing between the lines) with all details as per the enclosed format for direct reproduction by photo-offset process. Colored Photographs (4-5 good action photographs), tables and graphs should be accommodated within the report or should be annexed with captions. Sketches and diagrammatic illustrations may also be given giving step-by-step details about the methodology followed in technology development/modulation, transfer and training. Any correction or rewriting should be avoided. Please give information under each head in serial order.
3. Training/ Capacity Building Manuals (with detailed contents of training programme, technical details and techniques involved) or any such display material related to fellowship activities along with slides, charts, photographs should be sent at the NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora 263643, Uttarakhand. In all Knowledge Products, the Grant/ Fund support of the NMHS should be duly acknowledged.
4. The FTR Format is in sync with many other essential requirements and norms desired by the Govt. of India time-to-time, so each section of the NMHS-FTR needs to duly filled by the Fellowship Coordinator/ PI and verified by the Head of the Implementing Institution/ University.
5. Five (5) bound hard copies of the NMHS-Institutional Fellowship Final Technical Report (FTR) and a soft copy should be submitted to the **Nodal Officer, NMHS-PMU, GBP NIHE HQs, Kosi-Katarmal, Almora, Uttarakhand** *via* e-mail nmhspmu2016@gmail.com.

The FTR is to be submitted into following two parts:

Part A – Cumulative Fellowship Summary Report

Part B – Comprehensive Report

Following Financial and other necessary documents/certificates need to be submitted duly signed and verified along with Final Technical Report (FTR):

Annexure I	Consolidated and Audited Utilization Certificate (UC) & Statement of Expenditure (SE), including interest earned for the last Fiscal year including the duly filled GFR-19A (with year-wise break-up)
Annexure II	Consolidated Interest Earned Certificate
Annexure III	Consolidated Manpower Certificate and Direct Benefit Transfer (DBT) Details showing the education background, i.e. NET/GATE etc. qualified or not, Date of joining and leaving, Salary paid per month and per annum (with break up as per the Sanction Order and year-wise).
Annexure IV	Details and Declaration of Refund of Any Unspent Balance as Real-Time Gross System (RTGS) in favor of NMHS GIA General
Annexure V	Details of Technology Transfer and Intellectual Property Rights developed.

NMHS-Final Technical Report (FTR)

NMHS- Institutional Himalayan Fellowship Grant

DSL: *Date of Sanction Letter*

0	8	0	6	**2**	**0**	**1**	**8**
d	d	m	m	y	y	y	y

DFC: *Date of Fellowship Completion*

3	1	1	2	**2**	**0**	**2**	**1**
d	d	m	m	y	y	y	y

Part A: CUMULATIVE SUMMARY REPORT

(to be submitted by the Coordinating Institute/Coordinator)

1. Details Associateship/Fellowships

1.1 Contact Details of Institution/University

NMHS Fellowship Grant ID/ Ref. No.:	**HSF 2017-18/I-23/11**
Name of the Institution/ University:	**National Institute of Technology Nagaland**
Name of the Coordinating PI:	**Dr. Amrit Puzari**
Point of Contacts (Contact Details, Ph. No., E-mail):	amrit09us@yahoo.com (Ph. No. +91-9435316819)

1.2 Research Title and Area Details

i.	Institutional Fellowship Title:	Investigation of the possible health hazards associated with drinking water in South-West Nagaland and development of effective ways for water resource management					
ii.	IHR State(s) in which Fellowship was implemented:	Nagaland (South-west)					
iv.	Scale of Fellowship Operation	Local:	Yes	Regional:		Pan-Himalayan:	
iii.	Study Sites covered (*site/location maps to be attached*)	Dimapur District (map attached)					
v.	Total Budget Outlay (lakh) :	INR 16,06,968.00					

1.3 Details Himalayan Research /Project Associates/Fellows inducted

Type of Fellowship	Nos.	Work Duration	
		From	To
Research Associates	NA	NA	NA
Sr. Research Fellow	NA	NA	NA
Jr. Research Fellows	1	08.06.2018	31.12.2021
Project Fellows	NA	NA	NA

2. Research Outcomes

2.1. Abstract

Accessibility of safe drinking water is an important public health concern and therefore scientific community around the globe are continuously working on curving out more economic ways for providing safe drinking water and better sanitation to the common masses. It is universally accepted, and sustainable development goals have also been set for the same that everyone should have the privilege to adequate, continuous, safe, acceptable, physically accessible, and affordable water for drinking and personal use and preservation of the natural resources. DIMAPUR is one of the important districts of Nagaland due to its geographical position, growing population and economic development. With rapid modernization and change in lifestyle patterns, the number of infrastructural developments taking place in the city has led to many environmental problems concerning water pollution, increase waste mismanagement, urban deforestation etc. The majority of the population in Dimapur rely on groundwater and depend entirely on its availability and quality. Drinking water in the Dimapur district is regulated under the Public Health Engineering Department, which establishes a safe and potable drinking water supply, proper disposal of solid and liquid waste and environmental hygiene. Groundwater as part of the hydrological cycle is inadequately discussed in the district's water resource planning, although groundwater exploitation is rising at an unprecedented pace. The present groundwater development in the district is seen only in Dimapur valley. Hilly terrain where groundwater development has a limited scope occupies the rest area of the district. The discharge of untreated waste from domestic and commercial sources into water bodies is a major source of water contamination in Dimapur. Other contributing factors are poor sanitation and lack of awareness. Furthermore, the district doesn't have proper sewage treatment plants. In this context, it is mandatory to monitor physicochemical-bacteriological contaminants to assess water quality. To

execute this work, samples from several points of the district were collected and analysed the association between water quality and health implications. Ten Physico-chemical parameters such as Temperature, pH, Dissolved Oxygen, Conductivity, Total Dissolved Solids, Hardness, Iron, Nitrate, Phosphates and Sulphates and bacteriological experiments were performed under BIS and WHO guidelines. The results of this study provide an analytical foundation to better understand water quality conditions in Dimapur areas stretching from 1st mile to 7th mile and also make observed data publicly available and interoperable. The pH suggests corrosive nature, which could interfere with the overall nature of water. The chemical parameter of the main concern is the high content of iron. Therefore, the origin of iron needs to be investigated by considering the hydro-geological characteristics of the sampling sites. Understanding water conditions in the Dimapur district will yield strategies for future urban water management in other districts of Nagaland and beyond. Thus, scientific data and research have an essential role in the development and enactment of SDGs through evaluations from local to global scales.

2.2. Objective-wise Major Achievements

Sl. No.	Project Objectives	Major achievements (in bullets points)
1.	Quality assessment of drinking water in South-West Nagaland	▪ Sixty-four water samples were collected from the residential areas of different point sources from Dimapur district. ▪ The study areas covered in Dimapur District are listed below: Chumukedima, Tenyiphe, Sovima, Chekiye, Burma Camp, Rilan Village, Indisen Village, Samaguri, Walford, Purana Bazar, Half Nagarjan, Kuda Village, 2½ Mile, Chathe River, Lengrijan, Darogajan, Padam Pukhuri.
2.	Physico-chemical and bacteriological analysis of drinking water samples	▪ Water quality parameters based on various physicochemical properties such as Temperature, pH, Electrical Conductivity, Total Dissolved Solids, Dissolved Oxygen, Iron, Sulphate, Phosphate, Total Hardness, and Nitrate were carried out. ▪ Bacteriological Analysis was carried out for all the samples using the Bacteriological Field Test Kit using a standard protocol.

		NB: Aluminium, Chromium, Silver, Zinc, Fluoride and Nitrite are not included in the study since their concentrations were always below the detection limit of the analytical instruments.
3.	Identification of possible health hazards associated with drinking water	▪ Common health implications related to water contamination in the region are dysentery, diarrheal diseases, parasitic infestation, anaemia and most commonly gastrointestinal infection.
4.	To find out possible viable remedial measures for purification of contaminated water	▪ Simple and conventional filtration method can still be put to use to fix and restore the water quality. ▪ From our study, we tested the sample with the highest iron content and when filtered, the raw water sample shows no iron residue, suggesting that the concentration of iron can be removed by a simple filtration method.
5	Raise Awareness on the need for sustainable use of water resources employing the motto "Encourage Reuse, Discourage Overuse"	▪ An Awareness Program on "Water Quality in Nagaland and its related health issues" was conducted and the key points that was covered during the session are listed below: I. Current update on the availability of water resources in Nagaland II. Impacts on health associated with drinking water III. Role of an individual (or a community) to reduce water contamination IV. Measures adopted (known) to remediate the water related issues V. Need for the updated water quality information ▪ A total of 194 participants attended the program and it was the first-time experience for most of them. This program could deliver and share the awareness on the issues and concerns related to water in the district.

2.3. Outputs in terms of Quantifiable Deliverables*

S. No.	Quantifiable Deliverables*	Monitoring Indicators*	Quantified Output/ Outcome achieved	Deviations made, if any, and Reason thereof:
1	Drinking water quality data from different monitoring sites have been collected and analysed/documented for the reporting period.	• Physico-chemical and bacteriological analysis. • Statistical analysis	Seventeen 1-Chumukedima 2-Tenyiphe 3-Sovima 4-Chekiye 5-Burma Camp 6-Rilan Village 7-Indisen Village 8-Samaguri 9-Walford 10-Purana Bazar 11-Half Nagarjan 12-Kuda Village 13-2½ Mile 14-Chathe River 15-Lengrijan 16-Darogajan 17-Padam Pukhuri	No
2	Suggested remedial measures for purification of contaminated water	From the study, we tested the sample with the highest iron content and when filtered, the raw water sample shows no iron residue,	Simple and conventional filtration method can still be put to use to fix and restore the water quality. For the bacterial contamination, the	No

		suggesting that the concentration of iron can be removed by a simple filtration method.	treatment method include chlorination, UV disinfection, and ozone treatment. Additionally, regular monitoring, adherence to recommended dosages, and maintenance of disinfection residuals are crucial aspects to ensure sustained water safety.	

(*) As stated in the Sanction Letter issued by the NMHS-PMU.

2.4. Strategic Steps with respect to Outcomes (in bullets)

S. No.	Particulars	Number/ Brief Details	Remarks/ Enclosures
1.	New Methodology developed:	-	-
2.	New Models/ Process/ Strategy developed:	-	-
3.	New Species identified:	-	-
4.	New Database established:	Water quality-database from the year 2018-2020 has been established for the district.	-
5.	New Patent, if any:	Nil	-
	I. Filed (Indian/ International)		
	II. Granted (Indian/ International)		
	III. Technology Transfer (if any)		
6.	Others, if any:	-	-

3. Technological Intervention

S. No.	Type of Intervention	Brief Narration on the interventions	Unit Details (No. of villagers benefited / Area Developed)
1.	Development and deployment of indigenous technology	-	-
2.	Diffusion of High-end Technology in the region	-	-
3.	Induction of New Technology in the region	-	-
4.	Publication of Technological / Process Manuals	02	Awareness program conducted.
	Others (if any)	-	-

4. New Data Generated over the Baseline Data

S. No.	New Data Details	Existing Baseline	Additionality and Utilisation of New data (*attach supplementary documents*)
1.	Water quality-database during the project duration (2018 to 2021) was generated using simple statistical technique (mean ± standard deviation, minimum and maximum values).	• Sixty-four water samples from the residential areas of different point sources of Dimapur district. • Physico-chemical properties of the collected water samples which includes Temperature, pH, Dissolved Oxygen,	This database could supplement in understanding the processes and causes of variability in preserving the quality of drinking water.

		Turbidity, TDS, Salinity, Electrical conductivity, Resistivity and Total hardness. • Cationic compositions of Aluminium, Chromium, Iron, Manganese, Silver and Zinc. • Anionic compositions of Fluoride, Nitrate, Nitrite, Phosphate and Sulfate. • Bacteriological analysis of all the samples.	
2.	Hydro-chemical analysis of the selected ring/bore wells collected and analysed.	Analysis of major cations and anions were generated, namely; cations i.e. Na^+, Ca^{2+}, Mg^{2+}, K^+ and anions i.e. HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, F^- including pH, EC, TDS.	Annexure 2

5. Linkages with Regional & National Priorities (SDGs, INDC, etc.)/ Collaborations

S. No.	Linkages /collaborations	Details	No. of Publications/ Events Held	Beneficiaries
1.	Sustainable Development Goals (SDGs)	-	-	-

2.	Climate Change/INDC targets	-	-	-
3.	International Commitments	-	-	-
4.	National Policies	-	-	-
5.	Others collaborations	-	-	-

6. Financial Summary (Cumulative)*

Refer **Annexure-I**

7. Quantification of Overall Research Progress

S. No.	Parameters	Total (Numeric)	Attachments* with remarks
1.	IHR State(s) Covered:	*01*	
2.	Fellowship Site/ LTEM Plots developed:	*N/A*	
3.	New Methods/ Model Developed:	*N/A*	
4.	New Database generated:	*01*	
5.	Types of Database generated:	*N/A*	
6.	No. of Species Collected:	*N/A*	
7.	New Species identified:	*N/A*	
8.	Scientific Manpower Developed (PhDs awarded/ JRFs/ SRFs/ RAs):	*01 (SRF)*	
9.	No. of SC Himalayan Researchers benefited:	*N/A*	
10.	No. of ST Himalayan Researchers benefited:	*01*	
11.	No. of Women Himalayan Researchers empowered:	*01*	
12.	No. of Knowledge Products developed:	*N/A*	
13.	No. of Workshops participated:	*01*	
14.	No. of Trainings participated:	*01*	
15.	Technical/ Training Manuals prepared:	*N/A*	
	Others (if any):	---	

***** Please attach the soft copies of supporting documents word files and data files in excel.

8. Knowledge Products and Publications*

S. No.	Publication/ Knowledge Products	*Number*		*Total Impact Factor*	*Remarks/* Enclosures **
		Nationa l	International		
1.	Journal Research Articles/ Special Issue (Peer-reviewed/ Google Scholar)	--	1. International Journal of Energy and Water Resources (Published) 2. Environmental Nanotechnology, Monitoring & Management (Published)	1. – 2. –	Appendix - 2 For full details of article/ chapter/ technical report and conference
2.	Book Chapter(s)/ Books:	--	--		
3.	Technical Reports/ Popular Articles	--	--		
4.	Training Manual (Skill Development/ Capacity Building)	--	--		
5.	Papers presented in Conferences/ Seminars	--	ICAMEES	–	
6.	Policy Drafts (if any)	--	--		
7.	Others (specify)	--	--		

*Please append the list of KPs/ publications (with impact factor and URL link details) with due Acknowledgement to NMHS.

**Please provide supporting copies of the published documents.

9. Recommendation on Utility of Research Findings, Replicability and Exit Strategy

9.1 Utility of the Fellowship Findings

S. No.	*Research Questions Addressed*	*Succinct Answers (within 150–200 words)*
1	What are the key issues related to water in Nagaland today?	The greater part of Nagaland experiences the ill-effects of water shortage. Both surface and ground water supply have been stretched to the limit. Due to population growth and economic development, groundwater resources have been over-exploited; raising a second concern about water pollution. The over exploitation of ground water has brought about major decline in water tables and in the pollution of aquifers.
2	Whether people of the region are availing safe drinking water?	In general, water used by the people of the region under investigation are not availing safe drinking water. In most of the cases, iron content is significantly high and in other cases, even presence of pathogens has also been observed in the water samples.
3	Whether people are using appropriate scientific methods for purification of water?	Most of the people are not using efficient scientific methods for purification of water. Some people are using traditional ways for purification.
4	Whether sufficient drinking water is available in the region?	Since the region is having limited source of the drinking water, therefore available drinking water in the region are not sufficient for all the people. Specifically, during rainy season, some face acute drinking water crises.
5	Whether people are well aware about the need of safe drinking water?	Public awareness regarding the use of safe drinking water is not up to the mark and much efforts has to be devoted to create awareness among the people. There is also a need for strategic shift from water development to water management which includes encouraging reuse and safeguard the water supply from overuse.

6	Data on water quality in this region is inadequate. And identifying the root cause of any water problem is the first step in fixing it, which requires a huge dataset.	Significant amount of data (both primary and secondary data) has been generated through this project.

9.2 Recommendations on Replicability and Exit Strategy:

Particulars	Recommendations
Replicability of Fellowship, if any	The groundwater of Dimapur is highly ferruginous, especially in the localities of 1st Mile namely Walford, and in 2nd Mile localities of Darogajan, Purana Bazaar and Half-Nagarjan. The highest concentrations of iron were found in the boreholes and relatively lower values were observed in the ring wells followed by surface waters. Therefore, systematic analysis of all the bore wells in the region could give ideas whether the intervention is required or not. The water quality in the area should not be taken for granted, as this project research has demonstrated. Therefore, similar projects should be implemented in order to create an up to date database as increasing the water quality database and/or datasets will undoubtedly enable the locals to be more informed and cautious.
Exit Strategy:	The results of the physico-chemical analysis were shared with each family individually. This is done to raise people's awareness and caution regarding the quality of their water in the area. Additionally, the results obtained from the project has been made publicly available and interoperable. In order to achieve sustainable water resource development not only in Dimapur District but also in neighbouring districts of Nagaland, more study into water quality will support the establishment of a future water management system.

06.12.2023

(NMHS FELLOWSHIP COORDINATOR)

(Signed and Stamped)

Principal Investigator
National Mission on Himalayan Studies
National Institute of Technology Nagaland
Chumukedima - 797103 : Nagaland

06/12/2023

(HEAD OF THE INSTITUTION)

(Signed and Stamped)

Place: DIMAPUR
Date: 06./.12./.2023

Prof. S. Venugopal
Director
National Institute of Technology Nagaland
Chumukedima-797103, Nagaland

PART B: PROJECT DETAILED REPORT

1. EXECUTIVE SUMMARY

This project surveyed Dimapur District, the commercial capital of Nagaland, with a focus to identify the accessibility of safe drinking water and deduce the prevalence of harmful contaminants in water. Dimapur district is located at an elevation of 154 m above sea level in the south-western region of Nagaland. It enjoys a sub-tropical humid climate with the maximum temperature reaching up to 36°C and minimum winter temperature going down to 3.2°C with an average annual rainfall of 1504.7 mm. It has a total geographic area of 927 sq. km and a population density of 410 as per the 2011 census with four subdivisions, namely Medziphema, Dhansiripar, Niuland and Kuhuboto. Most of the region in the district is at risk of erosion hazard contributing to land degradation and ultimately affecting the quality of water. Data on land use in the year 1990, 2000 and 2010 show increased settlement area and decreased forest area with no change in rivers and tributaries. The geomorphic units identified in the study area are mostly covered by alluvial plain and structural hills. The depth to the water table in Dimapur areas are generally in the range of 1.04- 9.8 m bgl (below ground level). And the study area has a net groundwater availability of 9.66 mcm (million cubic meter) as per the report on dynamic groundwater resources of Nagaland, 2011.

Drinking water in the Dimapur district is regulated under the Public Health Engineering Department (PHED), which establishes a safe and potable drinking water supply, proper disposal of solid and liquid waste and environmental hygiene. Groundwater as part of the hydrological cycle is inadequately discussed in the district's water resource planning, although groundwater exploitation is rising at an unprecedented pace. The discharge of untreated waste from domestic and commercial sources into water bodies is a major source of water contamination in Dimapur. Other contributing factors are poor sanitation and lack of awareness. Furthermore, the district doesn't have proper sewage treatment plants. The majority of the population in Dimapur rely on groundwater and depend entirely on its availability and quality. Groundwater resources are generally described as good quality, but the major problem with the groundwater is that once contaminated, quality can hardly be restored as the geological contact and soil mineral composition influence the quality of water. The literature study also confirms that Dimapur's groundwater is highly contaminated with iron. Ground water in Nagaland is usually found to be high on the iron and fluoride contents. Press Information Bureau (PIB) have additionally referenced about the iron contamination in Nagaland zone. Analysis of water samples gathered from various water sources in Kohima uncovered elevated levels of iron, ammonia and nitrate

way above the drinking permissible limit for potable water as per the World Health Organization (WHO) guidelines. The trace elements namely iron, copper, zinc, nickel, manganese lead, cadmium, silver and arsenic have been resolved from five different districts/sub-divisions viz- Wokha, Tuensang, Zunheboto, Ungma in Mokokchung and Tseminyu in Kohima of Nagaland.

The greater part of Nagaland experiences the ill-effects of water shortage. Both surface and ground water supply have been stretched to the limit. Due to population growth and economic development, groundwater resources have been over-exploited; raising a second concern about water pollution. The over exploitation of ground water has brought about major decline in water tables and in the pollution of aquifers. In general, water used by the people of the region under investigation are not availing safe drinking water. In most of the cases, iron content is significantly high and in other cases, even presence of pathogens has also been observed in the water samples. Most of the people are using traditional ways for purification. Since the region is having limited source of the drinking water, therefore available drinking water in the region are not sufficient for all the people. Specifically, during rainy season, some face acute drinking water crises. Public awareness regarding the use of safe drinking water is not up to the mark and many efforts has to be devoted to creating awareness among the people. There is also a need for strategic shift from water development to water management which includes encouraging reuse and safeguard the water supply from overuse. In this research, a total of 64 samples were collected from sixteen different locations of Dimapur on an annual basis from the year 2018 to 2020. The sampling points were confined to rivers, bore-wells and ring-wells used for drinking and domestic purposes. The depth of the wells varies from 32–200 ft. Initially, we assessed 20 physicochemical parameters encompassing factors like Temperature, pH, Dissolved Oxygen (DO), Conductivity, Total Dissolved Solids (TDS), Salinity, Turbidity, Hardness, Aluminium, Chromium, Iron, Manganese, Silver, Zinc, Fluoride, Nitrate, Nitrite, Phosphates, and Sulphates. However, in the later phase, our focus narrowed to ten physicochemical parameters, namely, Temperature, pH, Dissolved Oxygen, Conductivity, Total Dissolved Solids, Hardness, Iron, Nitrate, Phosphates, and Sulphates alongside bacteriological experiments conducted in accordance with BIS and WHO guidelines. The exclusion of other parameters from the study was due to their consistently low concentrations falling below the detection limit of our analytical instruments and additionally, these parameters were deemed irrelevant to the study area.

The analysis of collected water samples was carried out using known standard methods. AR grade reagents, deionized water and borosil glass wares were used for the preparation of solutions. pH was estimated by digital pH meter (EuTech pH 610). TDS, Electrical conductivity and Salinity were measured using Multiparameter EuTech CD 650. Turbidity was determined using turbidity meter (EuTech TN 100). Total hardness was determined by complexometric titration using Erichrome Black-T as an indicator (EDTA method). Presence of cations such as Aluminium, Chromium, Iron, Manganese, Silver and Zinc and anions such as Fluoride, Nitrate, Nitrite, Phosphate and Sulphate were estimated using Hannah Instruments, HI-83200 Multiparameter Photometer. Bacteriological analysis was performed using the Bacteriological Field Test Kit using a standard protocol. The nature of drinking water and its contamination level was evaluated by the reference value assigned by BIS and WHO to quantify those samples that did not comply with the guidelines. Statistical correlation analysis was conducted by using IBM SPSS Statistics. The correlation between the parameters of the experimentally estimated water quality analysis was done by using the Pearson correlation matrix. Simple statistical parameters such as mean, standard deviation, minimum, and maximum were used to evaluate the data and to assess the distribution of the values for each parameter. Statistical data was used in this way to provide additional detail on the effects of the analyzed water sample. We used the computed Water Quality Index technique to evaluate the permissibility of water sources for human consumption. Nine parameters namely, pH, EC, TDS, DO, Fe, SO_4^{2-}, TH, NO_3^- and PO_4^{3-} were selected based on their importance in water quality to evaluate the permissibility of water sources for human consumption.

In pursuance of the objectives set for the study, the primary methods of data collection have been adopted. Considering-the constraints of time and mobility, it is not possible to cover all the districts of Dimapur. The district comprises of four blocks i.e., Medziphema, Dhansiripar, Nieuland, Kuhuboto and three circles i.e., Nihokhu, Chumukedima, Aghunaga and one Dimapur sadar. The present study covered two blocks, one circle and Dimapur Sadar that stretch from 1st mile to 7th mile of the district. Water quality reports are extremely inadequate in Nagaland as there is practically not many documentations on the status of water bodies. Therefore, we sought assistance from Public Health Engineering Department (PHED) that regulates drinking water in the Dimapur district for primary data. The key challenges encountered during the field survey are geographical and logistics constraints. Samples were taken from several households with the minimum distance of one kilometer between them from different localities. The project was brought to the attention of the locals, who were informed about the need to test their water and were alerted about the water-related health issues.

The descriptive statistical results of the physico-chemical study (mean ± standard deviation, minimum and maximum values) along with the number of evaluated samples (N), permitted BIS and WHO reference values for drinking water with potential risks and the analyses results are briefly discussed. The pH value of the samples in the study area varied from 5.31 to 8.41 in the year 2018; 5.32 to 7.17 in 2019 and 5.78 to 7.48 in 2020 with a mean value of 6.68, 6.30, and 6.31 respectively. The minimum and maximum pH values (5.31 and 8.41) were observed respectively in the ring well of Chekiye and the surface water of Chumukedima Village area. Given the values suggested by BIS and WHO, the majority of the sources uncovered mild acidic condition. Out of the 64 samples gathered from various point sources, 42 samples fall out of the guideline value (GV) which is up to 65.6%. It is evident from this analysis that the pH of water in the Dimapur district is lower than neutrality indicating corrosive nature and could also interfere with the overall nature of the water.

Total Dissolved Solids (TDS) corresponds to the total concentration of dissolved inorganic salts and dissolved organic compounds, usually measured in mg/L (milligrams per liter) or ppm (parts per million). The TDS values increase from 40 mg/L to 580 mg/L and lie in the range of excellent and good category except for some samples with very low concentrations. The analysis reveals wide variation in Electrical Conductivity values ranging between a minimum of 70 µS/Cm and a maximum of 1700 µS/Cm which falls in the category of non-saline to a slightly saline type of water. These results indicate that water in the study area was not considerably ionized and has a lower level of ionic concentration activity due to small, dissolved solids. The iron contamination levels in the study area varied from 0 to 2.7 in the year 2018; 0 to 5 in 2019 and 0 to 4.15 in 2020 with a mean value of 0.36, 4.08 and 1.09 respectively. The groundwater of Dimapur is highly ferruginous, especially in the localities of 1st Mile namely Walford, and in 2nd Mile localities of Darogajan, Purana Bazaar and Half-Nagarjan. 43% of the collected samples show a high iron content making them not suitable for drinking purposes. The highest concentrations of iron were measured in the boreholes and relatively lower values were observed in the ring wells followed by surface waters.

Concerning Dissolved Oxygen (DO), 46.8% of the sampled sources surpassed the WHO GV of >5 mg/L. The minimum value (0.4 mg/L) was observed in the borehole of the 2nd mile area. This signifies that the quality of water is nowhere near good. The presence of phosphorous compounds contributes significantly to the eutrophication of standing water resulting in the loss of dissolved oxygen in the water. The amount of phosphate that exceeds the allowed limit in this study is 73.4%. The mean phosphate levels in the study area were 1.94, 0.66 and 2.35 in the year 2018, 2019 and 2020 respectively suggesting very high nutrient contamination. Nitrate-based contaminations are quite common because of the excessive use of fertilizers. The overall amount of nitrate that exceeds the standard guideline is 10.7%. Manganese (Mn) in drinking water originates naturally within the bedrock, particularly in deep well water. Manganese concentrations below 0.1 mg/L are usually acceptable to consumers and above this limit, it can cause unpleasant taste and raise aesthetic concerns. Chemically, it tends to be viewed as a close relative of iron because of its occurrence in much the same form as iron. In this study, the elevated concentration of Mn and Fe showed comparable characteristics by some samples. Overall, more than 50% of the sampled water have higher Mn concentration thus rendering it unhealthy for consumption.

Based on the sources, all 64 samples were segregated into three categories: 15 out of 24 for bore wells; 22 out of 35 for ring wells and 4 out of 5 for surface waters showed the presence of bacteria rendering unfit for drinking. The results depict that surface waters have a higher degree of contamination compared to the bore wells and ring wells. As per the BIS of drinking water, 64 per cent of the samples were found to be contaminated based on the overall results of the bacteriological evaluation. The study aimed at assessing the drinking water quality in the Dimapur area and to identify the phenomenon that led to the contamination of these waters. According to the correlation report, TDS and EC are two important physicochemical parameters that determines the water quality since they are associated with the majority of water parameters. The pH suggests corrosive nature, which could interfere with the overall nature of water. The chemical parameter of the main concern is the high content of iron. Therefore, the origin of iron needs to be investigated by considering the hydro-geological characteristics of the sampling sites. A linear association between TDS and EC observed in the samples for three consecutive years indicates 'fairly fresh' nature of water. The overall characteristics of the water are shown as 'good' and 'predominantly poor' quality in the computed Water Quality Index. This analysis indicates that Dimapur District's water quality from 2018 to 2020 is not suitable for direct consumption without prior treatment. In conclusion, devising an innovative filtration unit to manage emerging contaminants is one way to address the issues of water quality but it will be more fundamental and compelling in terms of sustainable approach if one could stop the seepage of contaminants from the point source and avoid the pain of multiple trials and tests. Therefore, we suggest immediate intervention from the policymaker to develop a system-based strategy to guarantee the accessibility of contamination-free drinking water and also make water quality assessment data available to the public to raise awareness among the individuals.

2. INTRODUCTION

2.1. Background of the Project

Accessibility of safe drinking water is an important public health concern and therefore scientific community around the globe continuously working on curving out more economic ways for providing safe drinking water to the common masses and also for providing better sanitation. The grand initiatives taken up by Ministry of Environment, Forest & Climate Change, Govt. of India is a noble effort to find out sustainable management for water resources so that drinking-water can be made safe and affordable for each and every citizen of India. Nagaland suffer from geographical constraints along with the economic factor, for providing safe and affordable drinking water to urban and rural people. The project undertaken has the core objectives to study the possible health hazards associated with the drinking-water provided in South-West Nagaland and to find out sustainable management solution for those problems. DIMAPUR is one of the important districts of Nagaland due to its geographical position, growing population and economic development. With rapid modernization and change in lifestyle patterns, the number of infrastructural developments taking place in the city has led to many environmental problems concerning water pollution, increase waste mismanagement, urban deforestation etc. The rapid growth of the urban areas and the dense population of the region has impacted groundwater quality due to overexploitation of resources. The present groundwater development in the district is seen only in Dimapur valley. Hilly terrain where groundwater development has a limited scope occupies the rest area of the district. The discharge of untreated waste from domestic and commercial sources into water bodies is a major source of water contamination in Dimapur. Other contributing factors are poor sanitation and lack of awareness. Furthermore, the district doesn't have proper sewage treatment plants. The majority of the population in Dimapur rely on groundwater and depend entirely on its availability and quality. Data concerning the contamination of water resources by heavy metals in Dimapur district is still limited due to the lack of infrastructure and poor economic situation. Furthermore, water quality reports are extremely inadequate in Nagaland as there is practically not many documentations on the status of water bodies. Therefore, awareness of the vulnerability of groundwater is critical for the assurance of overall well-being and conservation of water resources. In this context, it is mandatory to monitor physicochemical-bacteriological contaminants to assess water quality. This study will provide an analytical foundation to better understand water quality conditions in Dimapur areas stretching from 1st mile to 7th mile and also make observed data publicly available and interoperable. Understanding water conditions in the Dimapur district will yield strategies for future urban water management in other districts of Nagaland and beyond.

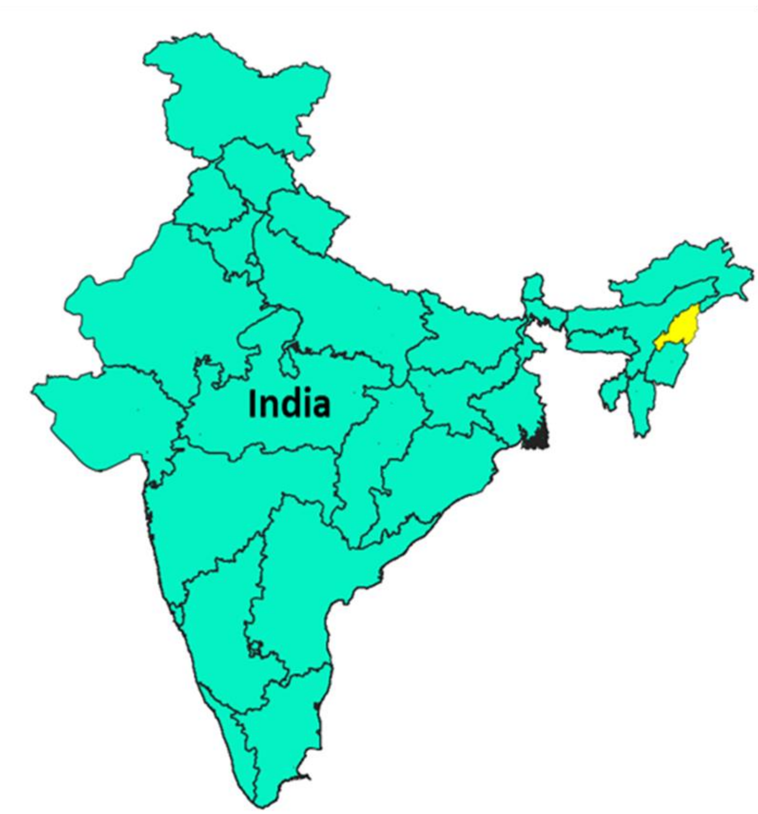
2.2. Overview of the Major Issues to be Addressed (max. 1000 words)

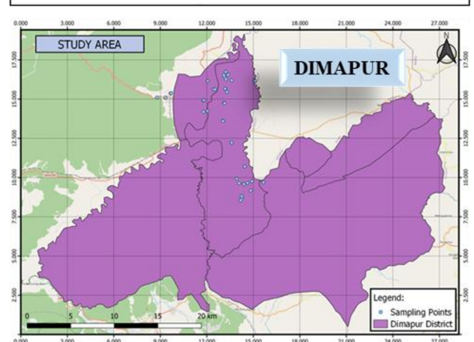
- Water quality reports are extremely inadequate in Nagaland as there is practically not many documentation on the status of water bodies. This project's primary focus is the data accumulation and analysis of drinking water quality as more data sets are necessary to comprehend the processes and mechanisms of drinking water quality variation.
- Out of 75 parameters outlined by the Central Pollution Control Board (Ministry of Environment and Forests 2010) for determining water quality, 20 physico-chemical parameters and bacteriological studies were used in correlation with BIS (IS: 10500, 2012) and WHO standards.
- The core objectives of this project is to study the possible health hazards associated with drinking-water and to find out sustainable management solution for those problems.
- Public awareness regarding the use of safe drinking water is not up to the mark and much efforts has to be devoted to create awareness among the people. There is also a need for strategic shift from water development to water management which includes encouraging reuse and safeguard the water supply from overuse.

2.3. Baseline Data and Project Scope

The study areas covered in Dimapur District are: Chumukedima, Tenyiphe, Sovima, Chekiye, Burma Camp, Rilan Village, Indisen Village, Samaguri, Walford, Purana Bazar, Half Nagarjan, Kuda Village, 2½ Mile, Chathe River, Lengrijan, Darogajan, Padam Pukhuri. The sampling points were confined to rivers, bore-wells and ring-wells used for drinking and domestic purposes. The depth of the wells varies from 32–200 ft. A total of 64 samples were collected from sixteen different locations of Dimapur. In the initial stage, a pilot study was carried out for 15 samples with 22 analysed parameters including bacteriological analysis. We collected additional samples in the subsequent years from several other points and analysed the association between water quality and health implications. Ten Physico-chemical parameters such as Temperature, pH, Dissolved Oxygen (DO), Conductivity, Total Dissolved Solids, Hardness, Iron, Nitrate, Phosphates and Sulphates and bacteriological experiments were performed under Bureau of Indian Standards (BIS, 2012) and World Health Organization guidelines (WHO). Aluminium, Chromium, Silver, Zinc, Fluoride and Nitrite are not included in the study since their concentrations were always below the detection limit of the analytical instruments. We used both correlation statistical analysis and the water quality index method to determine the cause of contamination and water quality conditions. Later on, 22 samples were gathered from the previously selected points and compared to highlight the interaction between geogenic factors and water chemistry. Physico-chemical data from the area are graphically classed by plotting them in Piper Trilinear and Durov diagrams with

Grapher software to understand the role of hydrochemistry, water quality, and its evaluation by comparing water types, and to interpret variation in hydro-chemical processes in the study area. Gibbs plots were constructed to interpret the hydro-geochemical operations about atmospheric precipitation, rock–water interaction, and evaporation over the administration of geochemistry of groundwater. The classification of the water samples (Richards, 1954) with respect to SAR (Sodium adsorption ratio) value was used to determine the irrigational quality parameters. Bacteriological tests were also performed on the collected water samples by serial dilution method.





2.4. Project Objectives and Target Deliverables (as per the NMHS Sanction Order)

S. No.	Project Objectives	Major achievements (in bullets points)
1.	Quality assessment of drinking water in South-West Nagaland	▪ Sixty-four water samples were collected from the residential areas of different point sources from Dimapur district. ▪ The study areas covered in Dimapur District are listed below: 1-Chumukedima

		2-Tenyiphe 3-Sovima 4-Chekiye 5-Burma Camp 6-Rilan Village 7-Indisen Village 8-Samaguri 9-Walford 10-Purana Bazar 11-Half Nagarjan 12-Kuda Village 13-2½ Mile 14-Chathe River 15-Lengrijan 16-Darogajan 17-Padam Pukhuri
2.	Physico-chemical and bacteriological analysis of drinking water samples	▪ Water quality parameters based on various physicochemical properties such as Temperature, pH, Electrical Conductivity, Total Dissolved Solids, Dissolved Oxygen, Iron, Sulphate, Phosphate, Total Hardness, and Nitrate were carried out. ▪ Bacteriological Analysis was carried out for all the samples using the Bacteriological Field Test Kit using a standard protocol.
3.	Identification of possible health hazards associated with drinking water	▪ Common health implications related to water contamination in the region are dysentery, diarrheal diseases, parasitic infestation, anaemia and most commonly gastrointestinal infection.
4.	To find out possible viable remedial measures for purification of contaminated water	▪ Simple and conventional filtration method can still be put to use to fix and restore the water quality. ▪ From our study, we tested the sample with the highest iron content and when filtered, the raw water sample shows no iron residue, suggesting that the

		concentration of iron can be removed by a simple filtration method.
5	Raise Awareness on the need of sustainable use of water resources employing the motto “Encourage Reuse, Discourage Overuse”	▪ An Awareness Program on “Water Quality in Nagaland and its related health issues” was conducted and the key points that was covered during the session are listed below: I. Current update on the availability of water resources in Nagaland II. Impacts on health associated with drinking water III. Role of an individual (or a community) to reduce water contamination IV. Measures adopted (known) to remediate the water related issues V. Need for the updated water quality information ▪ A total of 194 participants attended the program and it was the first-time experience for most of them. This program could deliver and share the awareness on the issues and concerns related to water in the district.

3. METHODOLOGIES, STRATEGY AND APPROACH

3.1. Methodologies used for the study (max. 1000 words)

Prior to the day of sample collection, all sample bottles were thoroughly washed, sterilized and dried. The bottles were rinsed with samples multiple times at the time of collection with proper labelling. The latitude and longitude of all the sampling sites were recorded using a GPS model (Model: Garmin GPS 72H) during the time of sample collection and a sampling location map is made by QGIS. Standard methods were followed for sample collection and preservation. Initially, we assessed 20 physicochemical parameters encompassing factors like Temperature, pH, Dissolved Oxygen (DO), Conductivity, Total Dissolved Solids (TDS), Salinity, Turbidity, Hardness, Aluminium, Chromium, Iron, Manganese, Silver, Zinc, Fluoride, Nitrate, Nitrite, Phosphates, and Sulphates. However, in the later phase, our focus narrowed to ten physicochemical parameters, namely, Temperature, pH, Dissolved Oxygen, Conductivity, Total Dissolved Solids, Hardness, Iron, Nitrate, Phosphates, and Sulphates alongside bacteriological experiments conducted in accordance with BIS and WHO guidelines. The exclusion of other parameters from the study was due to their consistently low concentrations falling below the detection limit of our analytical instruments and additionally, these parameters were deemed irrelevant to the study area.

The sample bottles were taken to the laboratory in an icebox to avoid external contamination and unusual change in physical and chemical properties in water quality and then stored at 4°C for further analysis of other parameters. Various sampling methods were followed depending on the type of analysis to be carried out. The temperature of the samples was determined on the spot. Temperature can affect parameters such as pH and conductivity and as a result, the analyses were carried out promptly following sample collection. Special care was taken while collecting samples for trace metals analysis. We gathered a minimum of 1L volume by grab sampling, leaving an air space of roughly 1% of container capacity. We subsequently preserved the samples by acidifying them with concentrated nitric acid (HNO_3) to pH <2 to reduce precipitation and adsorption on the container and transported them in an ice cold environment. Aeration and mixing space were maintained for microbiological analysis. To assess the degree of groundwater contamination and acceptability, the WQI was calculated using the Weighted Arithmetical Index technique (Table 1), considering 11 water quality indicators (i.e., pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, NO^{3-}, PO_4^{3-}). The nature of drinking water and its contamination level was evaluated by the reference value assigned by BIS and WHO to quantify those samples that did not comply with the guidelines. IBM SPSS Statistics was used to conduct the statistical correlation study. The Pearson correlation matrix was used to determine the relationship between the parameters of the experimentally estimated water quality study. To examine the data and assess the distribution of the values for each parameter, simple statistical metrics such as mean, standard deviation, minimum, and maximum were employed. Statistical data was utilised in this way to offer more information about the impacts of the water sample that was tested. Physico-chemical data from the area are graphically classed by plotting them in Piper Trilinear and Durov diagrams with Grapher software to understand the role of hydrochemistry, water quality, and its evaluation by comparing water types, and to interpret variation in hydro-chemical processes in the study area. Gibbs plots were constructed to interpret the hydro-geochemical operations about atmospheric precipitation, rock–water interaction, and evaporation over the administration of geochemistry of groundwater. The analysis of collected water samples was carried out using known standard methods. AR grade reagents, deionized water and borosil glass wares were used for the preparation of solutions. Bacteriological analysis was performed using the Bacteriological Field Test Kit using a standard protocol. Also, the presence of bacteria was determined by using the MPN method. In this method, the petri dish, micropipette, tips and spatula to be used were first sterilized in an autoclave, then kept in the laminar air flow free from any contamination. The petri dish is properly labelled for every sample. The agar nutrient solution was prepared in a conical flask fitted with a cotton wool plug and sterilized. The sterile molten agar medium is then poured on the petri dish by lifting the lid slightly. The petri dish is allowed to stand till the agar is solidified. 1 µL of the sample is then taken on the petri dish using micropipette and spread evenly over the agar using spatula. This procedure is repeated for all samples. Blank is also taken without any sample. The sample containing petri dish are then transferred to an incubator set at 37ºC and observation is made after 24 hours. During this procedure, maximum care is taken to ensure that the working environment is free from any contamination. Finally, the nature of drinking water and its contamination level was evaluated by the reference value assigned by BIS and WHO to quantify those samples that did not comply with the guidelines.

3.2. Details of Scientific data collected and Equipment Used

Description of different instruments used in the study are given here as under:

Sl. No.	Parameter	Analytical Method	Equipment Used
1	Temperature	Mercury Thermometer	Thermometer
2	pH	Electrometric method	EuTech pH 610
3	DO	Photometric method	HI-83200 Multiparameter Photometer
4	Conductivity, TDS, Salinity	Electrometric method	Multiparameter EuTech CD 650
5	Hardness	EDTA titrimetric method	Complexometric titration
6	Turbidity	Nephelometric method	EuTech TN 100
7	Aluminium, Chromium, Iron, Manganese, Silver, Zinc, Fluoride, Nitrate, Nitrite, Phosphate, Sulfate	Photometric method	HI-83200 Multiparameter Photometer
8	Bacteria	H_2S strip method developed by DRL, DRDO	Bacteriological Field Test Kit

3.3. Primary Data Collected

Details of primary data collected is given in **Annexure-1** and **Annexure-2**

3.4. Details of Field Survey arranged

In pursuance of the objectives set for the study, the primary methods of data collection have been adopted. Considering-the constraints of time and mobility, it is not possible to cover all the areas of Dimapur district. The district comprises of four blocks i.e., Medziphema, Dhansiripar, Nieuland, Kuhuboto and three circles i.e., Nihokhu, Chumukedima, Aghunaga and one Dimapur sadar. The present study covered two blocks, one circle and Dimapur Sadar that stretch from 1st mile to 7th mile of the district.

The following steps were followed to conduct field survey:

During the first six months after the project's initiation, the process of acquiring the chemicals and necessary field equipment for the study was completed, followed by the collection of field survey data. The field study was conducted mostly by addressing local residents with a drafted questionnaire in order to uncover concerns linked to water pollution and consumption. The initial preparation for sample collection began after identifying sampling locations for water collection. A total of 64 ring/bore/surface water bodies were selected and mapped by using the geographical coordinates (Latitude and Longitude) of the water sample sites from the years 2018 to 2020. The location of each sampling site was also recorded, along with its temperature, electrical conductivity, and pH level.

The key challenges encountered during the field survey are geographical and logistics constraints. Samples were taken from several households with the minimum distance of one kilometre between them from different localities. The project was brought to the attention of the locals, who were informed about the need to test their water and were alerted about the water-related health issues. Standard procedures were adopted while collecting samples.

4. KEY FINDINGS AND RESULTS

4.1. Major Research Findings

For all of the identified ring/bore/surface bodies in Dimapur, a database on water quality was created. The database contains (Latitude, longitude, EC, pH, temperature, sampling site codes, physico-chemical characteristics, etc.) for 64 samples spanning seven key areas of Dimapur and was maintained throughout the project research. An annual assessment of the physicochemical properties of selected ring/bore/surface data was conducted. Water quality analysis during the first year of the project indicates that, with regard to physico-chemical, cationic and anionic properties, all samples obtained from different locations comply with both WHO and Indian

Standards except for heavy metals such as Iron and Manganese, and nutrient Phosphate concentrations which are well above the acceptable limit and, therefore, not suitable for drinking and domestic purposes. Bacteriological contamination was likewise observed in some sample sources. The water quality analysis conducted during the second year reveals that majority of water sources are unfit for direct consumption without prior treatment. According to the correlation report, TDS and EC are two important physicochemical parameters that determines the water quality since they are associated with the majority of water parameters. The pH suggests corrosive nature, which could interfere with the overall nature of water. The chemical parameter of the main concern is the high content of iron. Therefore, the origin of iron needs to be investigated by considering the hydro-geological characteristics of the sampling sites. A linear association between TDS and EC observed in the samples for three consecutive years indicates 'fairly fresh' nature of water. Principal Component Analysis (PCA) gave rise to two principal components which were indicative of both natural and anthropogenic factors in regulation of water quality. The overall characteristics of the water are shown as 'good' and 'predominantly poor' quality in the computed Water Quality Index. In the final and extended work, a total of twenty-two groundwater (GW) water samples were obtained from different point sources in Dimapur district's residential areas. pH, Alkalinity, Turbidity, EC, TDS, Salinity, Resistivity, Aluminium, Calcium, Iron, Potassium, Magnesium, Manganese, Silver, Sodium, Zinc, Chloride, Fluoride, Nitrate, Phosphate, Sulphate, Bicarbonate is among the parameters studied. Ion chromatography technique was used to investigate the presence of cations and anions in water. Pearson correlation matrix depict good associations between cation and anion, suggesting that they are derived from similar geochemical process. Based on overall Water Quality Index (WQI) result, 50% belong to excellent water and 50% belong to good water. Therefore, the overall characteristics of the water show 'good' quality in terms of WQI. The Piper diagram plot shows the ionic supremacy of Ca^{2+} over Na^{+} + K^{+} and Mg^{2+} and of HCO^{3-} over $SO4^{2-}$ and Cl^{-}, pointing to a Ca^{2+}-Na^{+}-HCO^{3-} water type. As per the Durov plot, most of the GW samples were of the Ca–Na–HCO_3 type, and Ca^{2+}, Na^{+}, and HCO_3^{-} play an important role in defining the fresh groundwater carbonate hydrochemistry of the Dimapur area. The Gibbs diagram in this study demonstrates that all samples lie inside the rock dominance zone, implying that chemical weathering of rock-forming minerals via water–rock interaction is the major process determining Dimapur groundwater chemistry. Bacteriological analysis inferred that the collected water samples are not safe for direct human consumption.

4.2. Key Results

- pH of water in the Dimapur district is lower than neutrality indicating corrosive nature and could also interfere with the overall nature of the water.
- The water in the study area is not considerably ionized and has a lower level of ionic concentration activity due to small, dissolved solids.
- Concerning Dissolved Oxygen (DO), almost 50% of the sampled sources surpassed the WHO Guideline Value of >5 mg/L.
- The mean phosphate levels in the study area suggest very high nutrient contamination.
- The overall amount of nitrate that exceeds the standard guideline. The nitrate levels analysed in the previous study were also well below the permissible limit.
- More than 50% of the sampled water have higher Mn concentration thus rendering it unhealthy for consumption.
- The bacteriological analysis results depict that surface waters have a higher degree of contamination compared to the bore wells and ring wells.
- Our research findings revealed significant iron contamination in raw water samples from different depths prior to filtration. However, post-filtration, no detectable traces of iron were present, indicating the efficacy of a basic filtration method in diminishing iron concentration. This underscores the potential for improving water quality and addressing aesthetic concerns linked to iron contamination. The prevalence of particulate iron, rather than dissolved iron, in these samples suggests the suitability of straightforward filtration methods for removal. This optimistic outcome signifies the potential management of iron contamination in the water source using cost-effective treatment approaches like sedimentation and filtration.

4.3. Conclusion of the study

- In terms of physicochemical, cationic, and anionic properties, all samples obtained from various locations satisfy both WHO and Indian Standards, with the exception of heavy metals such as iron and manganese, and nutrient Phosphate concentrations that are well above the acceptable limit and thus unfit for drinking and domestic use. However, adequate water treatment before to usage can enhance water quality.
- Bacteriological contamination was likewise observed in most sample sources.
- The pH suggests corrosive nature, which could interfere with the overall nature of water.
- The key chemical parameter of concern is the high iron content. Our findings revealed a notable rise in iron contamination levels with increasing groundwater depth. The escalation in iron contamination levels as groundwater depth increases might suggest a potential correlation or connection between the geological composition at deeper levels and the

presence or mobilization of iron in the water. It could imply that certain geological layers or processes at greater depths influence the leaching or release of iron into the groundwater. Therefore, hydrogeological properties of the sampling locations must thus be taken into consideration when examining the origin of iron.

- TDS and EC are two essential physicochemical characteristics that influence water quality, according to the correlation study, because they are associated with the majority of water parameters. A linear relationship between TDS and EC recorded in samples for three consecutive years indicates that the water is 'very fresh.' In the calculated Water Quality Index, the general qualities of the water are represented as 'excellent' and 'predominantly bad.' According to this research, the water quality in Dimapur District from 2018 to 2020 is unfit for direct consumption without previous treatment.

5. OVERALL ACHIEVEMENTS

5.1. Achievement on Project Objectives

This project provides a wide scope to the individuals, and the society at large since no thorough investigation have been conducted to monitor or assess the problem of water issues in Dimapur. This study also highlights the contamination levels of water in the region. Despite the fact that the Government and PHED had contributed their essential role towards documenting the current database of the water quality, yet a periodic evaluation of the water is of great importance in understanding the causes, problems and awareness of its hazards. This study adds to the existing literature for quantitative and qualitative water related concerns with particular reference to Dimapur that can be used for further reference. This project generates a large data set that are required to understand the processes and mechanisms of variability in the quality of drinking water. Water issues is almost similar in every district of Nagaland and therefore, it is expected that whatever may be the finding of the study from this district, may be applicable to other districts too. Common health implications related to water contamination in the region are dysentery, diarrheal diseases, parasitic infestation, anaemia and most commonly gastrointestinal infection. Simple and conventional filtration method can still be put to use to fix and restore the water quality. It is imperative to underscore that our primary objective in conducting this study was to elevate awareness regarding the prevalent issue of drinking water contamination within the region. While conducting our investigation, we interacted with residents from various households and found a significant lack of knowledge about waterborne diseases among them. Many were surprised by the potential health risks associated with contaminated water. In response, we initiated online awareness program on “Water Quality in Nagaland and its related health issues”, which attracted considerable attention. This program delivered and shared the awareness on the issues and concerns related to water in the district covering the topics on current update on the availability of water resources in Nagaland, impacts on health associated with drinking water, role of an individual (or a community) to reduce water contamination, measures adopted (known) to remediate the water related issues and the need for the updated water quality information. Importantly, a substantial number of participants had never engaged in such programs before, indicating the novelty and importance of this initiative in raising awareness about water quality issues. Moreover, to empower residents to assess their water quality for household and drinking purposes, we actively shared personalized water sample analysis data. This collaborative effort aimed not just to increase awareness but also to facilitate informed decision-making about water usage. Overall, our commitment extended beyond research to actively engaging with the people, fostering a more profound impact on public understanding and contributing to long-term solutions for water quality management in the region.

5.2. Establishing New Database/Appending new data over the Baseline Data:

- Physico-chemical properties of the selected 64 water samples were monitored to analyse the variations in water quality during the project period.
- Analysis of major anions and cations were generated, namely; cations i.e. Na^+, Ca^{2+}, Mg^{2+}, K^+ and anions i.e. HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, F^- including pH, EC, TDS. The facies were identified using Piper Trilinear and Durov diagrams. The Piper diagram plot shows the ionic supremacy of Ca^{2+} over $Na^+ + K^+$ and Mg^{2+} and of HCO^{3-} over $SO4^{2-}$ and Cl^-, pointing to a Ca^{2+}-Na^+-HCO^{3-} water type. The Diamond diagram shows that 16 stations out of 22 falls into zone II and are sub-classified as HCO_3^--Ca^{2+} type.
- To interpret the hydro-geochemical processes relating to atmospheric precipitation, rock-water interaction, and evaporation over the management of groundwater's geochemistry, Gibbs plots were generated. The Gibbs diagram plots the GW water samples in water-rock dominance area (Figure 2). The distribution of sample points residing in the central part of Gibbs (1970) plot based on ratios of (Na+K)/(Na+K+Ca) and $Cl+NO_3/(Cl+NO_3+HCO_3)$ as a function of TDS, reflected the supremacy of weathering of rocks with some influence of evaporation crystallization in controlling geochemistry of water samples from the study area.
- The irrigational quality criteria were established by categorising the water samples according to their SAR (Sodium Adsorption Ratio) values. The classification of the water samples (Richards, 1954) from the study with respect to SAR value (0.41>SAR< 2.78) revealed that the water is excellent irrigation water (S1 type; SAR <10). Percent sodium

values ranged from 7.3 to 42.4 and classification of water samples on its basis (Wilcox, 1955) demonstrated that 91.67% the samples are safe for irrigation purpose as its value was below 40 (viz., excellent to good quality). Only two samples belong to permissible category (40- 60).

- By using the serial dilution procedure, bacterial tests were also performed on the collected water samples. From the bacterial analysis data, it is inferred that the collected water samples are not safe for direct human consumption.

6. PROJECT'S IMPACTS IN IHR

6.1. Socio-Economic Development (max. 500 words, in bullet points): Not relevant to project

6.2. Scientific Management of Natural Resources In IHR: Not relevant to project

6.3. Conservation of Biodiversity in IHR: Not relevant to project

7. EXIT STRATEGY AND SUSTAINABILITY

7.1. How effectively the project findings could be utilized for the sustainable development of IHR

This project provides a wide scope to the individuals, and the society at large since no thorough investigation have been conducted to monitor or assess the problem of water issues in Dimapur. This study also highlights the contamination levels of water in the region. This study adds to the existing literature for quantitative and qualitative water related concerns with particular reference to Dimapur that can be used for further reference. This project generates a data set that are required to understand the processes and mechanisms of variability in maintaining the quality of drinking water. Water issues is almost similar in every district of Nagaland and therefore, it is expected that whatever may be the finding of the study from this district, may be applicable to other districts too. Common health implications related to water contamination in the region are dysentery, diarrheal diseases, parasitic infestation, anaemia and most commonly gastrointestinal infection. Simple and conventional filtration method can still be put to use to fix and restore the water quality. The results of the physico-chemical analysis were shared with each family individually. This is done to raise people's awareness and caution regarding the quality of their water in the area. Additionally, the results obtained from the project has been made publicly available and interoperable. In order to achieve sustainable water resource development not only in Dimapur District but also in neighbouring districts of Nagaland, more study into water quality will support the establishment of a future water management system.

7.2. Identify other important areas not covered under this study needs further attention:

Throughout the project, the assessment of water quality was concentrated on Dimapur district due to its large population and prominence as the commercial centre of Nagaland state. Although knowing water conditions in the Dimapur district will provide plans for future urban water management, it is equally critical to examine and validate the water quality status in neighbouring districts of Dimapur such as Peren and Kohima district (capital city of Nagaland). Since scientific data and research play an important role in the formulation and implementation of SDGs at all dimensions, from local to global.

7.3. Major recommendations for sustaining the outcome of the projects in future

While developing an innovative filtration unit to manage emerging contaminants is one approach to addressing water quality issues, it would be more fundamental and compelling in terms of a long-term approach if one could stop the seepage of contaminants from the point source and avoid the pain of multiple trials and tests. As a result, we recommend that immediate action to be taken to design a system-based plan to ensure the availability of contaminant-free drinking water, as well as make water quality assessment data available to the public in order to promote awareness among citizens.

8. REFERENCES/BIBLIOGRAPHY

Annexure-1 & 2

9. ACKNOWLEDGEMENT

- National Mission on Himalayan Studies (NMHS), Ministry of Environment, Forest and Climate Change (MoEF & CC), Govt. of India.
- Director, G.B. Pant National Institute of Himalayan Environment, Kosi Katarmal, Almora, Uttarakhand.
- Director, National Institute of Technology Nagaland, Dimapur, Nagaland.

APPENDICES

Appendix 1 – Details of Technical Activities
Appendix 2 – Copies of Publications duly Acknowledging the Grant/ Fund Support of NMHS
Appendix 3 – List of Trainings/ Workshops/ Seminars with details of trained resources and dissemination material and Proceedings
Appendix 4 – List of New Products (utilizing the local produce like NTFPs, wild edibles, bamboo, etc.)
Appendix 5 – Copies of the Manual of Standard Operating Procedures (SOPs) developed
Appendix 6 – Details of Technology Developed/ Patents filed
Appendix 7 – Any other (specify)

******

(Signature of HRA/HJRF/HPF)

(NMHS FELLOWSHIP COORDINATOR)

(Signed and Stamped)

Principal Investigator
National Mission on Himalayan Studies
National Institute of Technology Nagaland
Chumukedima - 797103 : Nagaland

06.12.2023

(HEAD OF THE INSTITUTION)

(Signed and Stamped)

6/12/2023

Place: DIMAPUR

Date: 06 / 12 / 2023

Prof. S. Venugopal
Director
National Institute of Technology Nagaland
Chumukedima-797103, Nagaland

Appendix-2

Research papers

Research Publications:

[1] Mala Pamei, Naresh Guguloth, Dhiraj Dutta and Amrit Puzari (2020). Accessibility of safe drinking water in greater Dimapur area of Nagaland and related health hazards: An analytical study. **International Journal of Energy and Water Resources.** https://doi.org/10.1007/s42108-020-00074-5

[2] Mala Pamei, B Elizabeth Hemso and Amrit Puzari (2022). Evaluation of the Physico-Chemical and the sustainability of ground and surface water quality using statistical correlation method and Water Quality Index in Dimapur District, Nagaland. **Environmental Nanotechnology Monitoring and Management**. https://doi.org/10.1016/j.enmm.2022.100699

[3] Mala Pamei, Parineeta Das and Amrit Puzari. Assessment of hydro-geochemical attributes and bacteriological identification to evaluate the groundwater quality in Dimapur, India. (Under process)

Conference presentation

- Attended one conference during the course of the period (April, 2018- March, 2019). An oral presentation on the topic “Accessibility of safe drinking water in greater Dimapur area of Nagaland and related Health hazards: An analytical study” was delivered at ICAMEES-2018 (International Conference on Advanced Materials Energy and Environmental Sustainability), held at University of Petroleum and Energy Studies (UPES), Dehradun from 14th to 15th December, 2018.

Awareness program

- An Online Awareness Program on “Water Quality in Nagaland and its related health issues” was conducted (194 participants) on 9th September, 2020. This program could deliver and share the awareness on the issues and concerns related to water in the district.

INVESTIGATION OF THE POSSIBLE HEALTH HAZARDS ASSOCIATED WITH DRINKING WATER IN SOUTH-WEST NAGALAND AND DEVELOPMENT OF EFFECTIVE WAYS FOR WATER RESOURCE MANAGEMENT

Project under National Mission on Himalayan Studies (NMHS)

Implemented by the Ministry of Environment, Forest & Climate Change (MoEF&CC)

Nodal serving Hub: G.B. Pant National Institute of Himalayan Environment (GBPNIHE)

PROJECT ID: HSF 2017-18/I-23/11

(Project Fellow: Miss Mala Pamei)

Submitted

by

Dr. Amrit Puzari

Principal Investigator

National Institute of Technology Nagaland

Chumukedima, Dimapur

Pin: 797 103, NAGALAND

Annexure-1

Introduction

Accessibility of safe drinking water is an important public health concern and therefore scientific community around the globe continuously working on curving out more economic ways for providing safe drinking water to the common masses and also for providing better sanitation. It is universally accepted that everyone has the right to sufficient, continuous, safe, acceptable, physically accessible, and affordable water for personal and drinking use and sustainable development goals has been set for the same. Basic objective is to ensure safely managed drinking water services. According to World Health Organization (WHO) sources, in 2017, 5.3 billion people used safely managed drinking-water services and remaining 2.2 billion people are still deprived of safe and affordable drinking-water. Various reasons can be entangled with this issue which includes mainly sharp geographic, sociocultural and economic inequalities between urban and rural areas.

The grand initiatives taken up by Ministry of Environment, Forest & Climate Change, Govt. of India is a noble effort to find out sustainable management for water resources so that drinking-water can be made safe and affordable for each and every citizen of India. Nagaland is having lots of geographical constraints along with the economic factor, for providing safe and affordable drinking water to urban and rural people. The project undertaken has the core objectives to study the possible health hazards associated with the drinking-water provided in South-West Nagaland and to find out sustainable management solution for those problems. Currently, the project work is undergoing in greater Dimapur district and will be extended to other concerned areas in the later period.

Dimapur district with latitude 25°54'45'' North and longitude 93°44'30'' East is situated in the south-western region of Nagaland state, India. It is located at elevation of 154 meters above sea level and receives an average annual rainfall of 1504.7 mm with temperature ranging from 3.2˚C-36˚C (Ministry of Water Resources 2013). It has a total geographic area of 927 sq.km and has four subdivisions, namely Medziphema, Dhansiripar, Niuland and Kuhuboto. Dhansiri and Diphu rivers are the two major sources of water for irrigation and drinking purposes. Most of the region is at risk of erosion hazard contributing to land degradation and ultimately affecting the quality of water (Ministry of Environment and Forests 2010). With limited surface water available in the region, the only reliable sources of water are groundwater, where ring-well and bore-well are common. Increasing demand from residential, and agricultural use has resulted in depletion and declining quality of groundwater (Kalhor et al. 2019). According to 2001 and 2011 Census, Dimapur ranked highest in terms of population with a decadal growth rate of 23.13%. The rapid growth of the urban areas and the dense population of the region has impacted groundwater quality due to overexploitation of resources.

While the quantity of groundwater is associated with the sustainability issues, of equal importance is the quality of water. Water is susceptible to contamination with microorganisms and organic matter among other pollutants irrespective of the source. Contaminated water serves as one of the transmission tools for diseases (World Health Organization 2012) such as dengue, malaria, diarrheal diseases, parasitic infestation, anaemia etc. Therefore, the water quality must be tested at regular intervals on the grounds that human population suffers from varying water borne diseases due to the use of contaminated drinking water. In order to understand the status of the water quality, surface and ground water assessment has been carried out in selected areas of Dimapur Sadar and Chumukedima Circles of the district. A total of sixteen samples in the first dataset and seventeen samples in the second dataset were collected from rivers, tube-wells and ring-wells at different sites from total of 14 locations of Dimapur. Out of 75 parameters outlined by the Central Pollution Control Board (Ministry of Environment and Forests 2010) for determining water quality, 20 physico-chemical parameters was examined in correlation with BIS (IS: 10500, 2012) and WHO standards and bacteriological studies was carried out using Standard Plate Count method.

Most of the parameters under study are found to be within the permissible limit except for heavy metals such as Iron, nutrient Nitrate and Phosphate concentrations. Bacteriological contamination was likewise observed in most of the sample sources. This study revealed the nature of groundwater metal contamination in the region and that with continuous testing, more contaminated groundwater aquifers are bound to be identified (Bhuyan 2011).

FIRST DATASET:

1. Sample Collection:

Sampling location map is made by Google Maps and are shown in **Fig.1**. Time of collection, temperature of the samples and depth of the wells was recorded at the sampling site. The sampling points were confined to bore-wells and ring-wells used for drinking and domestic purposes and it is shown in **Fig.2**. The depth of the wells varies from 32-200 ft. A total of **16 samples** were collected from four different locations of Dimapur. All the collected water samples were colorless and odorless except **S12** which appears to be slightly brownish in color and have stale smell. Prior to the day of sample collection, all sample bottles were thoroughly washed, sterilized and dried. The bottles were rinsed with samples multiple times at the time of collection with proper labeling. The latitude and longitude of all the sampling sites were recorded using a GPS model (Model: Garmin GPS 72H) during the time of sample collection **(Table 1).** The sample bottles were taken to the laboratory in an icebox to avoid external contamination and unusual change in physical and chemical properties in water quality and then stored at 4°C for further analysis of other parameters. Standard methods were followed for sample collection and preservation.

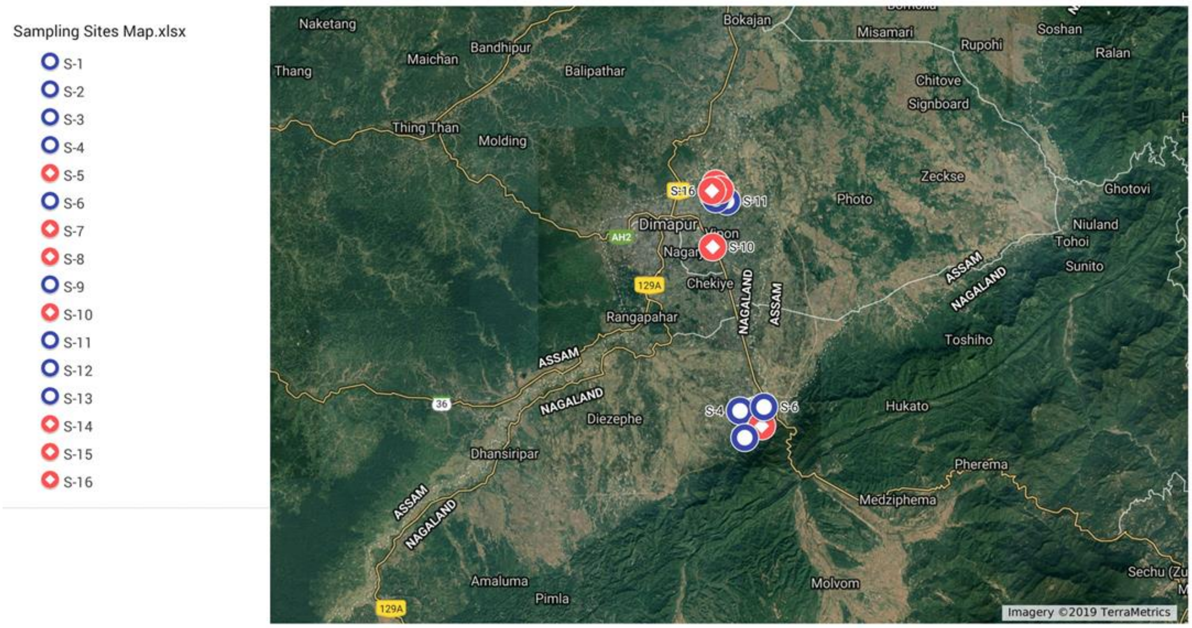


Figure 1: Location map of water collection points

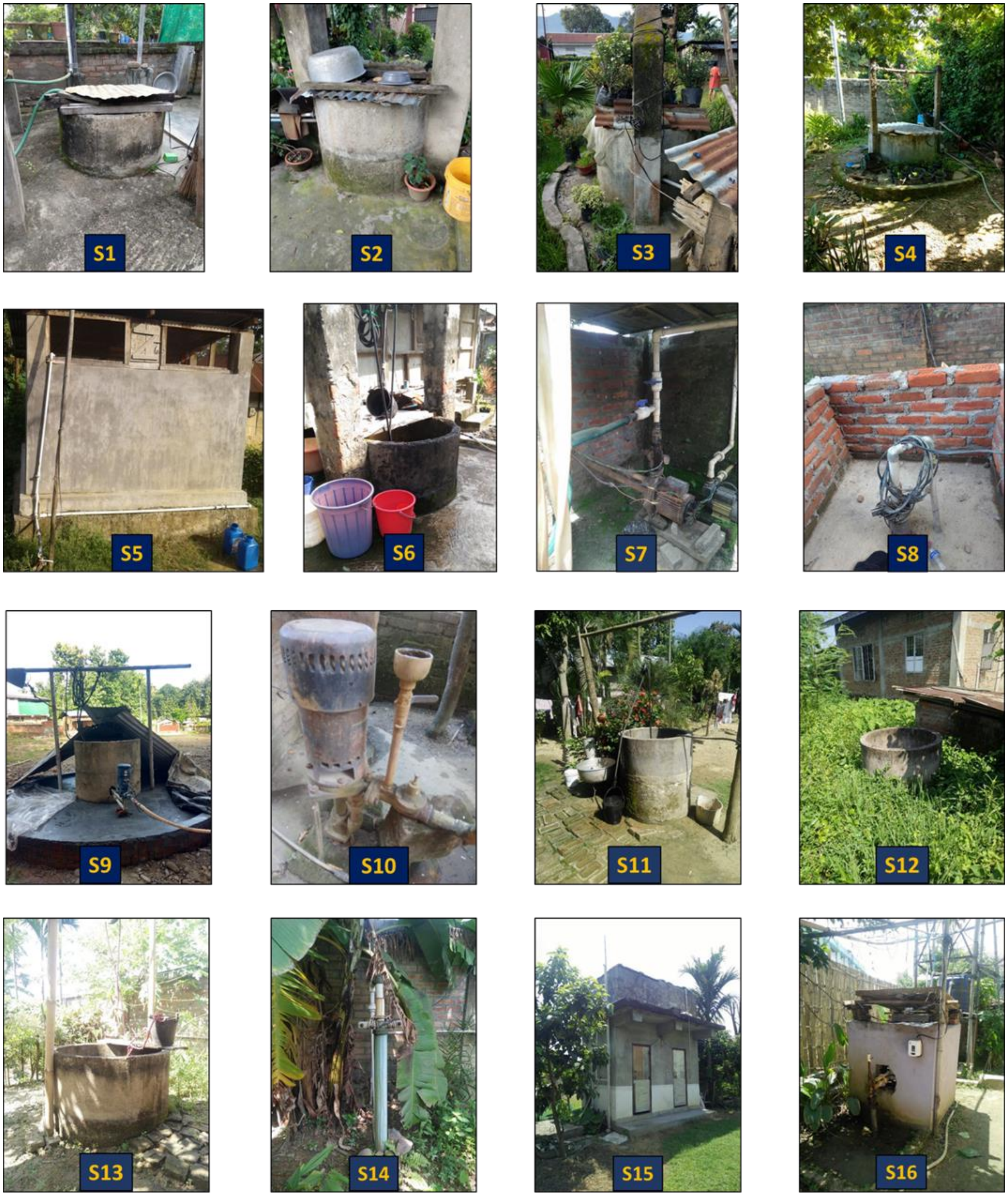


Figure 2: Sampling Sites

Table 1: Samples with GPS location

S. No	Samples	Water Source/ Locality	Depth of the Well (ft.)	Temperature (˚C)	GPS Location	
					Latitude	Longitude
1	S1	Ring well	35	29	25.805962	93.780479
2	S2	Ring well	35	28	25.804864	93.776101
3	S3	Ring well	35	29	25.804656	93.776485
4	S4	Ring well	35	29	25.805717	93.770909
5	S5	Bore well	180	29	25.797395	93.784263
6	S6	Ring well	35	29	25.807854	93.785624
7	S7	Bore well	160	29	25.924742	93.754653
8	S8	Bore well	200	30	25.790997	93.773773
9	S9	Ring well	40	29	25.790997	93.773773
10	S10	Bore well	120	28	25.896394	93.754019
11	S11	Ring well	35	29	25.921841	93.762578
12	S12	Ring well	32	34	25.922929	93.755942
13	S13	Ring well	32	30	25.931411	93.755696
14	S14	Bore well	200	27	25.931411	93.755696
15	S15	Bore well	146	26	25.928063	93.758565
16	S16	Bore well	150	27	25.927552	93.753574

2. Results and Discussions:

Physico-chemical analysis of all the collected water samples from different locations of Dimapur area was conducted. Results obtained from this study are shown in **Table 2**. The values of the analysis are compared to standard BIS values.

Table 2: Values of the measured Physico-Chemical parameters of the water samples

	pH	EC (µS/cm)	TDS (mg/L)	DO (mg/L)	Iron (mg/L)	Copper (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Phosphate (mg/L)
BIS							45-No relaxation		-

(Permissible limit)	6.5-8.5	300	500-2000	>5	0.3	-	NO_3-N	NO_3^-	100-200	P	PO_4^{3-}	P_2O_5
S1	5.54	210	120	2.6	Tr	0.023	7.2	31.7	25.0	2.0	0.6	1.5
S2	5.32	310	190	4.7	0.05	Tr	12.9	56.9	Tr	1.5	0.5	1.1
S3	6.11	310	180	5.5	0.03	0.062	3.3	14.6	15.0	0.8	0.3	0.6
S4	6.13	80	40	5.3	0.01	0.010	1.1	5.0	5.0	0.5	0.2	0.4
S5	7.06	210	130	0.5	0.32	Tr	Tr	Tr	Tr	1.6	0.5	1.2
S6	6.19	280	170	3.9	0.07	0.020	4.5	20.1	30.0	1.2	0.4	0.9
S7	5.79	100	60	0.4	5.00	Tr	Tr	Tr	Tr	0.9	0.3	0.6
S8	7.17	190	110	4.7	0.47	0.022	Tr	Tr	15.0	1.3	0.4	0.9
S9	7.11	360	210	7.1	0.03	0.131	0.5	2.4	30	2.4	0.8	1.8
S10	5.81	130	80	0.6	4.45	Tr	Tr	Tr	10	0.2	0.1	0.2
S11	6.26	160	90	5.0	0.41	Tr	Tr	Tr	20	0.4	0.1	0.3
S12	6.25	130	70	0.5	3.41	Tr	Tr	Tr	5	Tr	Tr	Tr
S13	6.70	160	90	4.0	0.49	0.032	Tr	Tr	25	0.8	0.3	0.6
S14	5.89	90	50	4.1	1.97	Tr	Tr	Tr	Tr	0.9	0.3	0.6
S15	5.86	110	60	2.6	5.00	Tr	Tr	Tr	Tr	Tr	Tr	Tr
S16	5.81	90	40	4.3	5.00	Tr	Tr	Tr	Tr	0.3	0.1	0.2

Temperature:

Chemical and Biological activities in water are dependent upon temperature. If the temperature increases, these activities will also increase. The ideal temperature for water supply should be between 10˚C and 25˚C. The samples collected have the temperature range between 26-30˚C.

pH:

pH level in water determines the acid-base equilibrium in most water and is one of the most significant operational water quality parameters. It is important to monitor the pH of a water body because it affects aquatic organisms. In the present study, the highest value of pH is found to be

7.17 (S8) and the lowest value is **5.32 (S2)**. The majority of the sources had a pH lower than the neutrality based on the BIS recommended value. Of the samples 43.7 % fell outside the recommended pH range and are skewed towards the acidic nature.

EC:

Electrical Conductivity of water is measured in micro-mhos per cm (μmho/cm) at 25˚C. It measures water salinity and is directly associated with the concentration of dissolved ionized solids in the water. Major positively charged ions that affect the conductivity of water are sodium, calcium, potassium and magnesium and major negatively charged ions are chloride, sulfate, carbonate and bicarbonate. Nitrates and phosphates are less likely to contribute to conductivity, but they are biologically very important. In this study, EC was measured using combined TDS/conductivity meter called Deluxe Cond/TDS Meter. The maximum and minimum values of EC are found in the sample **S9** and **S4** and it measures **360 μs/cm** and **80 μs/cm** respectively. Most of the samples are within the permissible limit recommended by BIS standards except for samples **S2**, **S3** and **S9** as shown in **Table 3**.

Table 3: Measurement of Electrical Conductivity (EC) at different temperatures:

Temp→ Sample ↓	0˚C	5˚C	10˚C	15˚C	20˚C	25˚C	30˚C	35˚C	40˚C
1	150	170	180	210	230	260	290	330	360
2	230	250	280	310	350	390	440	510	550
3	230	250	270	310	340	380	420	480	520
4	50	60	70	80	80	100	110	130	140
5	150	170	190	210	240	260	290	340	360
6	210	230	250	280	320	360	390	460	500
7	70	80	90	100	110	130	140	160	180
8	140	150	180	190	220	240	270	310	340
9	260	290	330	360	410	450	520	580	630
10	100	110	120	130	150	170	190	220	240
11	120	130	140	160	180	200	220	250	270
12	90	110	120	130	150	160	190	210	230

13	**110**	**130**	**140**	**160**	**180**	**200**	**220**	**250**	**270**
14	**60**	**70**	**80**	**90**	**100**	**110**	**130**	**140**	**150**
15	**70**	**80**	**90**	**110**	**120**	**130**	**150**	**170**	**180**
16	**60**	**70**	**80**	**90**	**100**	**120**	**130**	**150**	**160**

TDS:

Total Dissolved Solids comprises of dissolved inorganic salts and a small amount of organic matter. It is expressed in milligram per unit volume (mg/L). The acceptable range of TDS is 500 mg/L as suggested by BIS standards. In the present study, the range of TDS of analyzed water samples varied between 40-210 mg/L as shown in **Table 4**. The highest TDS value was observed for **S9** and the lowest value was observed for **S4 and S16**. However, all the values were within the standard limit of WHO (500 mg/L). Therefore, the drinking water is safe in terms of TDS.

Table 4: Measurement of Total Dissolved Solids (TDS) at different temperatures:

Temp→ Sample ↓	**0˚C**	**5˚C**	**10˚C**	**15˚C**	**20˚C**	**25˚C**	**30˚C**	**35˚C**	**40˚C**
1	**80**	**100**	**110**	**120**	**140**	**150**	**170**	**200**	**220**
2	**140**	**150**	**170**	**190**	**210**	**230**	**260**	**300**	**320**
3	**140**	**150**	**160**	**180**	**210**	**230**	**260**	**300**	**330**
4	**30**	**30**	**40**	**40**	**50**	**50**	**60**	**70**	**80**
5	**90**	**100**	**120**	**130**	**140**	**160**	**180**	**200**	**220**
6	**120**	**140**	**150**	**170**	**190**	**210**	**240**	**270**	**290**
7	**40**	**40**	**50**	**60**	**60**	**70**	**80**	**90**	**100**
8	**80**	**90**	**100**	**110**	**130**	**140**	**160**	**180**	**200**
9	**160**	**180**	**190**	**210**	**240**	**270**	**300**	**340**	**380**
10	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**130**	**140**
11	**60**	**70**	**80**	**90**	**110**	**120**	**140**	**159**	**170**
12	**50**	**60**	**70**	**70**	**80**	**90**	**110**	**120**	**130**
13	**60**	**70**	**80**	**90**	**110**	**120**	**130**	**150**	**170**

14	30	40	40	50	50	60	70	80	80
15	40	50	50	60	70	80	90	100	110
16	20	20	30	40	50	60	70	80	90

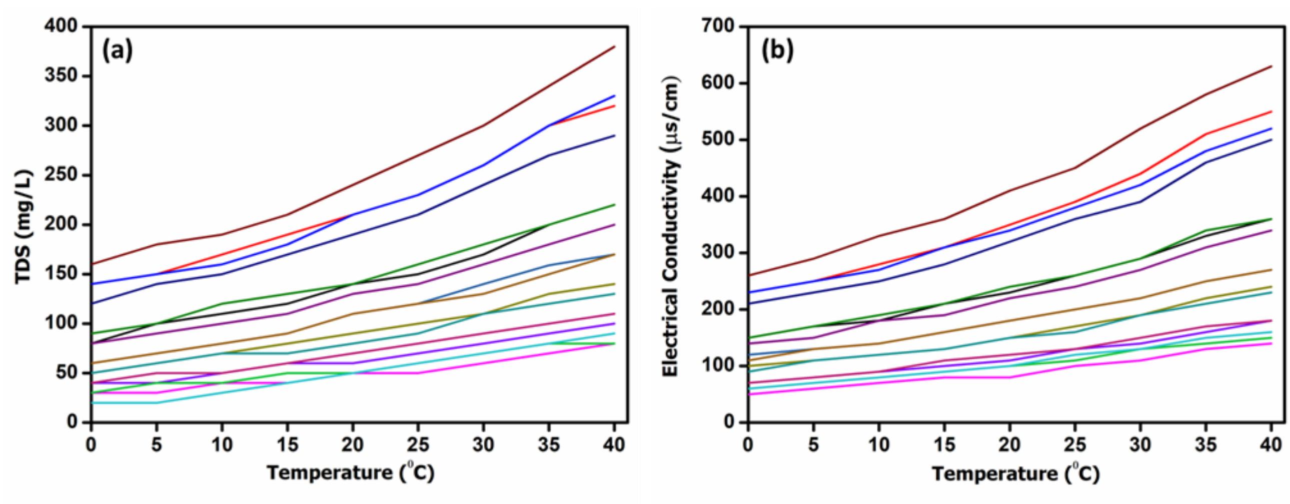


Figure 3: Measurement of TDS and EC at different temperatures

DO:

Dissolved oxygen analysis measures the amount of gaseous oxygen dissolved in an aqueous solution. Oxygen gets into water by diffusion from the surrounding air, by aeration and as a waste product of photosynthesis. The value of DO in this study, ranges from 0.4 to 7.1 mg/L. About most of the sampling locations are not up to permissible limit according to drinking water quality standards (BIS, 2006) i.e. >5 mg/L (tolerance level).

Iron:

Iron concentration depends on the sampled water table. It is generally observed that concentration of iron increases as the depth of the water increases. Since, most of the sampled sources have the depth between 32 to 200m, 62.5 % of the collected samples are found to have high concentration of iron making it not suitable for drinking purpose due to aesthetic reason. The amount of Iron that are above the permissible limit **(0.3 mg/L)** are shown in **Fig.4 and 5**.

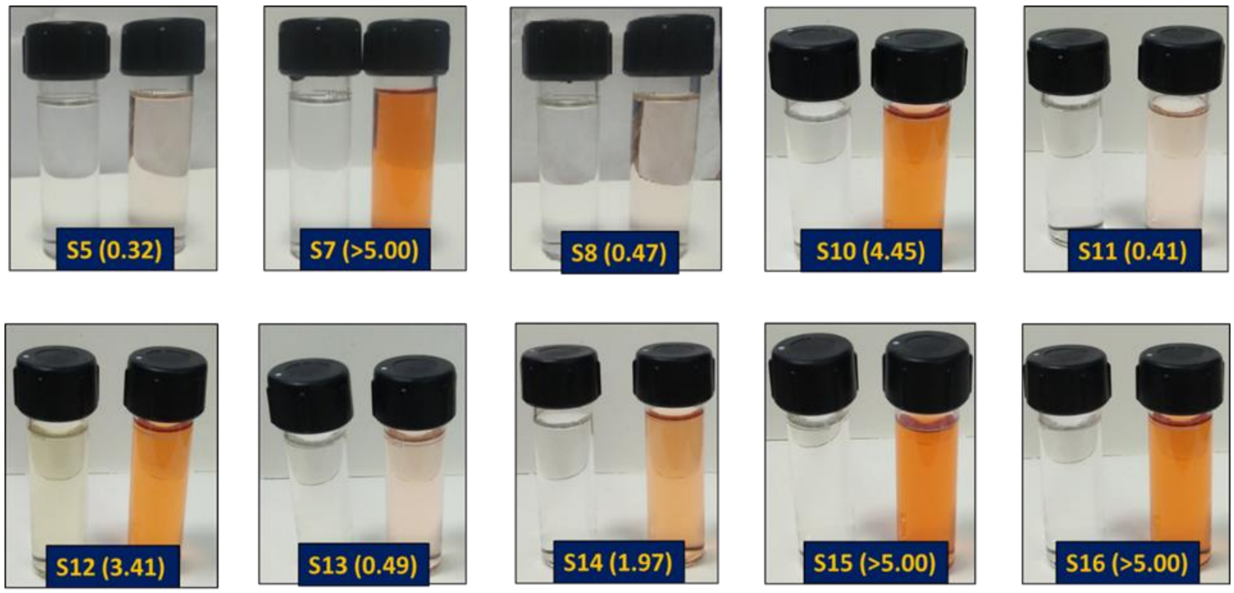


Figure 4: Samples with high iron concentration that exceeds permissible limit (0.3 mg/L) for consumption

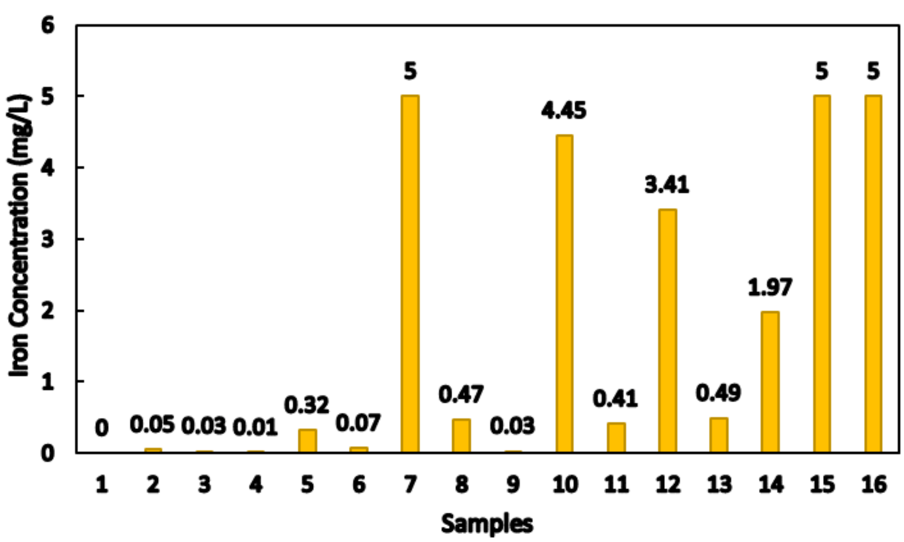


Figure 5: Iron concentration levels for all the Samples

Copper:

Copper in the form of salts are soluble in water imparting bluish-green color and give an unpleasant metallic, bitter taste to drinking water. The primary health concern is the potential for the presence of elevated levels of copper in the water. In this study, the concentration of copper varies from trace to 0.131 mg/L which is within the limit set by WHO. BIS standards have not specified fix concentration for copper.

Nitrate:

Nitrate in water is undetectable without testing because it is colorless, odorless, and tasteless. High nitrate concentration contribute to bacterial contamination in water. Therefore, determining whether the concentration of nitrate is under the acceptable standard is essential. The nitrate concentrations in this study are well within the permitted limit and secure for use.

Phosphate:

Phosphorus in the form of phosphate is an essential plant nutrient and a major component of most fertilizers. Phosphates are non-toxic unless they are present in very high levels. There is no limit set by BIS standard for phosphate however WHO recommends the permissible limit to be 0.1 mg/L. For this study, phosphate was measured using HI-83200 Multi-parameter Photometer. The present investigation found phosphate concentration ranging from trace amount to 0.6 mg/L. Most of the samples exceed the limit fixed by WHO and are not fit for consumption without filtration.

Sulfate:

The BIS standard suggest the concentration of Sulfate to be within 100-200 mg/L. The concentration of sulfate in water samples was observed to range from trace amounts to 30 mg/L which is within the permissible limit.

Conclusion:

From this study, it is found that, with respect to Physico-Chemical characteristics, all water samples gathered from distinct places comply with both WHO and Indian standards, with the exception of the iron concentration of 10 samples gathered from the nearby hospital and brick factory region. Therefore, water samples with high levels of iron are not suitable for drinking and domestic purposes. However, prior to use, proper iron treatment can improve the water quality. Also, periodic determination of various water quality parameters may help improve the water treatment process from the acquired analysis results.

SECOND DATASET:

1. Water Sample

Physico-chemical analysis of 17 water samples as shown in **Fig. 6** collected from several locations in Dimapur district have been carried out. Samples from both ground water and surface water sources were incorporated for the study. The values obtained from the analysis have been compared with the specifications for drinking water laid down by BIS (IS-10500). Samples were also tested for the presence of bacteria. The bacteriological analysis was done to determine the presence of bacteria in all samples. This examination is intended to identify water sources which have been contaminated with potential disease-causing microorganisms. Such contamination generally occurs either directly by human or animal faeces, or indirectly through improperly treated sewage or improperly functioning sewage treatment systems. The following parameters were checked in this study:

- pH
- Electrical Conductivity
- Total Dissolved Solids
- Dissolved Oxygen
- Nitrates
- Sulphates
- Phosphates
- Total Hardness
- Iron
- Bacteria

2. Aim of the assessment

The purpose of the assessment was to establish the baseline water quality in order to obtain data that could be used to form the basis for planning control measures to minimize water and environment pollution.

3. Methodology

- Prior to sample collection all the sample bottles are thoroughly washed with distilled water and dried. The bottles are rinsed with water sample to be collected at the time of collection.
- Proper labelling is done after collection.
- Time of collection, temperature of the samples and depth of the wells are recorded at the sampling site.
- During sample collection, the latitude and longitude of all the sampling sites along with the source are recorded.
- The samples are then stored in ice boxes to avoid external contamination and unusual change in physical and chemical properties in water quality.

4. Results and Discussion

Physico-chemical and bacteriological analysis of all the samples from different locations was carried out and the results are shown in Tables 5, 6 and 7.The detailed assessment of each parameter is discussed below one by one.

Table 5: Water Samples with GPS location

Sl. No	Sample	Locality	Source	Depth of well (in ft)	Temp	GPS Location	
						Latitude	Longitude
1	Sample 1	Chumukedima	Bore well	200	30 ºC	25.790997	93.773773
2	Sample 2	Chumukedima	Ring well	40	29 ºC	25.790997	93.773773
3	Sample 3	Samaguri	Ring well	40	28 ºC	25.922103	93.788472
4	Sample 4	Samaguri	Bore well	120	27 ºC	25.921395	93.788200
5	Sample 5	Walford	Bore well	180	28 ºC	25.911518	93.741524
6	Sample 6	Walford	Ring well	30	28 ºC	25.911647	93.743284
7	Sample 7	Purana Bazar	Ring well	40	28 ºC	25.912287	93.755261
8	Sample 8	Purana Bazar	Bore well	120	28 ºC	25.912335	93.754934
9	Sample 9	Half Nagarjan	Ring well	45	27 ºC	25.898987	93.730187
10	Sample 10	Half Nagarjan	Tube well	35	26 ºC	25.899525	93.730600
11	Sample 11	Kuda Village	Bore well	140	26 ºC	25.886263	93.730316
12	Sample 12	Kuda Village	Ring well	20	27 ºC	25.887274	93.734577
13	Sample 13	2½ Mile	Pond	_	26 ºC	25.895975	93.754390
14	Sample14	Purana Bazar	Pond	_	27 ºC	25.908786	93.757244
15	Sample 15	Chathe River	River	_	26 ºC	25.921026	93.789465
16	Sample 16	Lengrijan	Bore well	200	25 ºC	25.907227	93.692731
17	Sample 17	Lengrijan	Ring well	25	25 ºC	25.907298	93.693336

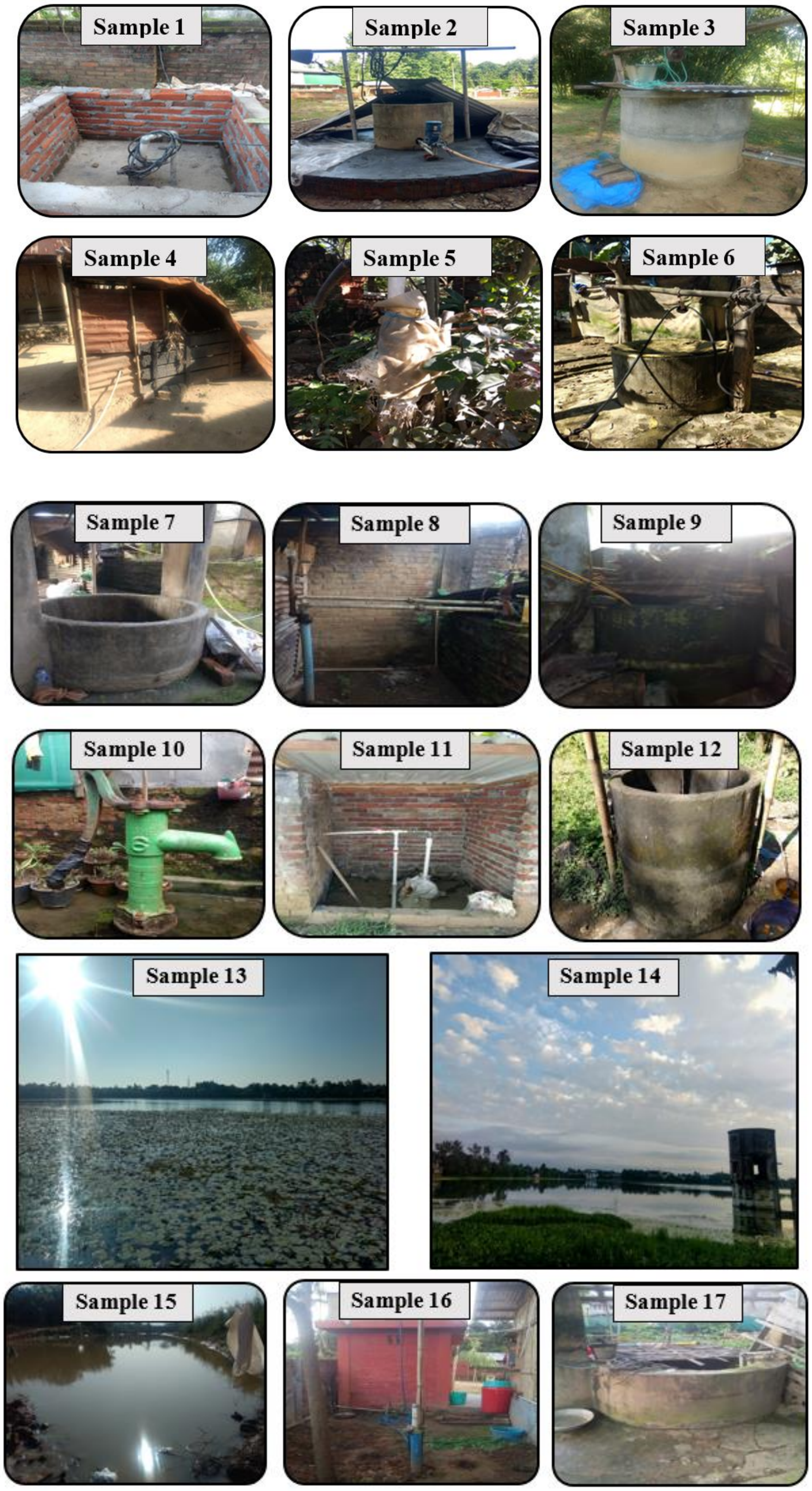


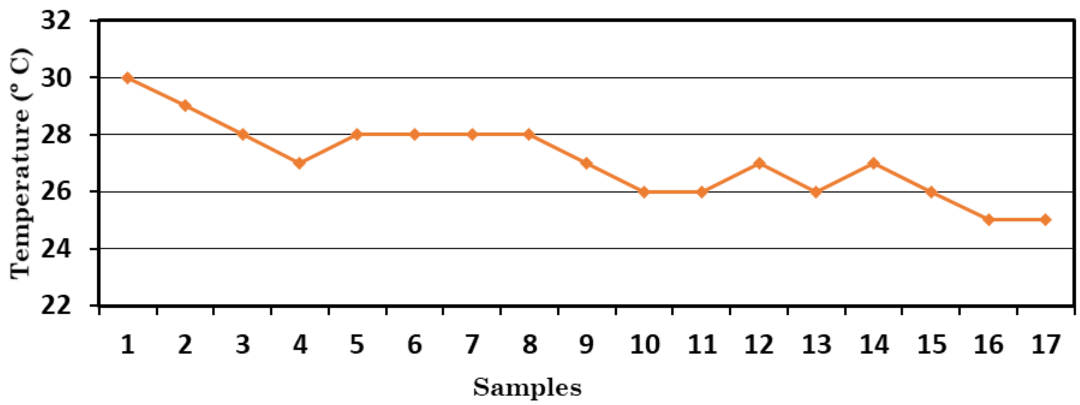
Figure 6: Sampling Points

Table 6: Physico-chemical analysis of samples collected from different locations in Dimapur

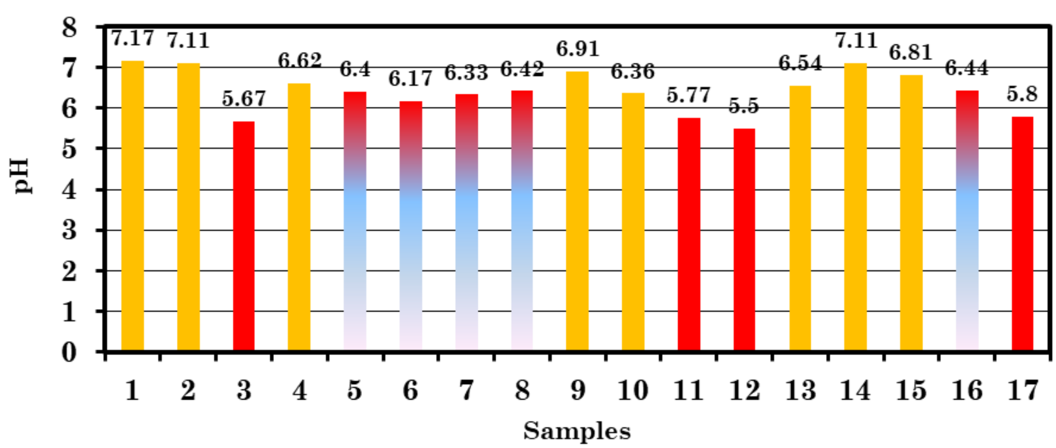
Parameter	pH	EC (µs/cm)	TDS (mg/L)	D.O (mg/L)	Iron (mg/L)	Nitrate (mg/L)		Sulphate (mg/L)	Phosphate (mg/L)			TH (mg/L)
						45-No relaxation			---			
						NO_3-N	NO^-_3		P	PO_4^{3-}	P_2O_5	
Sample 1	7.17	150	80	4.7	0.47	_	_	15	1.3	0.4	0.9	111.1
Sample 2	7.11	300	160	7.1	0.03	0.5	2.4	30	2.4	0.8	1.8	722.2
Sample 3	5.67	180	80	2.7	0.28	5.8	25.6	_	30	9.8	22.4	333.3
Sample 4	6.62	480	220	4.1	3.49	_	_	_	11.9	3.9	8.9	277.7
Sample 5	6.40	700	310	2.6	0.34	1.7	7.7	50	2.1	0.7	1.6	166.6
Sample 6	6.17	220	100	2.9	3.73	_	_	_	_	_	_	388.8
Sample 7	6.33	550	240	3.7	0.04	2.8	12.3	70	_	_	_	444.4
Sample 8	6.42	290	130	3.9	2.43	_	_	_	_	_	_	166.6
Sample 9	6.91	810	210	4.3	0.1	3.4	15.0	75	0.9	0.3	0.7	388.8
Sample 10	6.36	570	190	0.8	3.5	_	_	60	_	_	_	555.5
Sample 11	5.77	180	60	7.5	0.3	_	_	5	_	_	_	222.2
Sample 12	5.50	1700	580	3.9	0.1	30	132.8	100	1.2	0.4	0.9	944.4
Sample 13	6.54	170	60	3.0	0.2	14.1	62.4	5	0.9	0.3	0.7	111.1
Sample 14	7.11	210	70	5.6	0.1	1.5	6.7	_	0.6	0.2	0.5	166.6
Sample 15	6.81	110	60	7.7	0.55	1.5	6.5	20	0.8	0.2	0.6	111.1
Sample 16	6.44	220	130	7.0	0.58	30	132.8	5	_	_	_	222.2
Sample 17	5.80	440	240	7.4	0.02	17.8	78.9	5	0.4	0.1	0.3	166.6

1. **Temperature:** In an established system, the water temperature controls the rate of all chemical reactions, and affects aquatic organisms' growth, reproduction and immunity.

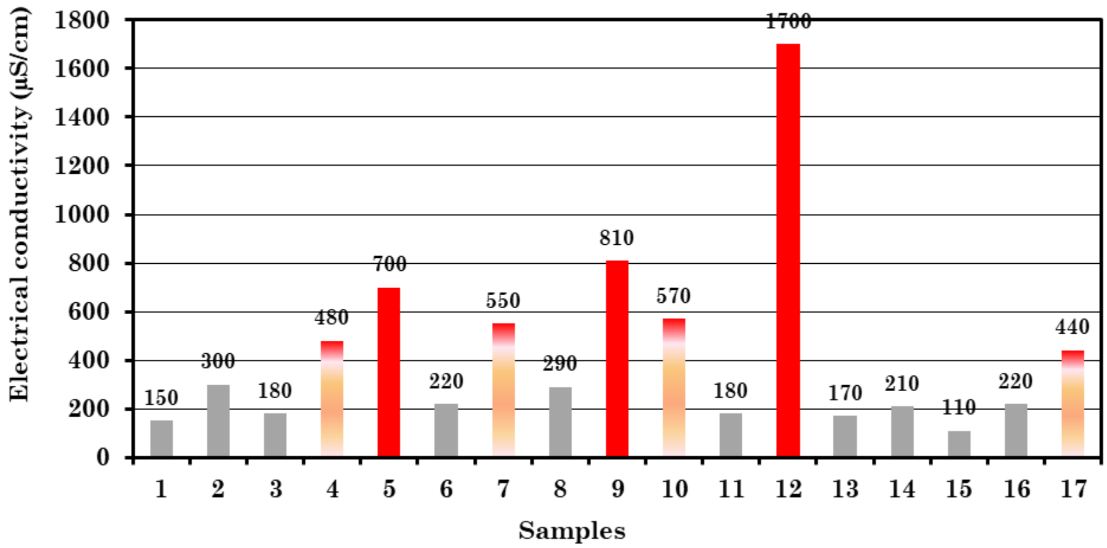
Drastic temperature changes can be fatal to aquatic organisms. The temperature for the samples collected ranges from 25-30 ºC.



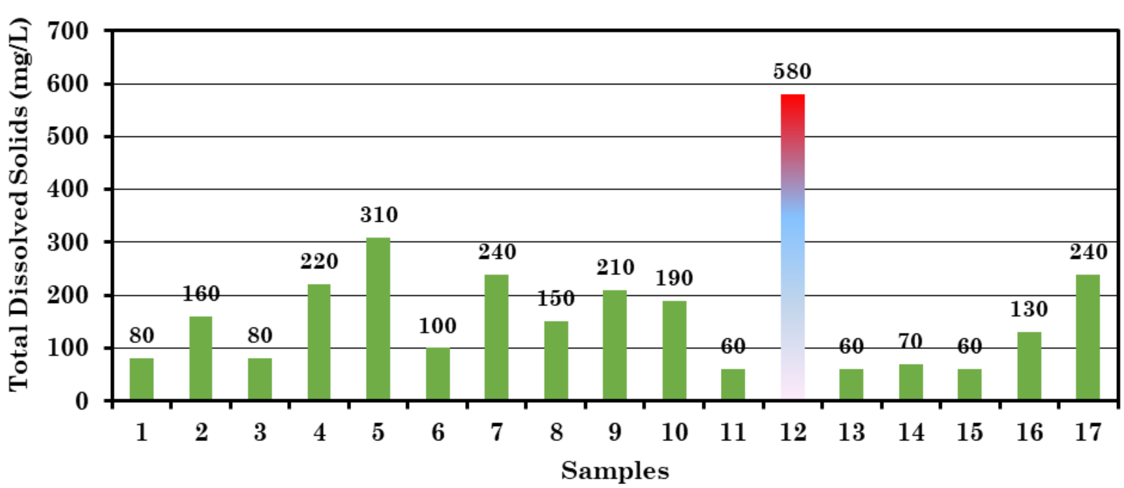
2. **pH:** The pH of any water body is a measure of its acidic or basic property. It is most important in determining the corrosive nature of water. The pH of water determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals. The pH values were found to vary from 5.5 to 7.17.



3. **EC:** Electrical conductivity is the ability of any medium; water in this case, to carry an electric current. The presence of dissolved ions in water samples carries the electric current through water. Higher Electrical Conductivity indicates there are more dissolved chemicals in water. According to WHO standards, EC value should not exceed 400 μS/cm. The current investigation indicated that EC value was 1700–110 μS/cm with an average value of 428.23 μS/cm. These results clearly indicate that water in the study area has high level of ionic concentration activity due to large amount of dissolve solids.

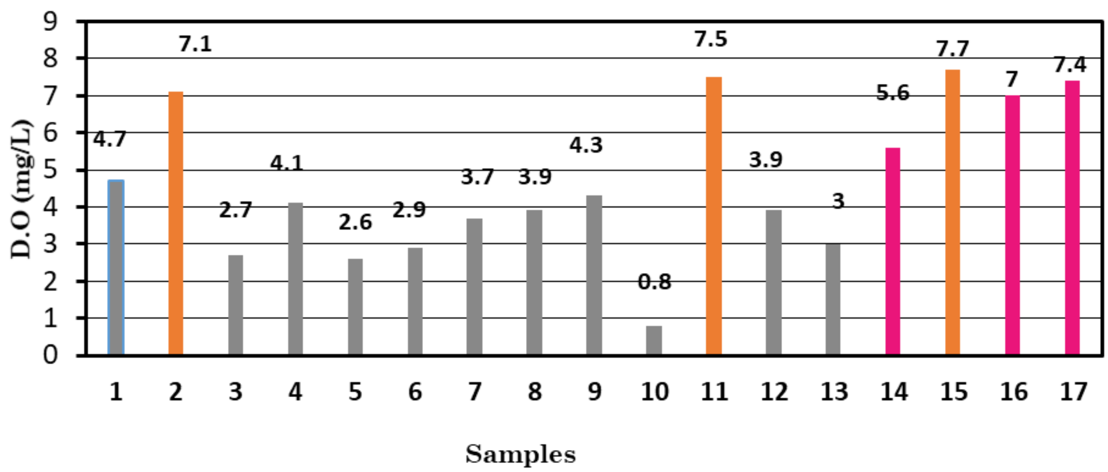


4. **TDS:** It is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized, or micro-granular (colloidal sol) suspended form. The acceptable range of TDS is 500 mg/L as suggested by BIS standards. In the present study, the range of TDS of analyzed water samples varied between 60–580 mg/L. However, all the values were within the standard limit of BIS and WHO (500 mg/L). Similar to electrical conductivity, Samples 12 recorded the highest TDS value that is above the acceptable limit but it is still within the permissible limit. Therefore, the drinking water is safe in terms of TDS.

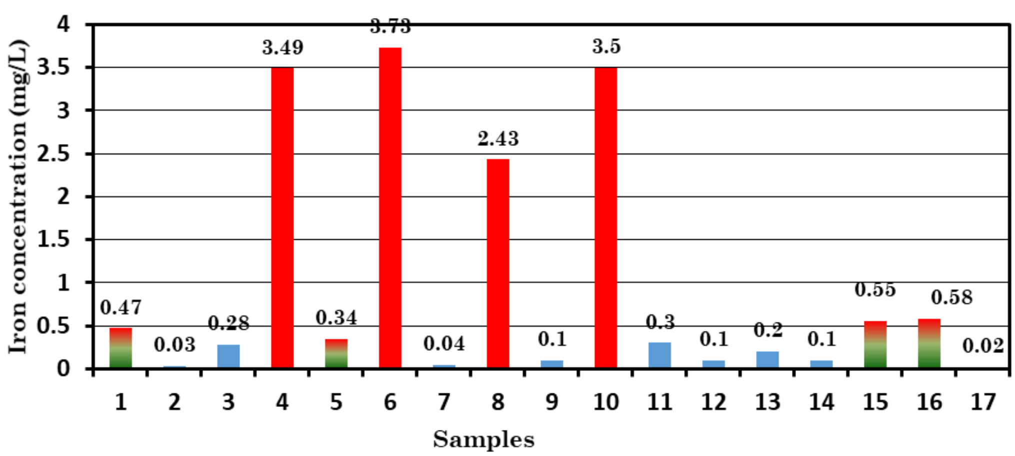


5. **Dissolved Oxygen:** It refers to the level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence

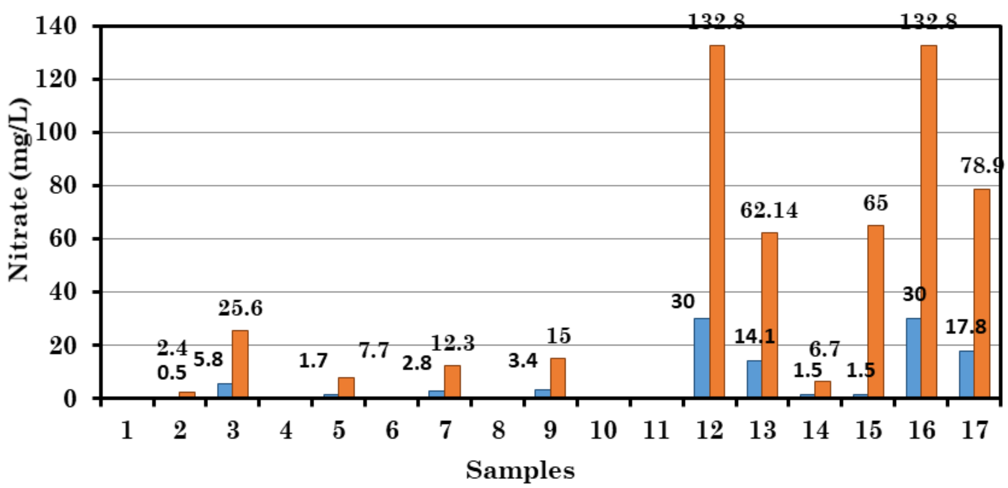
on the organisms living within a body of water. Only 6 of the samples have dissolved oxygen within the acceptable limit.



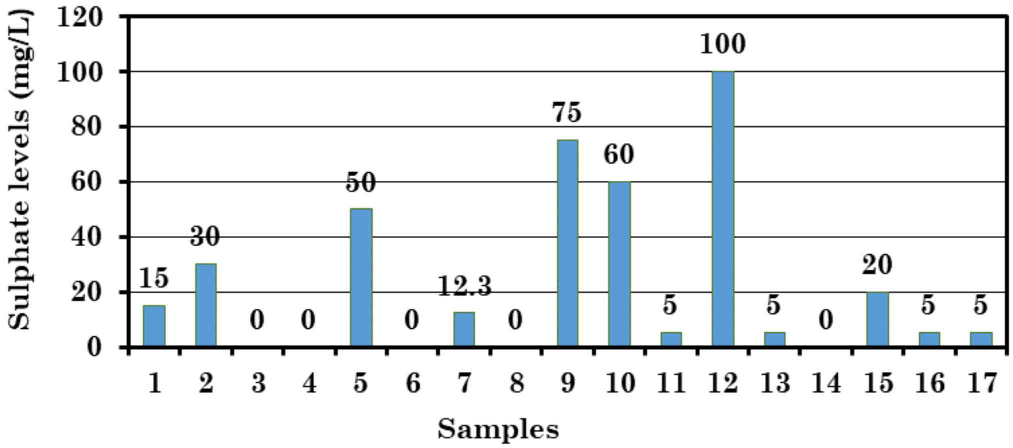
6. **Iron**: Rainwater as it infiltrates the soil and underlying geologic formations dissolves iron, causing it to seep into aquifers that serve as sources of groundwater for wells. It is a secondary contaminant and has no direct implications on human health. It can corrode pipes, utensils, damage laundry, etc. Iron concentration depends on the sampled water table. It is generally observed that the concentration of iron increases as the depth of the water increases. Since, most of the sampled sources have the depth between 20 to 200 m, 47% of the collected samples are found to have a high concentration of iron making it not suitable for drinking purpose without prior treatment due to aesthetic reason. Samples 4, 6, 8 and 10 have high levels of iron followed by 16, 15, 5 and 1.



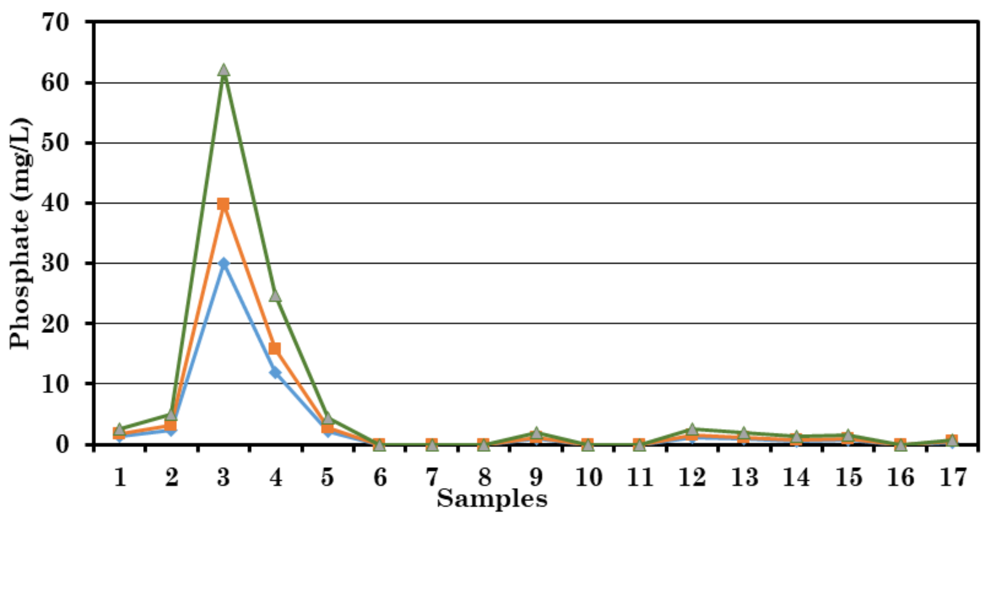
7. **Nitrate:** The natural nitrate concentration in groundwater under aerobic conditions is a few mg/L and depends strongly on soil type and on the geological situation. The increasing use of artificial fertilizers, the disposal of wastes and changes in land use are the main factors responsible for the progressive increase in nitrate levels in groundwater supplies. In surface water, concentrations are higher as a result of runoff and the discharge of sewage effluent and certain industrial wastes. Excessive nitrate concentration contributes to bacterial contamination in water and can transform normal hemoglobin to methemoglobin causing blue baby (Methaemoglobinemia) syndrome in children. It is, therefore, vital to determine whether the nitrate concentration is within the acceptable standard. The maximum permissible limit of nitrate in drinking water as per IS: 10500 is 45 mg/L. The nitrate concentrations for the samples 12, 16 and 17 in this study are much higher than the prescribed limit and are not secure for use without proper treatment.



8. **Sulphate:** Sulphate in water usually comes from dissolved minerals and decomposition of plant and animal matter. It can also come from fertilizers or sewage treatment. The BIS standard suggests the concentration of Sulfate to be within 100–200 mg/L. The concentration of sulfate in water samples was observed to range from trace amounts to 100 mg/L, which is within the permissible limit.

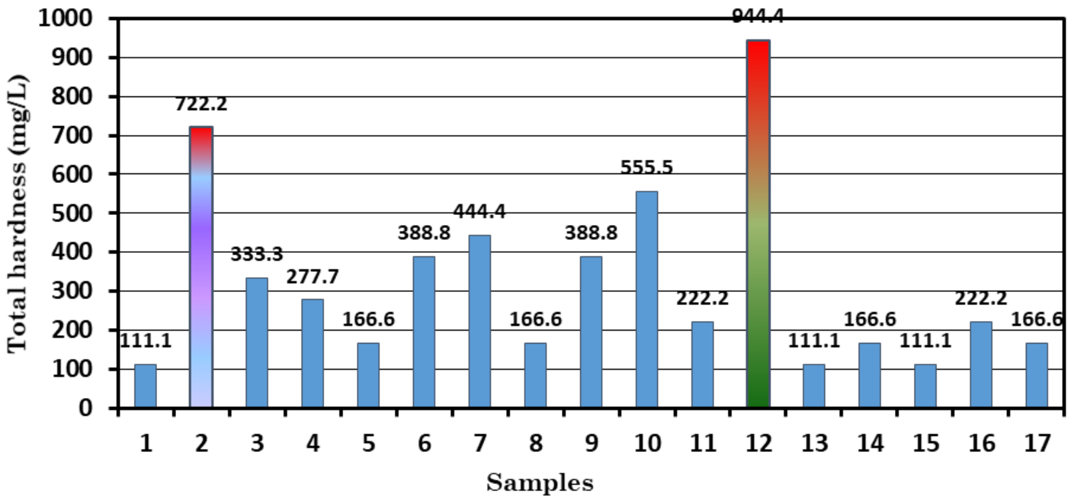


9. **Phosphate:** Sources of phosphate include decomposition of rocks and minerals, agricultural runoff, sedimentation, erosion, wastewater treatment plants and industrial discharges. The main issue with phosphates in water is the causation of Eutrophication. The minimum phosphate concentration that triggers algae blooms is only 0.05 mg/L. It is also routinely added in drinking water supplies to prevent the entry of lead and copper from the corrosion of old pipes. There is no limit set by BIS standard for phosphate however WHO recommends the permissible limit to be 0.1 mg/L. The present investigation found phosphate concentration ranging from trace amount to 9.8 mg/L. Most of the samples exceed the limit fixed by WHO and are not fit for consumption without filtration.

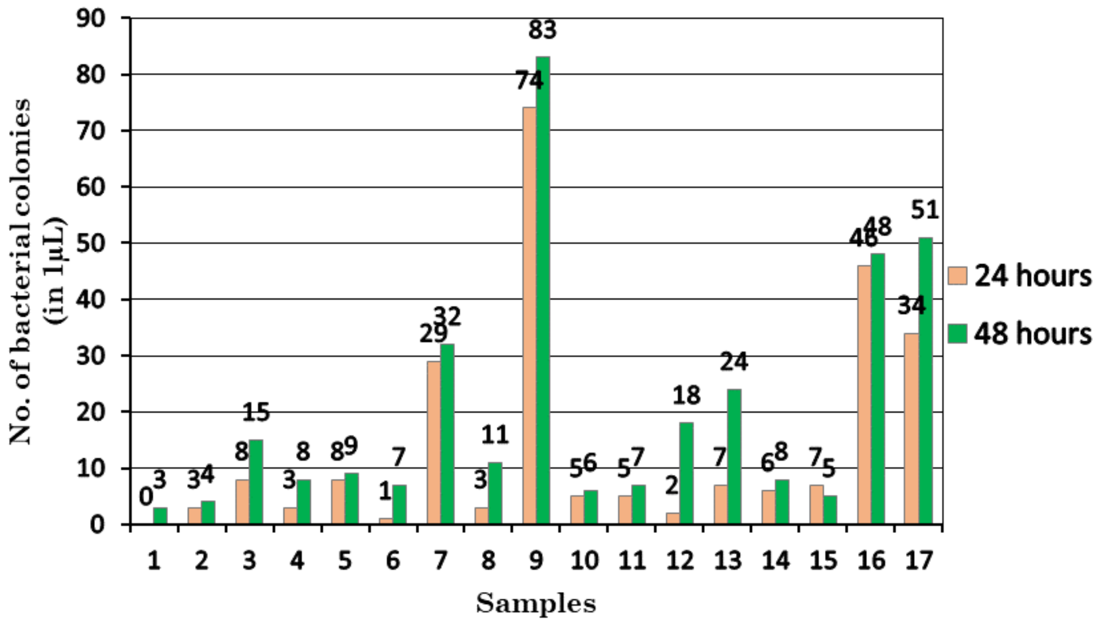


10. **Total hardness:** Total hardness is due to the presence of bicarbonates, chlorides and sulphates of calcium and magnesium ions. It is unfit for drinking, bathing, washing and it also

forms scales in boilers. The degree of hardness of drinking-water is important for aesthetic acceptability by consumers. No health-based guideline value is proposed for hardness in drinking-water (World Health Organization 2011). According to BIS, desirable and maximum permissible limits of Total hardness are 300 mg/L and 600 mg/L. The total hardness of the samples ranged 111.1 to 944.4 mg/L and is relatively high in some samples.



11. **Bacteria:** The presence of bacteria and other pathogens in drinking water is a cause for concern. Human and animal wastes are a primary source of bacteria in water. These sources of bacterial contamination include runoff from feedlots, pastures, dog runs, and other land areas where animal wastes are deposited. Additional sources include seepage or discharge from septic tanks, sewage treatment facilities, and natural soil/plant bacteria. Bacteria from these sources can enter wells that are either open at the land surface or do not have water-tight casings or caps. Other sources include inundation by flood waters or through insects, rodents and small animals. Bacteria were detected in all samples. Samples 9, 16 and 17 showed the presence of large number of bacterial colonies.



Determination of presence of bacteria:

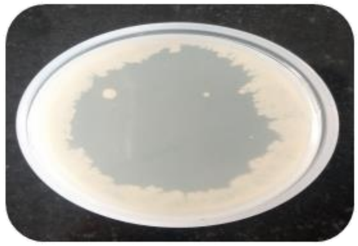
The presence of bacteria has been determined by following the standard procedure. During this procedure, maximum care is taken to ensure that the working environment is free from any contamination

1. The Petri dish, micropipette, tips and spatula to be used were first sterilized in an autoclave.
2. The equipment were then kept in the laminar air flow free from any contamination.
3. The Petri dish is properly labeled for every sample.
4. The agar nutrient solution was prepared in a conical flask fitted with a cotton wool plug and sterilized.
5. The sterile molten agar medium is then poured on the Petri dish by lifting the lid of the Petri dish slightly.
6. The Petri dish is allowed to stand till the agar is solidified.
7. 1 µL of the sample is then taken on the Petri dish using micropipette and spread evenly over the agar using spatula. This procedure is repeated for all samples. Blank is also taken without any sample.
8. The sample containing Petri dish are then transferred to an incubator set at 37ºC and observation is made after 24 hours and another observation at 48 hours.

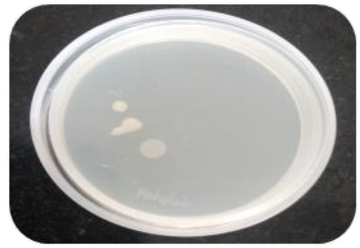
Table 7: Results of determination of bacteriological analysis.

S.No	No. of colonies (in 1 µL)	
	24 hours	**48 hours**
Sample 1	0	3
Sample 2	3	4
Sample 3	8	15
Sample 4	3	8
Sample 5	8	9
Sample 6	1	7
Sample 7	29	32
Sample 8	3	11
Sample 9	74	83
Sample 10	5	6
Sample 11	5	7
Sample 12	2	18
Sample 13	7	24
Sample 14	6	8
Sample 15	3	5
Sample 16	46	48
Sample 17	34	51

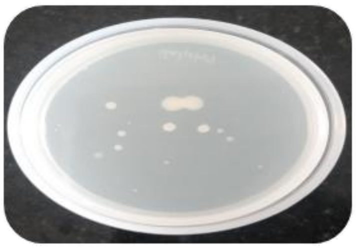
Blank



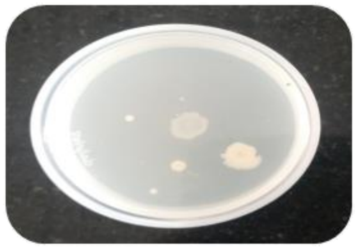
Sample 1



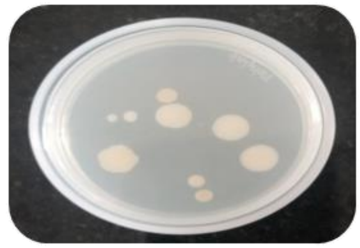
Sample 2



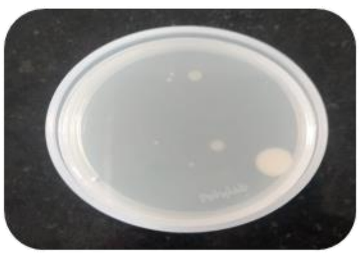
Sample 3



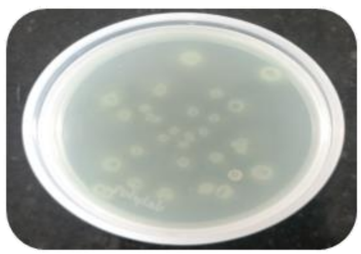
Sample 4



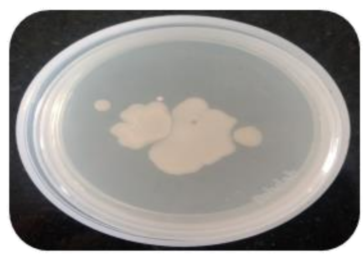
Sample 5



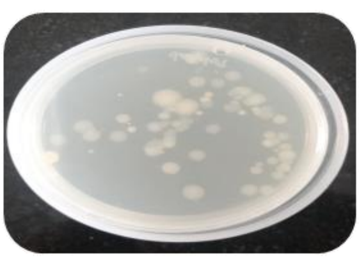
Sample 6



Sample 7

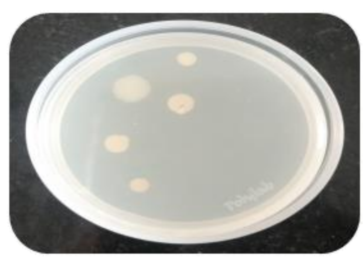


Sample 8

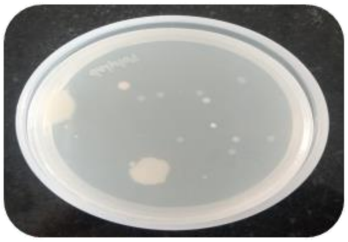


Sample 9

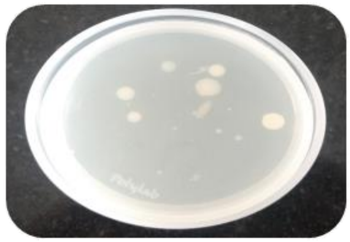
Sample 10



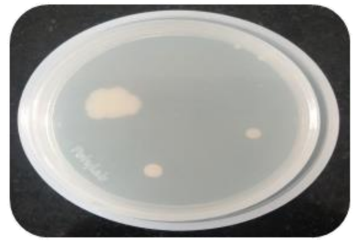
Sample 11



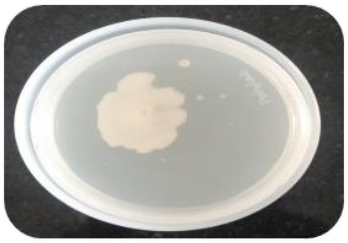
Sample 12



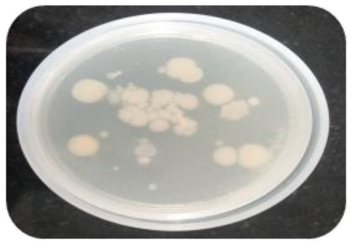
Sample 13



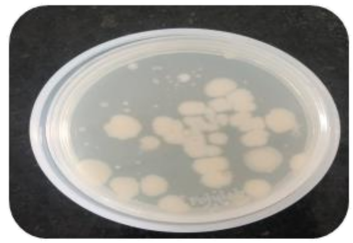
Sample 14



Sample 15



Sample 16



Sample 17

Figure 7: Observation of bacterial colonies in the samples

Isolation of bacteria from water sample:

First, the water sample to be tested for the presence of bacterial contamination was plated on general-purpose medium which supports a huge range of bacteria such as Nutrient Agar. After overnight incubation at 37° for 24 h, the colonies formed were purified by sub-culturing twice using the streaking plate method. Young cultures were used for primary screening which includes tests such as Gram Staining to isolate between the Gram Positive and Gram Negative bacteria, Indirect Staining of Bacteria (CAPSULE STAINING), Hanging Drop Method to determine bacterial motility and Endospore Staining to differentiate genera of bacteria, such as Bacillus and Clostridium which have the ability to produce resistant survival forms termed endospore. Further, secondary screening includes Biochemical tests which are used for characterization of the bacteria. These tests include Catalase test to detect the synthesis of catalase enzyme by bacteria, Oxidase test to determine the presence of cytochrome-c oxidase, an enzyme sometimes called indophenol oxidase, an enzyme of the bacterial electron transport chain, Indole production test, MR-VP test, Citrate utilization to perform citrate utilization test for the detection of faecal coliforms, Triple sugar iron test to determine whether gram-negative bacilli utilize glucose and lactose or sucrose fermentatively and produce hydrogen sulphide (H_2S), Carbohydrate Fermentation Test, Nitrate reduction test to check the differentiation between members of Enterobacteriaceae on the basis of their ability to produce nitrate reductase enzyme and Urease test to check the ability of the bacteria to produce urease enzyme. Alternatively, isolation of bacteria can also be done using differential media for different bacteria which support their growth. Some of those media include-

i. Tryptic Soy Agar (TSA) for the cultivation of non-fastidious bacteria, growth indicates non-fastidious bacteria present.
ii. Chocolate Agar for the cultivation of fastidious organisms such as Neisseria or Haemophilus sp.
iii. MacConkey (lactose) Agar which acts as both Selective and differential media. It selects for non-fastidious gram-negatives; red colonies indicate fermentation of lactose, white indicates no fermentation of lactose.
iv. Eosin-methylene Blue Agar (EMB) to differentiate lactose fermenters (E. coli) from non-fermenters (Salmonella, Shigella).
v. Mannitol Salt Agar selects for Staphylococci, which grow at high salt concentrations; differentiates Staphylococcus aureus from other Staphylococci. Staphylococcus aureus is yellow (ferments mannitol), other staphylococci are white.
vi. SS (Salmonella-Shigella) Agar is a selective medium used to isolate Salmonella and Shigella species.
vii. Thiosulphate-Citrate-Bile-Sucrose (TCBS) Agar is a selective medium used to isolate Vibrio cholera and other Vibrio species.
viii. Crystal violet blood agar is a selective media for Streptococcus pyogenes.

From the above study, it was inferred that only E. coli is present in the samples and this has been verified by multiple tests described above.

Treatment method for bacterial contamination:

According to IS10500:2012, if E. coli and total coliforms are found present in water after testing, several treatment methods are recommended for remediation. These methods primarily focus on disinfection and include chlorination, UV disinfection, and ozone treatment. Chlorination involves the use of chlorine-based compounds to eliminate bacteria by disrupting their cellular function. UV disinfection uses ultraviolet light to disrupt the DNA of microorganisms like E. coli and coliforms. Ozone treatment involves injecting ozone gas into water to effectively kill bacteria. These methods, when applied following BIS guidelines and standards, aim to ensure the removal or reduction of bacterial contaminants, thereby enhancing the safety and quality of drinking water in compliance with IS10500:2012. Regular monitoring, adherence to recommended dosages, and maintenance of disinfection residuals are crucial aspects to ensure sustained water safety.

Conclusion: According to the results obtained, we conclude with the following: Water quality in all water sampling sites with respect to Electrical Conductivity, Total Dissolved Solids, Dissolved Oxygen, Nitrates, Sulphates, Phosphates, Total Hardness and Iron was not consistent for at least one or more samples with the World Health Organization Drinking Water Quality (WHO) except for temperature and pH. Obtained results confirm the need to keep the concentration of nitrogen and nitrates in surface water under control, particularly considering the increasing trends of these nutrients which may lead to increased environmental overload and rapid eutrophication. Drinking water in some areas of Dimapur District are not suitable for human consumption due to high levels of bacterial contamination. The predominant bacteria found in this area are Escherichia coli (E. coli). To efficiently address microbiological contamination in surface waters, it is essential to follow the directives outlined by the Bureau of Indian Standards (BIS). BIS standards recommend a multifaceted approach involving robust water treatment processes like chlorination, ultraviolet (UV) disinfection, ozonation, or filtration to eliminate or reduce microbial contaminants (BIS, 10500:2012). Additionally, BIS-recommended methods for microbial analysis, including those for coliforms (BIS, 1622:2017) and other microbial indicators, play a significant role in assessing water quality. These standards offer critical insights into the presence of pathogens and microbial contamination, enabling the early detection of potential risks. Furthermore, BIS guidelines emphasize improved sanitation practices, efficient sewage treatment, and measures to control runoff from industrial or agricultural sources to prevent the introduction of pathogens into surface waters. By integrating these methods stipulated by BIS, communities can take comprehensive steps to safeguard surface waters, ensuring access to clean and microbiologically safe drinking water. Therefore, we recommend further studies in other regions of Dimapur with respect to suitability of drinking water for human consumption. This study revealed the nature of surface and groundwater contamination in the region and the periodic determination of various water quality parameters may help improve the water treatment process from the results of the acquired analysis and the probable economic management solution will be curved out of the whole analysis and field study.

References:

1. Bhuyan B (2011) Assessment of arsenic and iron contamination of ground water in four development blocks of Lakhimpur District, Assam, India. Der Chem Sin 2:316 – 323.

2. BIS (2012) Indian Standards Drinking Water Specifications IS 10500:2012. Bur Indian Stand Indian Stand Drink Water Specif 2:11.

3. Kalhor K, Ghasemizadeh R, Rajic L, Alshawabkeh A (2019) Assessment of groundwater quality and remediation in karst aquifers: A review. Groundw Sustain Dev 8:104–121. https://doi.org/10.1016/j.gsd.2018.10.004.

4. Ministry of Environment and Forests (2010) Status of Water Quality in India- 2010. Monit Indian Natl Aquat Resour Ser 1–141.

5. Ministry of Water Resources (2013) Ground Water Information Booklet Dimapur District, Nagaland.

6. World Health Organization (2012) Water quality and health strategy 2013-2020. 1–15.

7. World Health Organization (2011) Guidelines for Drinking-water Quality: Fourth Edition. 1–518.

8. World Health Organization (1997) Guidelines for drinking-water quality. 3: 1 – 28.

9. Bureau of Indian Standards. (2012). IS 10500:2012, Drinking Water - Specification (Second Revision).

10. Bureau of Indian Standards. (2017). IS 1622:2017, Water Quality - Enumeration of Coliforms - Membrane Filtration Method.

Annexure-2

Introduction

DIMAPUR is one of the important districts of Nagaland due to its geographical position, growing population and economic development. With rapid modernization and change in lifestyle patterns, the number of infrastructural developments taking place in the city has led to many environmental problems concerning water pollution, increase waste mismanagement, urban deforestation etc. The majority of the population in Dimapur rely on groundwater and depend entirely on its availability and quality. Drinking water in the Dimapur district is regulated under the Public Health Engineering Department, which establishes a safe and potable drinking water supply, proper disposal of solid and liquid waste and environmental hygiene. Groundwater as part of the hydrological cycle is inadequately discussed in the district's water resource planning, although groundwater exploitation is rising at an unprecedented pace. The present groundwater development in the district is seen only in Dimapur valley. Hilly terrain where groundwater development has a limited scope occupies the rest area of the district. The discharge of untreated waste from domestic and commercial sources into water bodies is a major source of water contamination in Dimapur. Other contributing factors are poor sanitation and lack of awareness. Furthermore, the district doesn't have proper sewage treatment plants.

Since groundwater is the main source of water, understanding the characteristics of the soil and geological setting is critical. About 64.9% of the area falls under forest and 50.03% suffers from moderate to severe erosion hazard. The study area is dominated by quaternary sediments and tertiary rocks. Quaternary sediments essentially consist of clay, sand and rock suitable for infiltration and replenishing groundwater whereas the tertiary rocks mainly composed of sandstone and shales forming the structural and residual hills that serve as runoff zones and therefore have less groundwater potential (Ministry of Water Resources, 2013). The composition of these rocks can significantly influence the chemical composition of groundwater. The interaction between rocks and groundwater can be considered as multi-faceted processes in hydrogeology where the groundwater chemistry can be resulted from leaching and/or minerals dissolution. The lithology of the region indicates the presence of two aquifer systems. An unconsolidated sandy aquifer with gravel and clay intercalations exists at a depth of 50 metres. The majority of the sand in this aquifer has a medium to coarse texture. The upper tertiary sandstone aquifers can be found at depths of 50-200 metres. Loamy sand, sandy clay and acidic soils are the three predominant types of soil found in the Dimapur district and the most common type of soil is red clay soil which generally contains a high amount of iron oxide.

In this context, it is mandatory to monitor physicochemical-bacteriological contaminants to assess water quality. To execute this work, samples from several points of the district were collected and analysed the association between water quality and health implications. Ten Physico-chemical parameters such as Temperature, pH, Dissolved Oxygen, Conductivity, Total Dissolved Solids, Hardness, Iron, Nitrate, Phosphates and Sulphates and bacteriological experiments were performed under BIS and WHO guidelines. Aluminium, Chromium, Silver, Zinc, Fluoride and Nitrite are not included in the study since their concentrations were always below the detection limit of the analytical instruments. The results of this study provide an analytical foundation to better understand water quality conditions in Dimapur areas stretching from 1st mile to 7th mile and also make observed data publicly available and interoperable. The pH suggests corrosive nature, which could interfere with the overall nature of water. The chemical parameter of the main concern is the high content of iron. Therefore, the origin of iron needs to be investigated by considering the hydro-geological characteristics of the sampling sites. Understanding water conditions in the Dimapur district will yield strategies for future urban water management in other districts of Nagaland and beyond. Thus, scientific data and research have an essential role in the development and enactment of SDGs through evaluations from local to global scales.

Description of the Sampling Site

Most of the sampling points were confined to bore-wells and ring-wells where the depth varies from 32–200 ft. Few samples have also been collected from rivers, given that certain parts of the region are still relying on them. The sampling points were chosen by identifying 16 locations from the seven representative villages in the district. About 3-5 water sources from every locality were sampled and analysed. The representative map of the study area are given in **Fig. 8**. In total, 64 water sources were examined, and samples were categorized into type 1, 2 and 3 according to depth as displayed in **Table 8**: bore well samples (N= 24) from 200 to 250-foot depth, ring well samples (N= 35) from 20 to 35-foot depth and surface water samples (n=5) are shown in the table below.

Table 8: Number of samples categorized into 3 types based on their depth.

Source Type based on Depth	No. of samples	Percentage
Type-1 (Bore Well)	24	37%
Type-2 (Ring Well)	35	54%
Type-3 (Rivers/Ponds)	5	7%

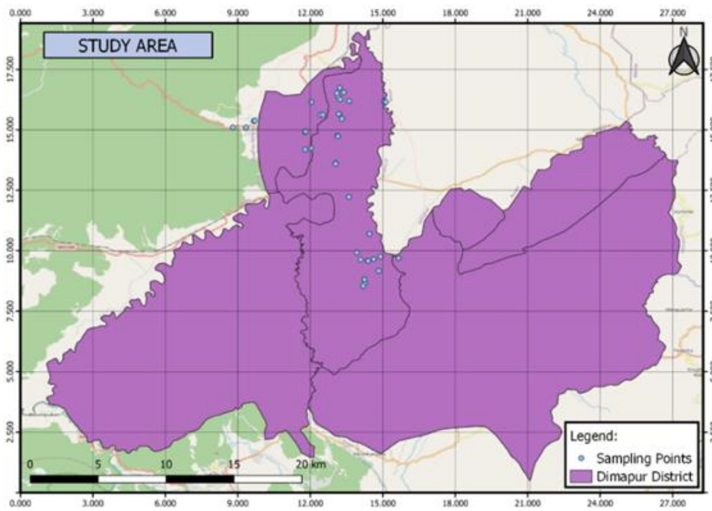


Figure 8: Representative map of the study area.

Methods for bacteriological analytical measurements and Statistical data Processing-Correlation, PCA and WQI analysis:

Bacteriological Analysis was carried out for all the samples using the Standard Plate Count method. The nature of drinking water and its contamination level was evaluated by the reference value assigned by BIS and WHO to quantify those samples that did not comply with the guidelines. Statistical correlation analysis was conducted by using IBM SPSS Statistics. The correlation between the parameters of the experimentally estimated water quality analysis was done by using the Pearson correlation matrix. Simple statistical parameters such as mean, standard deviation, minimum, and maximum were used to evaluate the data and to assess the distribution of the values for each parameter. Statistical data was used in this way to provide additional detail on the effects of the analysed water sample.

Principal Component Analysis (PCA) is a statistical technique that can be used to analyze and interpret complex datasets, such as water quality data. In this study, PCA was performed on EC, TDS, TH, sulphate, pH and nitrate based on Kaiser's criterion where only the components with eigen values more than one were considered (**Fig. 9**). An attempt has been made to evaluate the permissibility of water sources for human consumption based on the computed Water Quality Index (WQI) (Khangembam and Kshetrimayum, 2019). WQI is a water quality rating technique where bulk information is transformed into a simplified format that helps in estimating the impact of each parameter on the overall water quality. Nine parameters namely, pH, EC, TDS, DO, Fe, SO_4^{2-}, TH, NO_3^- and PO_4^{3-} were selected based on their importance in water quality. The calculated relative weight (***Wi***) values of each parameter concerning the Indian Standard

Specification for Drinking Water 2012 and the $\sum w_i$ and $\sum W_i$ were calculated as 31 and 1 respectively (see **Table 9**).

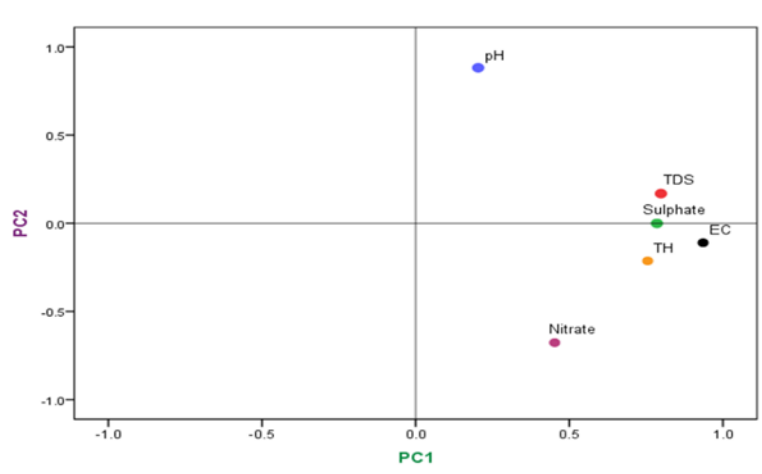


Figure 9: Plot of PC1 vs PC2

Table 9: Calculated relative weight (W_i) for each parameter to determine Water Quality Index of surface and groundwater in Dimapur District

Parameters	IS Guideline Value	Weight (w_i)	Relative Weight (W_i)
pH	6.5	4	0.129
Electrical Conductivity (EC)	600	3	0.097
Total Dissolved Solids (TDS)	500	4	0.129
Dissolved Oxygen (DO)	5	4	0.129
Iron (Fe)	0.3	4	0.129
Sulphate (SO_4^{2-})	200	4	0.129
Total Hardness (TH)	600	2	0.065
Nitrate (NO_3^-)	45	5	0.161
Phosphate (PO_4^{3-})	5	1	0.032
		$\sum w_i$=31	$\sum W_i$=1

The following steps were involved in the calculation of the WQI:

The first step involves weight assignment (between 1 to 5) to the individual 9 parameters based on their relative significance in determining water quality (Sahu and Sikdar, 2008). Due to its major significance in water quality assessment, a weight of 4 to 5 was allocated to pH, TDS, DO, Fe, SO_4^{2-} and NO_3^-. Minimum weights were given to other parameters such as EC, TH and PO_4^{3-}.

In the second and third step, relative weight, W_i, and quality rating scale, q_i, were calculated by using the equations 1 and 2 respectively:

$$W_i = \frac{w_i}{\Sigma w_i} \qquad (1)$$

where, w_i is the weight of individual parameter and $\sum w_i$ is the sum of the weights of all parameters.

$$q_i = \frac{C_i}{S_i} \times 100 \qquad (2)$$

where, C_i is the concentration of individual parameter, S_i is the Indian standard guideline value for each parameter.

To compute the WQI, the sub-index, SI_i, was first determined by multiplying relative weight with quality rating scale (equation 3). The summation of the sub-index values gives the WQI value.

$$SI_i = W_i \times q_i \qquad (3)$$

$$WQI = \sum SI_i \qquad (4)$$

Based on the above WQI values, the water quality is rated as excellent, good, poor, very poor and unfit for consumption as shown in the **Table 10**.

Table 10: Water Quality Rating as per the WQI (Sahu and Sikdar, 2008)

WQI	Water Type
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
> 300	Unfit for consumption

Results from Physical-Chemical Analyses:

Table 11 below displays the descriptive statistical results of the physico-chemical study (mean ± standard deviation, minimum and maximum values) along with the number of evaluated samples (N), permitted BIS and WHO reference values for drinking water with potential risks and the analyses results.

Table 11: Descriptive Statistical Results of the Physico-chemical Analysis with analysis results and probable effects

Parameter (Unit)	Year	N	Mean ± St. Dev.	Min.	Max.	BIS Limit (IS10500-2012)	WHO Limit (2004)	Risks (IS10500-2012)	Analyses Results
Temp (°C)	All	64				-	-	-	-
	2018	15	26.53 ± 2.16	22.00	29.00				
	2019	33	27.96 ± 1.77	25.00	34.00				
	2020	16	23.81 ± 2.66	20.00	28.00				
pH	All	64				6.5-8.5	6.5-8.5	Affects mucous membrane; Bitter taste; Corrosion.	Low pH (Acidic)
	2018	15	6.68 ± 1.02	5.31	8.41				
	2019	33	6.30 ± 0.54	5.32	7.17				
	2020	16	6.31 ± 0.50	5.78	7.48				
EC (μS/Cm)	All	64				300	-	Reduce water absorption by plants thus affecting its growth.	Non-saline to slightly saline type of water
	2018	15	292.62±112.94	81.43	470.10				
	2019	33	309.09±307.82	80.00	1700.00				
	2020	16	190.62±157.20	70.00	680.00				
TDS (mg/L)	All	64				500-2000	600-1000	Undesirable taste; Gastrointestinal irritation; corrosion or incrustation.	Lie in the range of excellent and good category
	2018	15	264.04± 98.81	77.93	411.10				
	2019	33	139.69±105.40	40.00	580.00				
	2020	16	123.75 ± 88.30	50.00	360.00				
DO (mg/L)	All	64				>5	-	-	Oxygen depletion observed in most samples
	2018	15	6.19 ± 1.15	5.02	9.14				
	2019	33	6.30 ± 0.54	0.40	7.70				
	2020	16	5.18 ± 1.35	2.10	7.10				
Iron (mg/L)	All	64				0.3	0.3	Iron bacteria causing slime; Bitter or metallic taste; colour and turbidity; rusty sediments.	Very high levels of iron. **Require immediate intervention**
	2018	15	0.36 ± 0.80	0.00	2.70				
	2019	33	4.08 ± 2.12	0.00	5.00				
	2020	16	1.09 ± 1.33	0.00	4.15				
Sulphate (mg/L)	All	64				100-200	-	Bitter or medicinal taste; Laxative effects; Gastrointestinal irritation.	Below permissible limit
	2018	15	14.33 ± 21.20	0.00	80.00				
	2019	33	18.78 ± 25.40	0.00	100.00				
	2020	16	10.62 ± 11.67	0.00	35.00				
Phosphate (mg/L)	All	64				-	0.1	Eutrophication.	Exceed the limit fixed by WHO
	2018	15	1.94 ± 2.25	0.50	7.50				
	2019	33	0.66 ± 1.77	0.00	9.80				
	2020	16	2.35 ± 5.95	0.00	24.20				
Total Hardness (mg/L)	All	64				600	-	Skin irritation: boiled meat and food become poor in quality.	Hard water
	2018	15	106.66 ± 71.78	37.50	300.00				
	2019	33	244.36±191.19	60.00	944.40				
	2020	16	176.56 ± 76.30	75.00	410.00				
Nitrate (mg/L)	All	64				45	50	Bacterial contamination, Methemoglobinemia or blue baby disease; algal growth.	Nutrient contamination
	2018	15	4.80 ± 8.16	0.00	25.20				
	2019	33	18.60 ± 35.37	0.00	132.80				
	2020	16	18.34± 27.92	0.00	84.50				

Results from Correlation study:

A correlation study provides the strength of association between variable parameters. The Pearson analysis at the probability of 0.05 indicated that EC and TDS, EC and pH, EC and Phosphate, EC and Nitrate, TDS and Sulphate, TDS and Phosphate, Fe and Temp, TH and Nitrate were significantly correlated.

EC demonstrated a strong positive correlation to TDS (.876) in the year 2018. In decreasing order, pH correlated positively and moderately with DO (.671), EC (.605), TDS (.596) and TH (.552). A moderate correlation between TH-pH (.552), TH-Sulphate (.666) and TH-DO (.664) was also observed. A total of eight significant correlation between parameters were identified around the same time. pH also showed a moderate negative correlation with nitrate (-0.633), which means that a decrease in pH value may increase the nitrate concentration in water (Amfo-Otu et al., 2014).

Another highly positive relationship between the EC and TDS (.952) can be seen from the 2019 water quality analysis. EC and TDS had both a moderately good correlation with sulphate (0.754), TH (0.753, 0.699) and nitrate (.511 and 0.5539). In all, eight strong positive correlations were identified in the region between different parameters. There was a moderate negative correlation between DO and Iron (-0.539) indicating that the concentration of iron increases with a reduction of DO. More samples were collected during the beginning of 2020 to analyse the strongly correlated variables. Again, a strong correlation has been found between the EC and TDS (.982) and with phosphate (.852 and .818) respectively. Temperature with iron (.712) and TDS with nitrate (.527) showed a moderate positive correlation. A moderately negative correlation was observed in TDS-iron (-0.537) and DO-TH (-0,537), indicating the inverse correlation of these parameters. One thing that all of the samples obtained over the years have in common is that EC and TDS have the highest positive correlation. Thus, correlation results indicate that TDS and EC are two significant physicochemical parameters of drinking water quality because they are correlated with the majority of the water parameters.

Table 12: Correlation study for different parameters for the year 2018, 2019 and 2020.

Strong-1 Moderate-7 Weak-12 Negative-25

2018	Temp	pH	EC	TDS	DO	Iron	Sulphate	Phosphate	TH	Nitrate
Temp	1									
pH	-0.37	1								

EC	-.633*	.605*	1							
TDS	-0.424	.596*	.876**	1						
DO	-0.16	.671**	0.415	.551*	1					
Iron	0.09	-0.205	0.019	-0.049	-0.143	1				
Sulphate	-0.124	0.133	-0.228	-0.107	0.117	-0.095	1			
Phosphate	0.2	-0.345	-0.411	-0.478	-0.292	0.276	-0.145	1		
Total Hardness	-0.306	.552*	0.27	0.345	.664**	-0.202	.666**	-0.257	1	
Nitrate	0.109	-0.502	0.034	0.12	-0.201	-0.283	-0.198	-0.026	-0.286	1

Strong-2 Moderate-6 Weak-10 Negative-27

2019	Temp	pH	EC	TDS	DO	Iron	Sulphate	Phosphate	TH	Nitrate
Temp	1									
pH	0.193	1								
EC	-0.202	-0.105	1							
TDS	-0.144	-0.114	.952**	1						
DO	-0.344	0.224	-0.001	0.054	1					
Iron	-0.011	-0.265	-0.234	-0.296	-.539**	1				
Sulphate	-0.049	0.072	.826**	.754**	-0.021	-0.307	1			
Phosphate	0.004	-0.125	-0.010	-0.006	-0.094	-0.079	-0.144	1		
Total Hardness	-0.109	-0.005	.753**	.699**	0.029	-0.075	.691**	0.111	1	
Nitrate	-.414*	-0.319	.511**	.539**	0.237	-0.336	0.257	-0.001	0.320	1

Strong-3 Moderate-3 Weak-14 Negative-25

2020	Temp	pH	EC	TDS	DO	Iron	Sulphate	Phosphate	TH	Nitrate
Temp	1									
pH	-0.178	1								
EC	-0.307	-0.054	1							
TDS	-0.405	-0.024	.982**	1						
DO	-0.328	0.021	0.042	-0.002	1					
Iron	.712**	-0.38	-0.493	-.537*	-0.313	1				
Sulphate	-0.393	0.101	0.258	0.34	-0.17	-0.375	1			
Phosphate	-0.31	-0.142	.852**	.818**	0.354	-0.395	-0.058	1		

Total Hardness	0.024	0.007	0.201	0.313	-.537*	-0.095	0.352	-0.01	1	
Nitrate	-0.113	-0.26	0.488	.527*	-0.209	-0.355	0.177	0.308	.700**	1

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

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

Results from Principal Component Analysis (PCA) analysis:

Two principal components were generated which cumulatively accounted for 71.11% of the total variance. PC1 accounted for 49.08% of the total variance. It exhibited high positive loadings on EC followed by TH, Sulphate and TDS (.941, .779, .776 and .763 respectively). Since EC shows strong loading in PC1, it can be considered as the salinity component. PC2 accounted for 21.367% of the total variance. It showed strong loadings on pH and nitrate (.902 and -.600 respectively). The positive loading on pH and the negative loading on nitrate corresponds to their negative correlation (**Table 13**). The presence of nitrate in water is mainly attributed to anthropogenic activities, particularly the use of fertilizers in agriculture. The anthropogenic usage of nitrogen fertilizers brings about nitrification, which results in H+ ions and nitrite, which is then oxidized to form nitrates (Kim et al. 2019). pH is reduced as nitrate levels increases.

Table 13: The loading matrix and total variance explained by each PC.

	Components	
Parameters	PC1	PC2
EC	**.941**	.034
TH	**.779**	-.096
Sulphate	**.776**	.120
TDS	**.763**	.288
pH	.067	**.902**
Nitrate	.550	**-.600**
Eigen values	2.985	1.282
% Of variance	49.750	21.367
Cumulative %	49.750	71.116

Results from Water Quality Index (WQI) analysis:

WQI values for all the 64 samples range from 47.6 to 498.3 (**Table 14**). In the year 2018 as shown in the Table, the WQI values lie between 47.6 and 178.5 and fall in the categories of ‘excellent’ to ‘very poor’. In 2019, the WQI falls in a wide range of 53.65 to 498.5 showing that water quality falls in 'poor to very poor' categories over the years. Furthermore, the WQI analysis in early 2020 ranges from 64.65 to 264.49 indicating 'very low' quality water. Based on overall WQI result, except for one sample, 28% belong to good water, 43% belong to poor water, 18% belong to very poor water and close to 7% of the collected samples belong to the unsuitable category which may be due to the presence of elevated trace elements like Fe. Therefore, the overall characteristics of the water show ‘good’ and ‘predominantly poor’ quality in terms of WQI. Based on the WQI Analysis of Dimapur District’s water quality from 2018 to 2020, the water of the studied area is not suitable for direct consumption.

Table 14: Calculation of WQI depicting the status for individual samples

Sample No	WQI	Water Status	Sample No	WQI	Water Status
1	88.02	Good water	33	305.04	Unsuitable
2	169.15	Poor water	34	171.318	Poor water
3	114.83	Poor water	35	286.82	Very poor water
4	96.6	Good water	36	121.24	Poor water
5	68.52	Good water	37	325.64	Unsuitable
6	65.83	Good water	38	210.63	Very poor water
7	178.58	Poor water	39	195.07	Poor water
8	73.18	Good water	40	201.47	Very poor water
9	55.35	Good water	41	382.29	Unsuitable
10	71.53	Good water	42	128.13	Poor water
11	47.6	Excellent water	43	498.3	Unsuitable
12	128.45	Poor water	44	114.02	Poor water
13	141.78	Poor water	45	102.09	Poor water
14	87.46	Good water	46	105.67	Poor water
15	95.05	Good water	47	228.34	Very poor water
16	83.9	Good water	48	155.70	Poor water
17	125.22	Poor water	49	118.92	Poor water
18	117.54	Poor water	50	121.06	Poor water
19	53.65	Good water	51	144.66	Poor water
20	89.57	Good water	52	64.65	Good water
21	113.69	Poor water	53	95.51	Good water
22	311.38	Unsuitable	54	119.85	Poor water
23	96.46	Good water	55	215.96	Very poor water

24	182.85	Poor water	56	82.15	Good water
25	263.05	Very poor water	57	239.57	Very poor water
26	102.92	Poor water	58	264.49	Very poor water
27	229.10	Very poor water	59	86.23	Good water
28	104.98	Poor water	60	211.92	Very poor water
29	147.38	Poor water	61	175.62	Poor water
30	279.73	Very poor water	62	180.30	Poor water
31	293.93	Very poor water	63	169.55	Poor water
32	91.85	Good water	64	193.69	Poor water

Table 15: Water Quality Index for drinking purpose in Dimapur District (year-wise)

Year	**Index value (Year)**	**Overall status**
2018	61.2	Good water
2019	223.8	Very poor water
2020	89.7	Good water

TDS/EC Ratio:

The TDS/EC ratio study provides an overview of the quality of water (Rusydi, 2018) and their relation are usually expressed in a simple equation: TDS = k EC (in 25°C)

Where k is the conversion factor associated with the chemical composition of the water. This correlation between EC and TDS is not always consistent but often estimated with a conversion factor of around 0.65 that is pre-programmed into a conductivity meter. The value of the conversion factor determines the nature/type of water. For a solution containing mostly sodium and chloride ions, a conversion factor value of 0.49 to 0.56 is typical. From this study, a linear association between TDS and EC is observed with a correlation ratio of 0.767, 0.325 and 0.551 in the samples for three sequential years (2018-2020) which indicates the nature of water is fairly fresh. The R^2 values for each year ranged from 0.767 to 0.964, indicating fairly strong correlations.

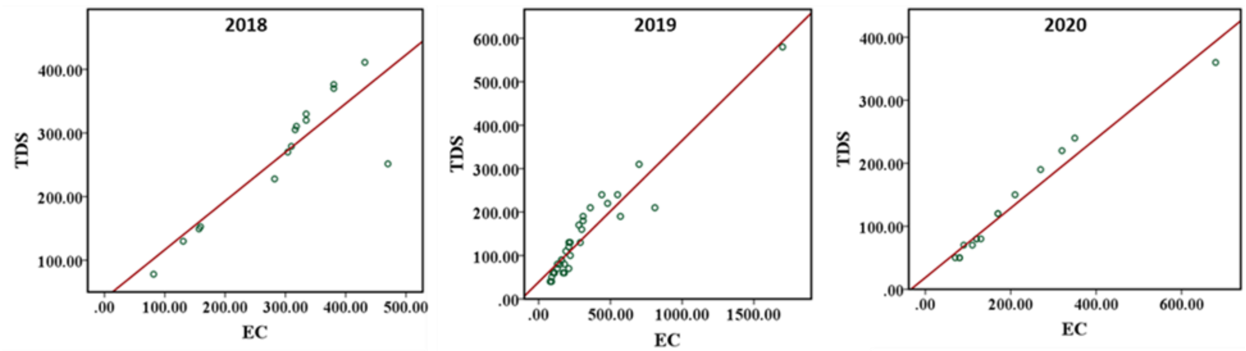


Figure 10: Correlation study of TDS and EC for the year (a) 2018 (b) 2019 (c) 2020.

Results from Bacteriological Study:

The most frequently encountered health effects associated with drinking water in rural areas are of biological origin. To evaluate the microbiological consistency of the various sampled sources, 64 samples were collected and analysed for the presence of bacteria. Based on the sources, all 64 samples were segregated into three categories: 15 out of 24 for bore wells; 22 out of 35 for ring wells and 4 out of 5 for surface waters showed the presence of bacteria rendering unfit for drinking (**Table 16**). The results depict that surface waters have a higher degree of contamination compared to the bore wells and ring wells. As per the BIS of drinking water, 64 per cent of the samples were found to be contaminated based on the overall results of the bacteriological evaluation.

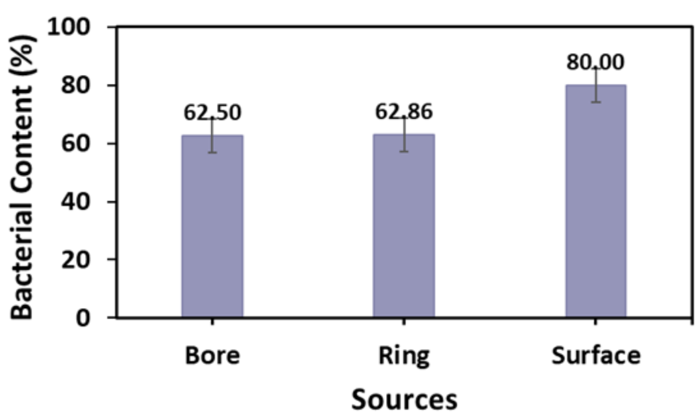
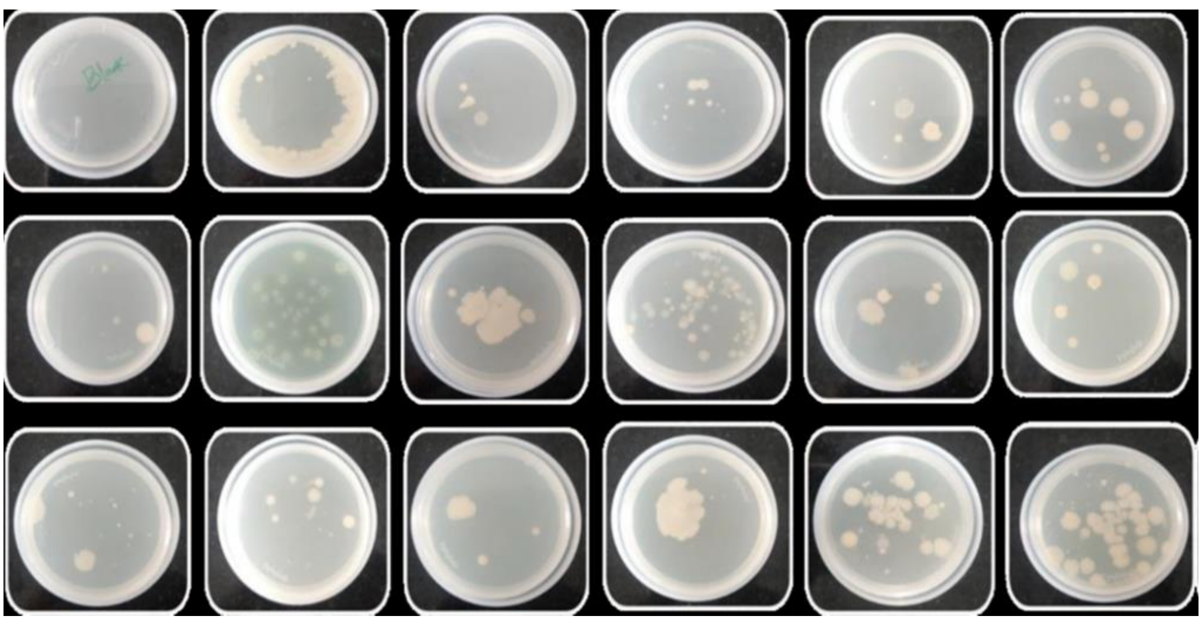


Figure 11: Percentage of bacterial content from different sources of water

Table 16: Water samples showing the presence of bacterial contamination

Sample No	Water Status	Sample No	Water Status	Sample No	Water Status	Sample No	Water Status

1	Nil	17	Nil	33	Yes	49	Yes
2	Nil	18	Nil	34	Yes	50	Yes
3	Yes	19	Nil	35	Yes	51	Yes
4	Yes	20	Nil	36	Yes	52	Yes
5	Nil	21	Yes	37	Nil	53	Yes
6	Yes	22	Yes	38	Yes	54	Yes
7	Yes	23	Nil	39	Yes	55	Yes
8	Nil	24	Nil	40	Yes	56	Yes
9	Yes	25	Nil	41	Yes	57	Yes
10	Nil	26	Nil	42	Yes	58	Yes
11	Nil	27	Nil	43	Yes	59	Yes
12	Yes	28	Nil	44	Yes	60	Yes
13	Nil	29	Yes	45	Yes	61	Yes
14	Nil	30	Nil	46	Yes	62	Yes
15	Nil	31	Nil	47	Yes	63	Yes
16	Nil	32	Yes	48	Yes	64	Yes



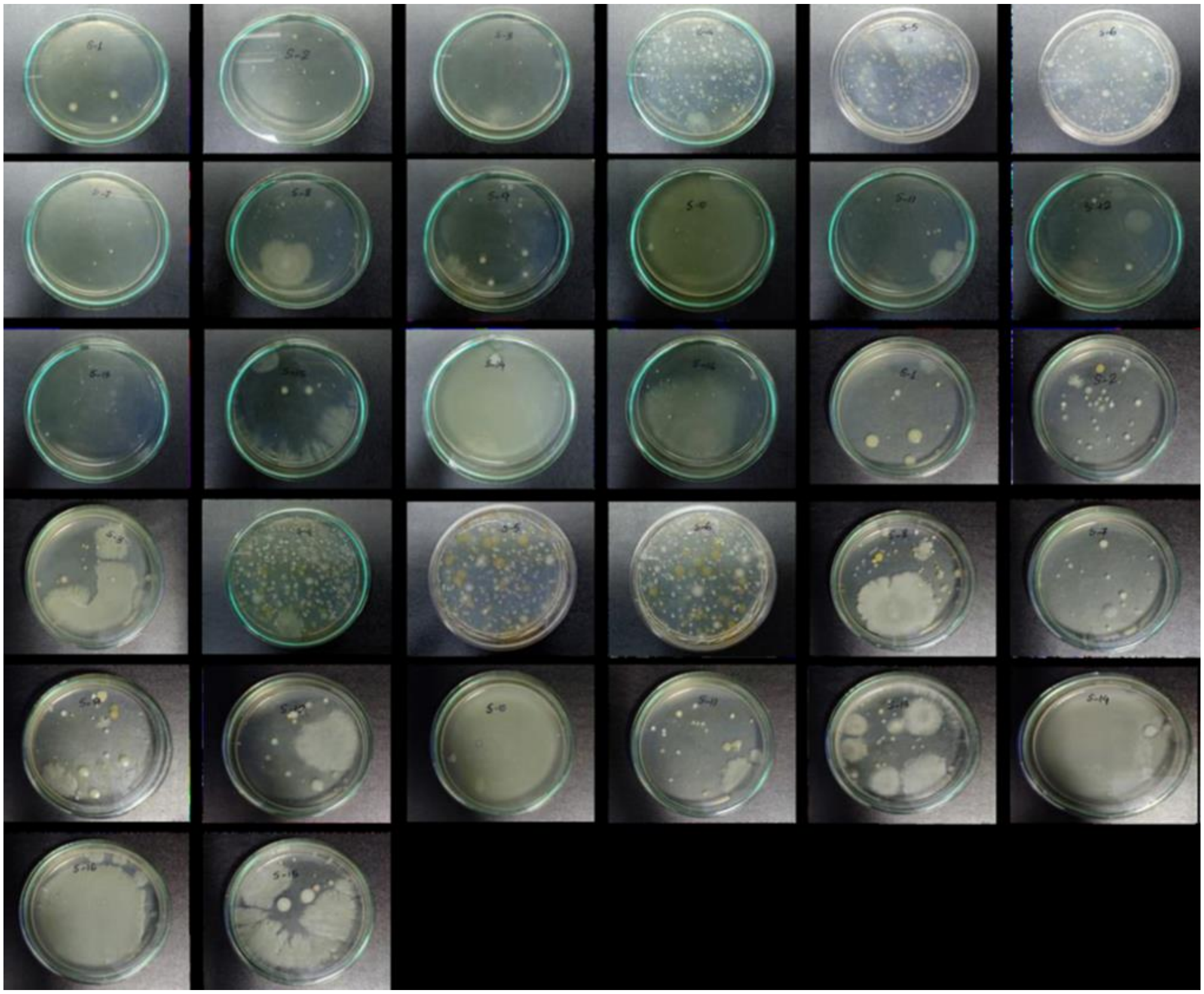


Figure 12: Bacterial Colonies observed in the samples after 24 hours.

<u>Achievements:</u>

This project provides a wide scope to the individuals, and the society at large since no thorough investigation have been conducted to monitor or assess the problem of water issues in Dimapur. This study also highlights the contamination levels of water in the region. This study adds to the existing literature for quantitative and qualitative water related concerns with particular reference to Dimapur that can be used for further reference. This project generates a data set that are required to understand the processes and mechanisms of variability in maintaining the quality of drinking water. Water issues is almost similar in every district of Nagaland and therefore, it is expected that whatever may be the finding of the study from this district, may be applicable to other districts too. Common health implications related to water contamination in the region are dysentery, diarrheal diseases, parasitic infestation, anaemia and most commonly gastrointestinal infection. Simple and conventional filtration method can still be put to use to fix and restore the water quality.

Conclusion:

The study aimed at assessing the drinking water quality in the Dimapur area and to identify the phenomenon that led to the contamination of these waters. According to the correlation report, TDS and EC are two important physicochemical parameters that determines the water quality since they are associated with the majority of water parameters. A linear association between TDS and EC observed in the samples for three consecutive years indicates 'fairly fresh' nature of water. The overall characteristics of the water are shown as 'good' and 'predominantly poor' quality in the computed Water Quality Index. This analysis indicates that Dimapur District's water quality from 2018 to 2020 is not suitable for direct consumption without prior treatment.

In conclusion, devising an innovative filtration unit to manage emerging contaminants is one way to address the issues of water quality but it will be more fundamental and compelling in terms of sustainable approach if one could stop the seepage of contaminants from the point source and avoid the pain of multiple trials and tests. Therefore, we suggest immediate intervention from the policymaker to develop a system-based strategy to guarantee the accessibility of contamination-free drinking water and also make water quality assessment data available to the public to raise awareness among the individuals.

References:

Alam, W., Singh, K.S., Gyanendra, Y., Laishram, R.J., Nesa, N., 2020. Hydrogeochemical assessment of groundwater quality for few habitations of Chandel District, Manipur (India). Appl. Water Sci. 10, 1–13. https://doi.org/10.1007/s13201-020-01208-0

Amfo-Otu, R., Agyenim, J.B., Nimba-Bumah, G.B., 2014. Correlation Analysis of Groundwater Colouration from Mountainous Areas, Ghana. Environ. Res. Eng. Manag. 67, 16–24. https://doi.org/10.5755/j01.erem.67.1.4545

Enyegue A Nyam, F.M., Yomba, A.E., Tchikangoua, A.N., Bounoung, C.P., Nouayou, R., 2020. Assessment and characterization of groundwater quality under domestic distribution using hydrochemical and multivariate statistical methods in Bafia, Cameroon. Groundw. Sustain. Dev. 10, 100347. https://doi.org/10.1016/j.gsd.2020.100347

Howladar, M.F., Chakma, E., Jahan Koley, N., Islam, S., Numanbakth, M.A. Al, Ahmed, Z., Chowdhury, T.R., Akter, S., 2021. The water quality and pollution sources assessment of

Surma river, Bangladesh using, hydrochemical, multivariate statistical and water quality index methods. Groundw. Sustain. Dev. 12, 100523. https://doi.org/10.1016/j.gsd.2020.100523

Khan, M.N., Mobin, M., Abbas, Z.K., Alamri, S.A., 2018. Fertilizers and their contaminants in soils, surface and groundwater, Encyclopedia of the Anthropocene. Elsevier Inc. https://doi.org/10.1016/B978-0-12-809665-9.09888-8

Khangembam, S., Kshetrimayum, K.S., 2019. Evaluation of hydrogeochemical controlling factors and water quality index of water resources of the Barak valley of Assam, Northeast India. Groundw. Sustain. Dev. 8, 541–553. https://doi.org/10.1016/j.gsd.2019.02.001

Kim HR, Yu S, Oh J, et al (2019) Nitrate contamination and subsequent hydrogeochemical processes of shallow groundwater in agro-livestock farming districts in South Korea. Agric Ecosyst Environ 273:50–61. https://doi.org/10.1016/j.agee.2018.12.010

Ministry of Environment and Forests, 2010. Status of Water Quality in India- 2010. Monit. Indian Natl. Aquat. Resour. Ser. 1–141.

Ministry of Water Resources, 2013. Central Ground Water Board.

Nagaland Pollution Control Board, 2019. Envis Nagaland.

Pamei, M., Naresh, G., Dutta, D., Puzari, A., 2020. Accessibility of safe drinking water in greater Dimapur area of Nagaland and related health hazards: an analytical study. Int. J. Energy Water Resour. 4, 245–255. https://doi.org/10.1007/s42108-020-00074-5

Rusydi, A.F., 2018. Correlation between conductivity and total dissolved solid in various type of water: A review. IOP Conf. Ser. Earth Environ. Sci. 118, 1–6. https://doi.org/10.1088/1755-1315/118/1/012019

Sahu, P., Sikdar, P.K., 2008. Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. Environ. Geol. 55, 823–835. https://doi.org/10.1007/s00254-007-1034-x

Verma, P., Singh, P.K., Sinha, R.R., Tiwari, A.K., 2020. Assessment of groundwater quality status by using water quality index (WQI) and geographic information system (GIS) approaches: a case study of the Bokaro district, India. Appl. Water Sci. 10, 1–16. https://doi.org/10.1007/s13201-019-1088-4

World Health Organization, 2017. Guidelines for Drinking-water Quality, Fourth edition incorporating the first addendum.

Extended work:

Figure 13 shows the sampling locations, which were chosen from seven representative localities in the district. 2-4 water sources were sampled and analyzed from every location. Bore-wells and ring-wells with depths ranging from 32 to 200 feet were chosen as groundwater (GW) samples.

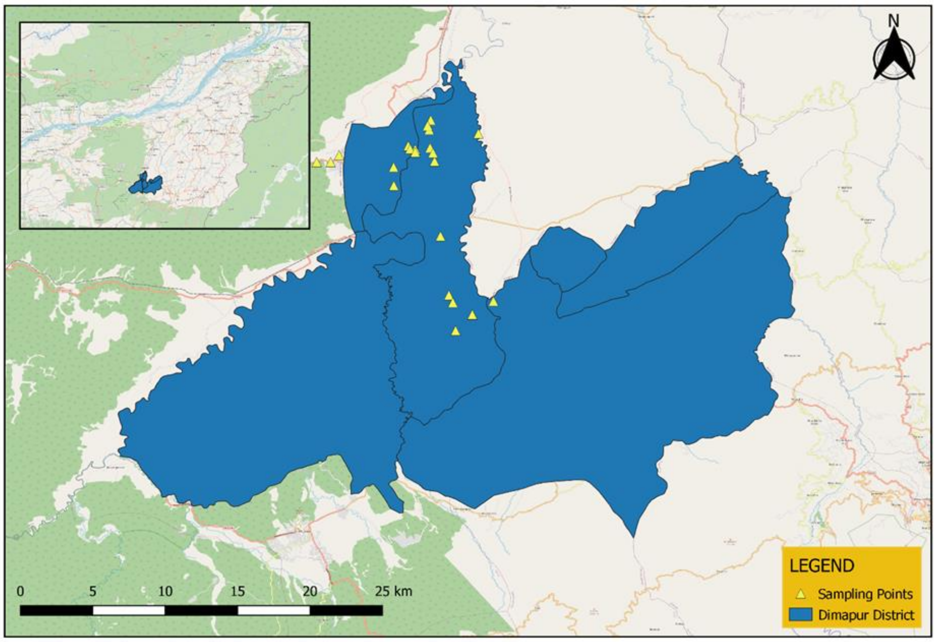


Figure 13. Groundwater sampling Sites

Materials and Methods

1. Physico-chemical Analyses

In this study, a total of 22 GW samples were collected in polyethylene bottles from the ring and bore wells from various locations of Dimapur District, Nagaland, India in October 2021. The analytical parameters include hydrogen ion concentration (pH), Alkalinity, Turbidity (Tur), Electrical conductivity (EC), Total dissolved solids (TDS), Salinity (Sal), Resistivity, Aluminium, Iron, Manganese, Silver, Zinc, and significant cations such as Sodium (Na^+), Calcium (Ca^{2+}), Potassium (K^+), and Magnesium (Mg^{2+}) as well as anions such as Sulphate (SO_4^{2-}), Phosphate (PO_4^{2-}), Chloride (Cl^-), Bicarbonates (HCO_3^-), Nitrates (NO_3^-), Fluoride (F^-), and heavy metals

(Cu, Mn and Zn). Sensitive water quality parameters such as pH were evaluated soon after the samples were brought into the laboratory using a digital pH metre (EuTech pH 610). Alkalinity was measured using Hanna Instruments benchtop, Multiparameter Spectrophotometer. The Multiparameter, EuTech CD 650 was used to test the TDS, EC, and Salinity. A turbidity metre (EuTech TN 100) was used to measure the turbidity. Mineral properties like presence of cations (Na^+, Ca^{2+}, K^+, Mg^{2+}) and anions (SO_4^{2-}, PO_4^{2-}, Cl^-, HCO_3^-, NO_3^-) were determined by using Ion Chromatograph (Metrohm 882 Compact IC Plus). Fluoride (F^-) was estimated by ion meter. (Thermoscientific ORION 4 STAR). Heavy metals, Cu, Mn, and Zn concentration was measured with the atomic absorption spectrophotometer (AAS). The water samples were analysed in the laboratory for chemical contents such as significant ions using established procedures recommended by the WHO (2007). The quality of the ground water was determined using Bureau of Indian Standards (BIS IS12000-2012) and World Health Organization (WHO, 2007) guidelines.

2. Determination of Water quality index (WQI)

The water quality index (WQI) is a rating technique that converts large amount of data into a simple format that aids in determining the overall quality of water. To assess the degree of groundwater contamination and acceptability, the WQI was calculated using the Weighted Arithmetical Index technique (**Table 17**), considering 11 water quality indicators (i.e., pH, EC, TDS, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, NO^{3-}, PO_4^{3-}).

Table 17. Calculated relative weight (Wi) for each parameter to determine Water Quality Index of groundwater in Dimapur District

Parameters	**WHO (2014)**	**Weight (w_i)**	**Relative Weight (W_i) (w_i)**
pH	6.5-8.5	4	0.125
Electrical Conductivity (EC)	1000	4	0.125
Total Dissolved Solids (TDS)	600	5	0.156
Calcium	75	2	0.062
Magnesium	50	2	0.062
Sodium	200	3	0.093
Potassium	10	2	0.062
Chloride	250	1	0.031
Bicarbonate (HCO_3^-)	120	3	0.093
Nitrate (NO_3^-)	45	5	0.156

Phosphate (PO_4^{3-})	5	1	0.031
		$\sum w_i$=32	$\sum W_i$=1

The following steps were involved in the calculation of the WQI:

The first step is to assign a weight (from 1 to 5) to each of the eleven parameters based on their relative importance in assessing water quality (refer WQI ref.). pH, TDS, EC and NO^{3-} were given a weight of 4 to 5 because of their importance in water quality assessment. Other metrics like Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^-, PO_4^{3-} were assigned minimum weights.

In the second and third step, relative weight, W_i, and quality rating scale, q_i, were calculated by using the equations 1 and 2 respectively:

$$W_i = \frac{w_i}{\sum w_i} \qquad (1)$$

where, w_i is the weight of individual parameter and $\sum w_i$ is the sum of the weights of all parameters.

$$q_i = \frac{C_i}{S_i} \times 100 \qquad (2)$$

where, C_i is the concentration of individual parameter, S_i is the Indian standard guideline value for each parameter.

To compute the WQI, the sub-index, SI_i, was originally obtained by multiplying relative weight with the quality rating scale to calculate the WQI (equation 3). The WQI value is calculated by adding the sub-index values together (equation 4).

$$SI_i = W_i \times q_i \qquad (3)$$

$$WQI = \sum SI_i \qquad (4)$$

The water quality is graded excellent, good, bad, very poor, and unfit for consumption based on the above WQI values, as indicated in Table 18.

Table 18. Water Quality Rating as per the WQI

WQI	**Water Type**
< 50	Excellent
50-100	Good

100-200	Poor
200-300	Very poor
> 300	Unfit for consumption

3. Correlation Matrix

IBM SPSS Statistics was used to conduct the statistical correlation study. The Pearson correlation matrix was used to determine the relationship between the parameters of the experimentally estimated water quality study. To examine the data and assess the distribution of the values for each parameter, simple statistical metrics such as mean, standard deviation, minimum, and maximum were employed. Statistical data was utilised in this way to offer more information about the impacts of the water sample that was tested.

4. Piper, Durov and Gibb's Diagram

Physico-chemical data from the area are graphically classed by plotting them in Piper Trilinear and Durov diagrams with Grapher software to understand the role of hydrochemistry, water quality, and its evaluation by comparing water types, and to interpret variation in hydro-chemical processes in the study area. Gibbs plots were constructed to interpret the hydro-geochemical operations about atmospheric precipitation, rock–water interaction, and evaporation over the administration of geochemistry of groundwater.

Results and discussion

1. Physical-Chemical Analyses

The table (**Table 19**) below shows the descriptive statistical findings of the physicochemical study (mean, standard deviation, minimum and maximum values), as well as the number of evaluated samples (N), authorised BIS and WHO reference values for drinking water.

Table 19. Descriptive Statistical Results of the Physico-chemical Analysis (N=22)

Parameter (Unit)	Mean ± St. Dev.	Min.	Max.	BIS Limit (IS10500-2012)	WHO Limit (2014)	Potential Risks (IS10500-2012)	Analyses Results
pH	7.50 ± .67	6.47	8.96	6.5-8.5	6.5-8.5	Mucous membrane irritation; bitter taste; corrosion.	Neutral range

Alkalinity (mg/L)	110.45 ± 95.21	15	415				Under permissible limit
Turbidity (NTU)	3.55 ± 11.67	0.11	55.4	1-5	5	Indicator of potential pollution in a water body.	With the exception of two samples, all of the samples fall within the permissible range.
EC (µS/Cm)	312.39 ± 240.33	73.79	911.5	300	1500	Impede plants' ability to absorb water, which hinder their growth.	Non-saline to somewhat saline water
TDS (mg/L)	319.78 ± 247.98	98.52	936.6	500-2000	600-1000	Unpleasant taste, digestive discomfort, incrustation.	Lie in the range of excellent and good category
Salinity (mg/L)	324.17 ± 256.35	91.82	963.4	-	-	Corrosion, poor health of vegetation, reduction in crop yields.	Fall between the excellent and good category
Resistivity (KΩ)	169.62 ± 322.97	1.06	965.6	1–5	-	-	Fall between the excellent and good category
Aluminium (mg/L)	.21 ± .28	.00	1.01	0.2	0.2	Excessive exposure has been linked to nerve damage, allergies, and is thought to be carcinogenic.	Under permissible limit
Calcium (mg/L)	53.56 ± 38.58	0.86	129.45	200	300	Significantly alters the nature of freshwater.	Under permissible limit
Iron (mg/L)	.79 ± .81	0	2.28	0.3	0.3	Rusty deposits, a bitter or metallic taste, a colour and turbidity, and iron bacteria that cause slime.	High iron concentrations. Need to be addressed right away
Potassium (mg/L)	9.91 ± 13.26	0.11	41.01	-	12	-	Under permissible limit
Magnesium (mg/L)	18.28 ± 8.99	6.93	41.05	100	50	Adverse effects on domestic use	Under permissible limit
Manganese (mg/L)	1.09 ± 1.25	0	4.01	0.3	0.4	Pipe clogs, poor-tasting water, Staining, prolonged exposure leads to fertility problems.	Exceed the limit recommended by BIS and WHO.

Silver (mg/L)	.015 ± .032	0	0.1	0.1	0.1	Organ damage, bluish-grey staining of the skin, eyes, gums, nails, and internal organs.	Under permissible limit
Sodium (mg/L)	45.01 ± 37.79	9.56	125.87	-	50	-	Under permissible limit
Zinc (mg/L)	.066 ± .14	0	0.51	5	-	Metallic taste, astringency and milky turbidity in the water.	Under permissible limit
HCO_3^- (mg/L)	134.86 ± 116.2	18	506	-	500	-	Under permissible limit
Chloride (mg/L)	.35 ± .51	0	2.05	250	250	Corroding pipes, salty taste, hypertension, blackening and pitting of stainless steel.	Under permissible limit
Fluoride (mg/L)	.18 ± .22	0	0.64	1.5	1.5	Severe dental mottling, bone disorders, and fluorosis of the skeleton	Under permissible limit
Nitrate (mg/L)	4.53 ± 6.71	0	21.57	45	50	Algal proliferation; bacterial contamination; Methemoglobinemia or the blue infant illness.	Nutrient contamination
Phosphate (mg/L)	1.19 ± .93	0	3.19	-	0.1	Eutrophication.	Exceed the limit fixed by WHO
Sulphate (mg/L)	8.20 ± 8.82	0	26.05	200	250	Laxative effects; a bitter or medicinal taste; and intestinal inflammation.	Below permissible limit

Table 20. Violation values for water samples

Parameter	WHO limit	Violation no	Violation (%)	Within (%)
pH	6.5-8.5	4	18	82
Turbidity	5	2	9	91
EC (µS/Cm)	1500	8	36	64
TDS (mg/L)	600-1000	0	0	100
Salinity (mg/L)	-	0	0	100
Resistivity (KΩ)	-	0	0	100
Aluminium (mg/L)	0.2	6	27	73
Calcium (mg/L)	300	0	0	100

Iron (mg/L)	0.3	12	55	45
Potassium (mg/L)	12	7	32	68
Magnesium (mg/L)	50	0	0	100
Manganese (mg/L)	0.4	14	64	36
Silver (mg/L)	0.1	1	5	95
Sodium (mg/L)	50	6	27	73
Zinc (mg/L)	-	0	0	100
Chloride (mg/L)	250	0	0	100
Fluoride (mg/L)	1.5	0	0	100
Nitrate (mg/L)	50	0	0	100
Phosphate (mg/L)	0.1	18	82	18
Sulphate (mg/L)	250	0	0	100

2. Water Quality Index (WQI)

WQI values for 22 samples range from 31.95 to 93 (**Table 21**) and fall in the categories of 'excellent' to 'good' indicating overall good quality water. Based on overall WQI result, 50% belong to excellent water and 50% belong to good water. Therefore, the overall characteristics of the water show 'good' quality in terms of WQI.

Table 21. Calculation of WQI depicting the status for individual samples

Sample No	WQI	Water Status
1	93.00	Good
2	51.00	Good
3	73.10	Good
4	39.46	Excellent
5	37.20	Excellent
6	37.65	Excellent
7	74.52	Good
8	73.40	Good
9	49.02	Excellent
10	51.67	Good
11	49.26	Excellent
12	39.48	Excellent
13	57.86	Good

14	58.61	Good
15	42.29	Excellent
16	40.77	Excellent
17	48.30	Excellent
18	65.17	Good
19	55.41	Good
20	87.90	Good
21	42.17	Excellent
22	31.95	Excellent

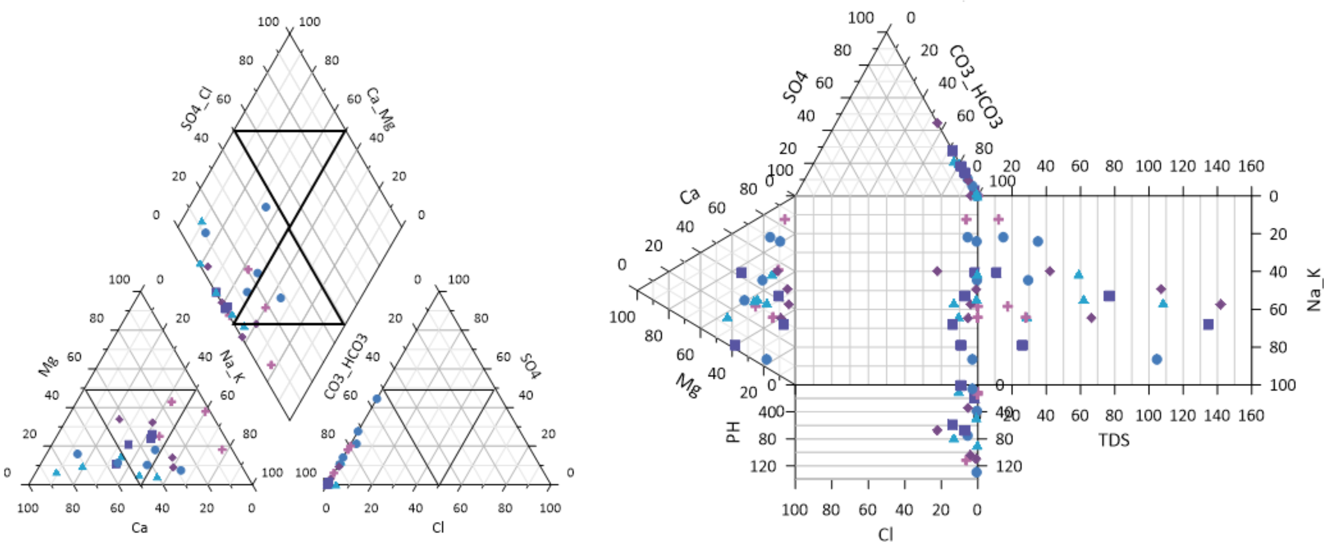
3. Correlation Matrix

Table 22 shows the Pearson correlation matrix derived from our experiments for each parameter. EC has a significant positive correlation with TDS (.997), Salinity (.989), and Resistivity (.784); and TDS has a strong positive association with Salinity (.993) and Resistivity (.786), indicating that EC and TDS increase with Salinity and Resistivity at all sites. The results revealed that there were no significant positive associations between EC and major ions. This can be attributed in part to spatial variances. Furthermore, groundwater constituents, such as Ca^{2+}, show a moderate negative relationship with EC (-.454), TDS (-.447), and salinity (-.447). (-.404). Ca^{2+}–Tur (0.336), Ca^{2+}–Cl^{-} (0.465), which are generally derived through natural processes, such as dissolution and rock–water contact (weathering), show a moderate positive connection. It is further seen that pH has significant positive correlation with Alkalinity (0.787) and HCO_3^{-} (0.787), Alkalinity with HCO_3^{-} (1.00), Turbidity with Cl^{-} (0.784), and Salinity with Resistivity (.764) and Alkalinity (0.661). Good associations were also observed between cation and anion, suggesting that they are derived from similar geochemical process.

Table 22. Correlation matrix of parameters (N = 22)

Correlation	pH	Alk	Tur	EC	TDS	Sal	Res	Al	Ca	Fe	K	Mg	Mn	Ag	Na	Zn	Cl	F	NO3	PO4	SO4	HCO3
pH	1																					
Alk	.787**	1																				
Tur	-0.196	-0.165	1																			
EC	0.403	.616**	-0.202	1																		
TDS	0.406	.622**	-0.199	.997**	1																	
Sal	.454*	.661**	-0.201	.989**	.993**	1																
Res	0.223	0.411	-0.134	.784**	.786**	.764**	1															
Al	-0.113	-0.062	.628**	-0.022	-0.013	-0.016	-0.059	1														
Ca	-0.131	-0.144	0.336	-.454*	-.447*	-0.404	-0.368	-0.056	1													
Fe	0.018	-0.269	0.113	-.448*	-.438*	-.425*	-0.396	-0.125	0.21	1												
K	-.438*	-0.242	0.119	-0.14	-0.166	-0.183	0.024	0.162	0.264	-0.336	1											
Mg	-.517*	-0.244	-0.186	-0.093	-0.091	-0.112	0.078	-0.106	-0.079	-0.096	0.177	1										
Mn	0.148	0.103	.519*	-0.185	-0.166	-0.162	-0.116	0.202	0.361	0.326	-0.098	-0.274	1									
Ag	0.23	.546**	-0.123	.496*	.498*	.477*	.547**	0.144	-0.172	-0.392	0.313	0.184	-0.112	1								
Na	-0.146	-0.17	.445*	-0.392	-0.411	-0.363	-0.336	0.201	0.245	.433*	0.034	0.142	0.197	-0.326	1							
Zn	-0.121	0.258	-0.068	0.256	0.259	0.237	0.355	-0.018	-0.033	-.436*	.586**	0.326	-0.087	.539**	-0.267	1						
Cl	-0.184	-0.266	.784**	-0.249	-0.242	-0.245	-0.26	0.389	.465*	0.14	-0.069	0.038	0.401	-0.282	0.388	-0.137	1					
F	-0.205	-0.11	.478*	-0.29	-0.275	-0.278	-0.318	0.307	0.246	-0.113	-0.228	-0.184	0.271	-0.246	0.115	-0.199	.467*	1				
NO3	-0.123	-0.08	-0.164	0.244	0.248	0.248	0.102	-0.02	0.042	-0.142	0.035	-0.049	-0.376	0.163	-0.267	0.129	-0.007	0.114	1			
PO4	-0.34	-0.258	-0.022	-0.085	-0.069	-0.108	0.07	0.273	-0.092	-0.128	0.085	.483*	-0.311	0.225	-0.155	0.135	0.178	0.133	0.206	1		
SO4	0.033	-0.006	-0.195	-0.206	-0.234	-0.24	-0.29	0.036	-0.123	0.041	0.072	0.022	-0.029	-0.075	0.024	0.183	-0.156	-0.071	0	-0.129	1	
HCO3	.787**	1.000**	-0.165	.616**	.622**	.660**	0.411	-0.063	-0.143	-0.268	-0.242	-0.244	0.103	.545**	-0.169	0.258	-0.266	-0.11	-0.08	-0.257	-0.007	1

4. Piper, Durov and Gibb’s Diagram



I. Cl-Na type; II. HCO_3-Ca type; III. Mixed type; IV. Cl-Ca type; V. HCO_3-Na type

Figure 14. Piper diagram (a) and Durov diagram (b) showing the hydro-chemical facies and processes of dissolution and mixing in GW samples.

Piper diagrams are useful for hydro-chemical analysis when a set of water quality data is presented in a geographical context (Piper 1944). It is a widely used method for studying and documenting the chemical development of groundwater that uses pattern recognition algorithms and allows water to be classified. It may also be used to identify patterns of spatial change in water chemistry between geological units, such as along a section line or a route line. It is useful for determining water flow and quality, as well as changes in water types and mixing relationships, using relative proportions of key ions rather than bulk concentrations. As a result, it is the most frequently applied tool for tracing hydro-chemical history and identifying key mechanisms that influence water chemistry. The Piper diagram plot shows the ionic supremacy of Ca^{2+} over Na^+ + K^+ and Mg^{2+} and of HCO_3^- over $SO4^{2-}$ and Cl^-, pointing to a Ca^{2+}-Na^+-HCO_3^- water type (Figure 2a). The Diamond diagram shows that 16 stations out of 22 falls into zone II and are subclassified as HCO_3^--Ca^{2+} type. While the Piper trilinear diagram is useful for understanding the association between rock types and water composition, the Durov diagram is also effective in detecting specific geochemical processes that may impact groundwater genesis.

The chemical composition of water samples is used to create a Durov diagram, which is a simple method for primary characterisation and categorization of groundwater types (Durov 1948). As shown in the diagram (Figure 2b), all samples fall into the C zone of the top triangle, suggesting the dominance of HCO_3^-. The key cations that regulate groundwater types are depicted in the left triangle. Most of the GW samples were of the Ca–Na–HCO_3 type, and Ca^{2+}, Na^+, and HCO_3^- play an important role in defining the fresh groundwater carbonate hydrochemistry of the Dimapur area. The Ca–Na–HCO_3 type groundwater indicates a combination of alkaline earth and alkali metals (Ca^{2+}, Na^+) and a weak acid (HCO_3^-) predominating over strong acids (Cl and SO_4^{2-}).

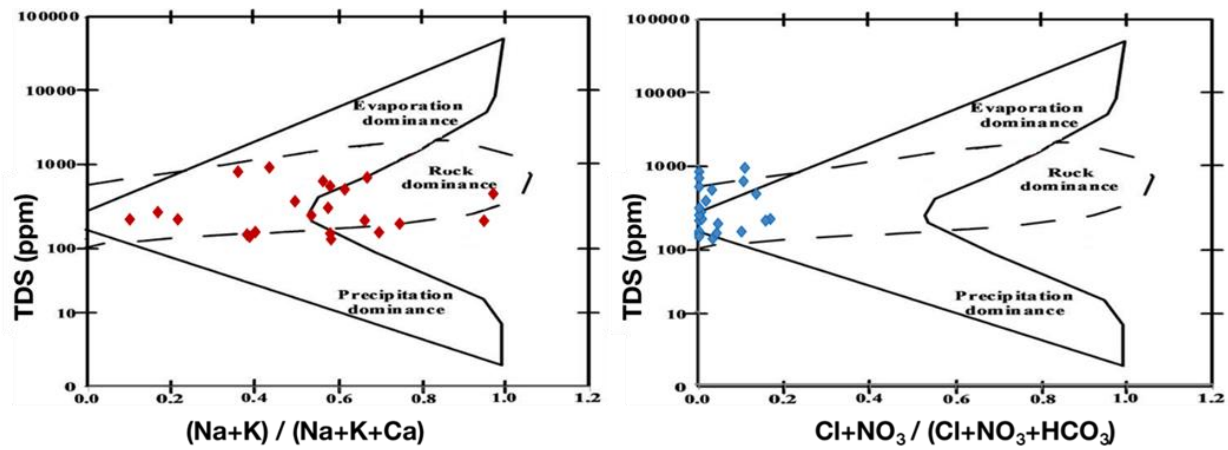


Figure 15. Gibb's plots depicting the processes that influence the groundwater geochemical characteristics.

Gibbs plots (Fig. 3), a plot of TDS against $Na^+ + K^+ / (Na^+ + K^+ + Ca^{2+})$ and $Cl^- + NO_3^- / (Cl^- + NO_3^- + HCO_3^-)$, is a useful graphical tool to determine the natural processes (water–rock interaction, precipitation, and evaporation) that govern the evolution of groundwater major-ion chemistry. Although originally utilised for surface water geochemical research, Gibbs plots have been frequently employed for groundwater studies. Gibbs plots mainly focused with the major cations and anions that represent the natural water systems of the end members, with Ca^{2+} and HCO_3^- for freshwater bodies and Na^+ and Cl^- for saline water bodies. The Gibbs diagram in this study demonstrates that all samples lie inside the rock dominance zone, implying that chemical weathering of rock-forming minerals via water–rock interaction is the major process determining Dimapur groundwater chemistry.

Irrigational quality parameters

The classification of the water samples from the study with respect to SAR value (1.5>SAR< 26.27) with an average value of 7.94, revealed that 16 water samples were found to be good for irrigation (S1 type; SAR <10), 5 samples fall in medium range and 1 sample exceed the recommended SAR value. The range of percent sodium values was 9.13 to 77.4, and classification of the water samples according to Wilcox, 1955 showed that 8 samples were safe for irrigation because their value was below 40 (i.e., excellent to good quality), 11 samples were within the permissible range (40-60), and 2 samples were bordering on the unsuitable range.

5. Bacteriological analysis

Bacteriological tests were performed on the collected water samples by serial dilution method. The water samples were put under incubation for 24 hours at a temperature of 37°C. From the data as shown in **Table 23** it can be inferred that the collected water samples are not safe for direct human consumption. The contamination level is highest for the Sample 19 with a value of 9.45×10^5 CFU/ml and least for Sample 16 with 2.50×10^4 CFU/ml. Sample 20 and 21 is also showing a higher bacterial count of 6.65×10^5 CFU/ml and 7.75×10^5 CFU/ml.

Table 23. Bacteriological study of the collected water samples

Sample	Bacteria (CFU/ml)
1	3.25×10^5
2	3.55×10^5
3	2.25×10^5
4	1.30×10^5
5	2.45×10^5
6	1.40×10^5
7	5.50×10^4
8	6.00×10^4
9	7.00×10^4
10	1.05×10^5
11	3.00×10^4
12	7.00×10^4
13	1.60×10^5
14	2.10×10^5
15	6.50×10^4
16	2.50×10^4
17	3.00×10^4
18	3.40×10^5
19	9.45×10^5
20	6.65×10^5

21	7.75×10^5
22	3.47×10^5

Conclusions

A total of twenty-two GW water samples were obtained from different point sources in Dimapur district's residential areas. pH, Alkalinity, Turbidity, EC, TDS, Salinity, Resistivity, Aluminium, Calcium, Iron, Potassium, Magnesium, Manganese, Silver, Sodium, Zinc, Chloride, Fluoride, Nitrate, Phosphate, Sulphate, Bicarbonate is among the parameters studied. Ion chromatography technique was used to investigate the presence of cations and anions in water. Pearson correlation matrix depict good associations between cation and anion, suggesting that they are derived from similar geochemical process. Based on overall WQI result, 50% belong to excellent water and 50% belong to good water. Therefore, the overall characteristics of the water show 'good' quality in terms of WQI. The **Piper** diagram plot shows the ionic supremacy of Ca^{2+} over Na^{+} + K^{+} and Mg^{2+} and of HCO^{3-} over $SO4^{2-}$ and Cl^{-}, pointing to a Ca^{2+}-Na^{+}-HCO^{3-} water type. As per the **Durov** plot, most of the GW samples were of the Ca–Na–HCO_3 type, and Ca^{2+}, Na^{+}, and HCO_3^{-} play an important role in defining the fresh groundwater carbonate hydrochemistry of the Dimapur area. The **Gibbs** diagram in this study demonstrates that all samples lie inside the rock dominance zone, implying that chemical weathering of rock-forming minerals via water–rock interaction is the major process determining Dimapur groundwater chemistry. The **sodium adsorption ratio** (SAR) shows that water quality in all the aquifers demonstrated that 8 samples were safe for irrigation purpose, 11 samples were under permissible limit and 2 samples were close to unsuitable range. Bacteriological analysis inferred that the collected water samples are not safe for direct human consumption.

References

1. World Health Organization. *State of the world's drinking water: An urgent call to action to accelerate progress on ensuring safe drinking water for all*. (2022).

2. Margat, J. & Gun, J. van der. *Groundwater around the world*. (2013).

3. Beyene, G., Aberra, D. & Fufa, F. Evaluation of the suitability of groundwater for drinking and irrigation purposes in Jimma Zone of Oromia, Ethiopia. *Groundw. Sustain. Dev.* **9**, 1–8 (2019).

4. Saxena, V. K. & Ahmed, S. Inferring the chemical parameters for the dissolution of fluoride in groundwater. *Environ. Geol.* **43**, 731–736 (2003).

5. Vijayakumar, V., Krishnakumar, S. & Vasudevan, S. An Environmental Quality Assessment on Groundwater Geochemistry in Western Part of Perambalur District, Tamilnadu, India. *J. Environ. Sci. Pollut. Res.* **2**, 54–56 (2016).

6. Singh, A. K. Arsenic Contamination in Groundwater of North Eastern India. *Natl. Semin. Hydrol. with focal theme "Water Qual.* 1–8 (2004).

7. Li, P. & Wu, J. Drinking Water Quality and Public Health. *Expo. Heal.* **11**, 73–79 (2019).

8. Aghzar, N., Berdai, H., Bellouti, A. & Soudi, B. Ground water nitrate pollution in Tadla (Morocco). *Rev. des Sci. l'Eau* **15**, 459–492 (2002).

9. Jacks, G., Bhattacharya, P., Chaudhary, V. & Singh, K. P. Controls on the genesis of some high-fluoride groundwaters in India. *Appl. Geochemistry* **20**, 221–228 (2005).

10. Ali, S. *et al.* Concentration of fluoride in groundwater of India: A systematic review, meta-analysis and risk assessment. *Groundw. Sustain. Dev.* **9**, 1–10 (2019).

11. Yadav, K. K. *et al.* Fluoride contamination, health problems and remediation methods in Asian groundwater: A comprehensive review. *Ecotoxicol. Environ. Saf.* **182**, 1–23 (2019).

12. Reddy, A. G. S., Reddy, D. V., Rao, P. N. & Prasad, K. M. Hydrogeochemical characterization of fluoride rich groundwater of Wailpalli watershed, Nalgonda District, Andhra Pradesh, India. *Environ. Monit. Assess.* **171**, 561–577 (2010).

13. Alobaidy, A. H. M. J., Maulood, B. K. & Kadhem, A. J. Evaluating Raw and Treated Water Quality of Tigris River within Baghdad by Index Analysis. *J. Water Resour. Prot.* **02**, 629–635 (2010).

14. Ombaka, O. & Gichumbi, J. M. Water quality assessment of Ruguti River in Meru South, Kenya. *Int. J. Water Resour. Environ. Eng.* **4**, 404–414 (2012).

15. Richards, L. A. *Diagnosis and improvement of saline and alkaline soils*. (1954).

16. Wilcox, L. V. *Classification and use of irrigation waters*. (1955).

Annexure-I

Consolidated and Audited
Utilization Certificate (UC) and Statement of Expenditure (SE)

For the Period: 01.04.2018 to 31.12.2021

1.	Title of the fellowship/Scheme:	Investigation of the possible health hazards associated with drinking water in south-west Nagaland and development of effective ways for water resource management.	
2.	Name of the Principal Investigator & Organization:	Dr. Amrit Puzari National Institute of Technology Nagaland	
3.	NMHS-PMU, G.B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, Uttarakhand Letter No. and Sanction Date of the Fellowship:	Letter No.- GBPNI/NMHS-2017-18/HSF-1 Sanction date- 28.03.2018	
4.	Amount received from NMHS-PMU, G.B. Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora, Uttarakhand during the fellowship period (Please give number and dates of Sanction Letter showing the amount paid):	**Sanction date** **1. 28.03.2018** **2. 06.05.2020** **3. 25.10.2021**	**Amount** **1. 5,21,400.00** **2. 5,21,400.00** **3. 4,24,050.28**
5.	Total amount that was available for expenditure (including commitments) incurred during the fellowship period:	**Rs. 14,70,642.00**	
6.	Actual expenditure (excluding commitments) incurred during the fellowship period:	**Rs. 13,68,116.8**	
7.	Unspent Balance amount refunded, if any (Please give details of Cheque no. etc.):	-	
8.	Balance amount available at the end of the fellowships:	**Rs. 1,02,525.2**	
9.	Balance Amount:	**Rs. 1,02,525.2**	
10.	Accrued bank Interest: FY 2021-22 (Rs. 3787.00) FY 2022-23 (Rs. 2398.00)	**Rs. 6185.00**	

06.12.2023
Principal Investigator
National Mission on Himalayan Studies
National Institute of Technology Nagaland
Chumukedima - 797103 : Nagaland

06/12/23
ASSISTANT REGISTRAR
National Institute of Technology
Chumukedima : Nagaland - 797103

6/12/23
Prof. S. Venugopal
Director
National Institute of Technology Nagaland
Chumukedima-797103, Nagaland

Certified that the expenditure of **Rs. 13, 68,116.80 (Thirteen Lakh Sixty-Eight Thousand One hundred Sixteen)** mentioned against Sr. No. 6 was actually incurred on the fellowship/scheme for the purpose it was sanctioned.

Date: 06|12|2023

06.12.2023	06/12/23	6/12/2023

(Signature of Principal Investigator)

Principal Investigator
National Mission on Himalayan Studies
National Institute of Technology Nagaland
Chumukedima - 797103 : Nagaland

(Signature of Registrar/ Finance Officer)

ASSISTANT REGISTRAR
National Institute of Technology
Chumukedima : Nagaland - 797103

(Signature of Head of the Institution)

Prof. S. Venugopal
Director
National Institute of Technology Nagaland
Chumukedima-797103, Nagaland

OUR REF. No.

ACCEPTED AND COUNTERSIGNED

Date:

COMPETENT AUTHORITY
NATIONAL MISSION ON HIMALAYAN STUDIES (GBP NIHE)

Statement of Consolidated Expenditure

[Institution Name here]

Statement showing the expenditure
of the period from Sanction No. and Date : 1. GBPNI/NMHS-2017-18/HSF-1 (**28.03.2018**)
2. GBPNI/NMHS-2017-18/HSF-11/605/484 (**06.05.2020**)
3. GBPNI/NMHS-2017-18/HSF-11/605/484/172/104/168 (**25.10.2021**)

1. Total outlay of the Fellowship : **16,06,968.00**

2. Date of Start of the Fellowship : 09.06.2018

3. Duration : 3 years and 9 months

4. Date of Completion : 31.12.2021

a) Amount received during the fellowship period : **14,70,642.00**

b) Total amount available for Expenditure : **14,70,642.00**

S. No.	Budget head	Amount received	Expenditure	Amount Balance/ excess expenditure
1	Salaries	Rs. 9,74,592.00	Rs. 9,36,948.00	Rs. 37,644.00
2	Contingencies	Rs. 4,01,250.00	Rs. 3,36,368.8	Rs. 64,881.2
3	Institutional charges	Rs. 94,800.00	Rs. 94,800.00	Rs. 0
4	Accrued bank Interest*	Rs. 6185.00		Rs. 6,185.00
5	**Total**	**Rs. 14,76,827.00**	**Rs. 13,68,116.8**	**Rs. 1,08,710.2**

*An amount of Rs. 3787/- and Rs. 2398/- (Total= 6185/-) earned towards bank interest during FY 2021-22 and FY 2022-23.

06.12.2023
Principal Investigator
National Mission on Himalayan Studies
National Institute of Technology Nagaland
Chumukedima - 797103 : Nagaland

06/12/23
ASSISTANT REGISTRAR
National Institute of Technology
Chumukedima : Nagaland - 797103

6/12/2023
Prof. S. Venugopal
Director
National Institute of Technology Nagaland
Chumukedima-797103, Nagaland

Certified that the expenditure of **Rs. 13, 68,116.80 (Thirteen Lakh Sixty-Eight Thousand One hundred Sixteen)** mentioned against Sr. No.5 was actually incurred on the fellowship/ scheme for the purpose it was sanctioned.

Date: 06/12/2023

06.12.2023	06/12/23	6/12/2023
(Signature of Principal Investigator)	(Signature of Registrar/ Finance Officer)	(Signature of Head of the Institution)
Principal Investigator, National Mission on Himalayan Studies, National Institute of Technology Nagaland, Chumukedima - 797103 : Nagaland	ASSISTANT REGISTRAR, National Institute of Technology, Chumukedima : Nagaland - 797103	Prof. S. Venugopal, Director, National Institute of Technology Nagaland, Chumukedima-797103, Nagaland

OUR REF. No.

ACCEPTED AND COUNTERSIGNED

Date:

COMPETENT AUTHORITY
NATIONAL MISSION ON HIMALYAN STUDIES (GBP NIHE)

Annexure-II

राष्ट्रीय प्रौद्योगिकी संस्थान नागालैंड

NATIONAL INSTITUTE OF TECHNOLOGY NAGALAND

(An Institute of National Importance under Ministry of Education, Govt of India)

Chumukedima, Dimapur, Nagaland-797 103

Consolidated Interest Earned Certificate

Sl. No.	Financial year (FY)	Interest Amount
1	2018-2019	Rs. 13,008.00
2	2019-2020	Rs. 17,072.00
3	2020-2021	Rs. 3787.00
4	2021-2022	Rs. 3787.00
5	2022-2023	Rs. 2398
	Total	**Rs. 40,052.00**

Certify that an amount of Rs. **Rs. 40,052.00 (Forty Thousand and Fifty-Two**) has been earned interest under NMHS Project during the fellowship period.

Annexure-III

DIRECT BENEFIT TRANSFER (DBT) DETAILS

Scheme Name:	**National Mission on Himalayan Studies (NMHS)**
Scheme Type:	**Central Sector (CS) Grant-in-Aid Scheme**
Scheme Code:	**NMHS**
Category:	**Fellowship Grant**
Month-Year:	**April 2018-December 2021**

PRO FORMA FOR DBT DETAILS

University/Institution Name: National Institute of Technology Nagaland

S#	Position (H-RA, H-JRF/ H-JPF)	Name	DoB*	DoI*	PI	Research title	Objectives	Study Area, IHR State	Contact details (Complete corresponding address), Mobile No., E-mail ID	Bank details (Account number, IFSC Code)	Emoluments /Fellowship	Aadhaar No.
1.	H-SRF	Ms. Mala Pamei	27-04-1987	08-06-2018	Dr. Amrit Puzari	Investigation of the possible health hazards associated with drinking water in south-west Nagaland and development of effective ways for water resource management.	To identify the available water resources and conduct physical and chemical analysis from different sources of South-West Nagaland for possible toxic contaminants and look for possible remedial measures.	South West Nagaland	National Institute of Technology Nagaland, Chumukedima-Dimapur, Nagaland-797103. Cont #: 7085473939 Email: ciliupam@gmail.com	Acc. No. 913010053717049 Acc. Name: Mala Pamei IFSC Code: UTIB0000378 Branch Name: Dimapur	Rs. 9,36,948.00	933592049857

Note: For each month, the DBT Details Pro forma dully filled and signed for each Himalayan Fellowship Grant under NMHS must be submitted at finance.nmhspmu2017@gmail.com; nmhspmu2016@gmail.com. *DoB (Date of Birth); DoJ (Date of Joining).

Principal Investigator
National Mission on Himalayan Studies
National Institute of Technology Nagaland
Chumukedima - 797103 : Nagaland

ASSISTANT REGISTRAR
National Institute of Technology
Chumukedima : Nagaland - 797103

(Authorized Signatory)

Month **2019 – Latest Updated List of Himalayan Researchers or Fellows** *(working in the current time)*

S#	Name	Fellowship (RA/JRF/JPF)
1.	**Ms. Mala Pamei**	**SRF**

Annexure-IV

Details and Declaration of Refund of Any Unspent Balance

Please provide the details of refund of any unspent balance as RTGS (Real-Time Gross System) in favor of **NMHS GIA General** and declaration on the official letterhead duly signed by the Head of the Institution.

Kindly note the further Bank A/c Details as follows:

Name of NMHS A/c:	NMHS GIA General
Bank Name & Branch:	Central Bank of India (CBI), Kosi Bazar, Almora, Uttarakhand 263643
IFSC Code:	CBIN0281528
Account No.:	3530505520 (Saving A/c)

In case of any queries/ clarifications, please contact the NMHS-PMU at e-mail: nmhspmu2016@gmail.com

Technology Transfer and/ or Intellectual Property Rights Certificate

With a view to encourage the institutions to file patent applications on their innovations, motivate them to transfer their technologies for commercialization, and facilitate them to reward their inventions, the following instructions are issued.

1. In these instructions:

(a) **"Institution"** means any technical, scientific or academic establishment where research work is carried out through funding by the Central / State Government.

(b) **"Intellectual Property Rights"** include patents, registered designs, copyrights and layout design of integrated circuits.

(c) **"Inventor"** means an employee of the institution whose duties involve carrying out of scientific or technical research.

2. **Scope:** These instructions apply to those institutions receiving funds for research projects/ fellowships from NMHS, the Ministry of Environment, Forest and Climate Change (MoEF&CC).
3. **Inventions by institutions:** Institutions shall be encouraged to seek protection of Intellectual Property Rights (IPR) to the results of research through R&D projects/ fellowships. While the patent may be taken in the name(s) of inventor(s), the institutions shall ensure that the patent is assigned to it & DBT, GOI. The institution shall take necessary steps for commercial exploitation of the patent on non-exclusive basis. The institution is permitted to retain the benefits and earnings arising out of the IPR. However, the institution may determine the share of the inventor(s) and other persons from such actual earnings. Such share(s) shall be limited to 1/3rd of the actual earnings.
4. **Inventions by institutions and industrial concerns:** IPR generated through joint research by institution(s) and industrial concern(s) through joint efforts can be owned jointly by them as may be mutually agreed to by them and accepted by the Department through a written agreement. The institution and industrial concern may transfer the technology to a third party for commercialization on exclusive/non-exclusive basis. The third party, exclusively licensed to market the innovation in India, must manufacture the product in India. The joint owners may share the benefits and earnings arising out of commercial exploitation of the IPR. The institution may determine the share of the inventor(s) and other persons from such actual earnings. Such share(s) shall not exceed 1/3rd of the actual earnings.
5. **Patent Facilitating Fund:** The institution shall set apart not less than 25 per cent of such earnings for crediting into a fund called Patent Facilitating Fund. This Fund shall be utilized by the institution for updating the innovation, for filing new patent applications, protecting their rights against infringements, for creating awareness and building competency on IPR and related issues.
6. **Information:** The institutions shall submit information relating to the details of the patents obtained, the benefits and earnings arising out of IPR and the turnover of the products periodically to the Department/Ministry, which has provided funds.
7. **Royalty-free license:** The Government shall have a royalty-free license for the use of the intellectual property for the purposes of the Government of India.

(HEAD OF THE INSTITUTION) 6/12/2023

(Signed and Stamped)

Prof. S. Venugopal
Director
National Institute of Technology Nagaland
Chumukedima-797103, Nagaland

06/12/2023
Principal Investigator
National Mission on Himalayan Studies
National Institute of Technology Nagaland
Chumukedima - 797103 : Nagaland