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Assessment of Drinking Water Accessibility and Quality in the Indo-Bhutan Himalayan Foothill Region of Assam, India

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ABSTRACT

Despite fairly heavy rainfall, the Bhutan Himalayan foothill region of Assam has been facing serious water scarcity problems mainly due to the subsurface structure and soil condition. The local people of the region with their community efforts and traditional knowledge have developed a water management system locally known as Dong-bandh. This traditional canal water system provides the most reliable source of water to the people residing in the area. Besides the canals, they also collect water from the streams, natural springs, and wells. The quality of water is getting deteriorated over time under the influence of the growing population and their activities in the upstream areas. The present study is an attempt to investigate the status of water accessibility in the area and the quality of the drinking water used by the people. For this study, data and information have collected through field investigation, GPS survey, focus group discussion, and interviews with some key informants. A total of 14 drinking water samples were collected randomly from 14 foothill villages (both from the ground and surface) and tested to determine various physiochemical characteristics. The results were compared with the WHO and BIS/ ICMR water quality standards. Finally, the status of water quality was analyzed in terms of the Water Quality Index (WQI). The WQI values were found to lie between 21.75 to 502.38.

INTRODUCTION

Easy availability and accessibility of safe drinking water are not only the pre-requisite for preventing diseases but also for improving the economic condition and quality of life (Khound & Bhattacharyya 2018, Nabila et al. 2014, Rawal et al. 2018, Rickert et al. 2016). United Nations (Sustainable Development Goal 6.1) make a target to achieve universal and equitable access to safe and affordable drinking water facilities by 2030. But still, billions of people across the world have been suffering from a lack of safe and adequate drinking water supply (Mandour 2012). According to an estimate, there were 2.2 billion people throughout the world without safely managed drinking water in 2017, out of which 144 million people used surface water (UNICEF & WHO 2019). The condition is more acute in highly populated countries like India where more than 163 million people still do not have clean and safe drinking water. The people in the Himalayan region have been primarily using surface water and natural spring for their drinking purposes (Sharma et al. 2005). However, the water quality is deteriorating currently due to the rapid population growth, deforestation, and expansion of agriculture, industries, and other anthropogenic activities (Effendi 2016, Mir et al. 2019, Sabha et al. 2019, Seth et al. 2016). Therefore, the assessment of water quality has become a matter of concern in recent times for ensuring a safe drinking water supply and reduction of water-borne diseases (Ameen 2019).

Like other people of the Himalayan states in India, the local communities in the Bhutan Himalayan foothill region of Assam also mainly depend on surface water for their survival. The indigenous communities of this region have invented a traditional canal water management system, locally called the *dong-bandh* system. They have diverted the river/stream water by putting small check dams and canalizing into their villages through earthen canals, called *dong*. These century-old traditional dongs have been used as the principal source of drinking water in the entire Bhutan Himalayan foothill region of the State (Saha et al. 2020). In the recent past, few community wells have been constructed by the government in some villages. But the construction of a dug well or tube well is very difficult due to rocky underground sub-surface and very low level of groundwater. Construction of dug well is also very costly; therefore, the individual households cannot effort such costs. Very recently, the government has also installed a deep tube well and water tank locally called 'pani tanki' in the villages of this area. But the number of deep tube wells is not sufficient. Only one deep tube well was installed in some villages against every 50-120 households. However, this initiative of the government has reduced the drinking water supply problems of this area to some extent. However, many of the government-supported wells and tube wells have become defunct. Therefore, many villages along the Himalayan foothill zone still depend on man-made canals, natural springs, small streams, and rivers. Although few research works on the water management system of this region were done, the issues of drinking water accessibility and quality were not addressed in any one of these works. Therefore, the present study has been carried out to know the status of drinking water accessibility and quality in this foothill region.

BACKGROUND OF THE STUDY AREA

This study has been carried out in the Bhutan Himalayan foothill region of the Baksa district in Assam, India. The study area lies along the Indo-Bhutan border extending from 26°42’11” N to 26°49’57” N latitude and from 91°4’39” E to 91°44’20” E longitude (Fig. 1). The area encompasses a geographical area of 513.25 sq. km. with a population of 204381 as per the 2011 Census. The area is located between the Shiwalik Himalayan range on the north and the floodplain zone of the mighty Brahmaputra river on the south; Barnadi Wildlife Sanctuary on the east and Manas National Park on the west. The average elevation of the area varies between 350m and 70m. The region is crisscrossed by several perennial and ephemeral streams and is covered with dense forests. It receives heavy rain during the monsoon season (June- September). The average annual rainfall of the area is 2971.6 mm and the average monthly rainfall during monsoon ranges between 568.15 mm and 274.16 mm. The people of this area, however, face major water scarcity difficulties, particularly during the winter and pre-monsoon season, due to heavy deposition of coarse sediments due to the sharp fall in gradient and the sub-surface flow of channel water due to high porosity of sediments (Saha et al. 2021).

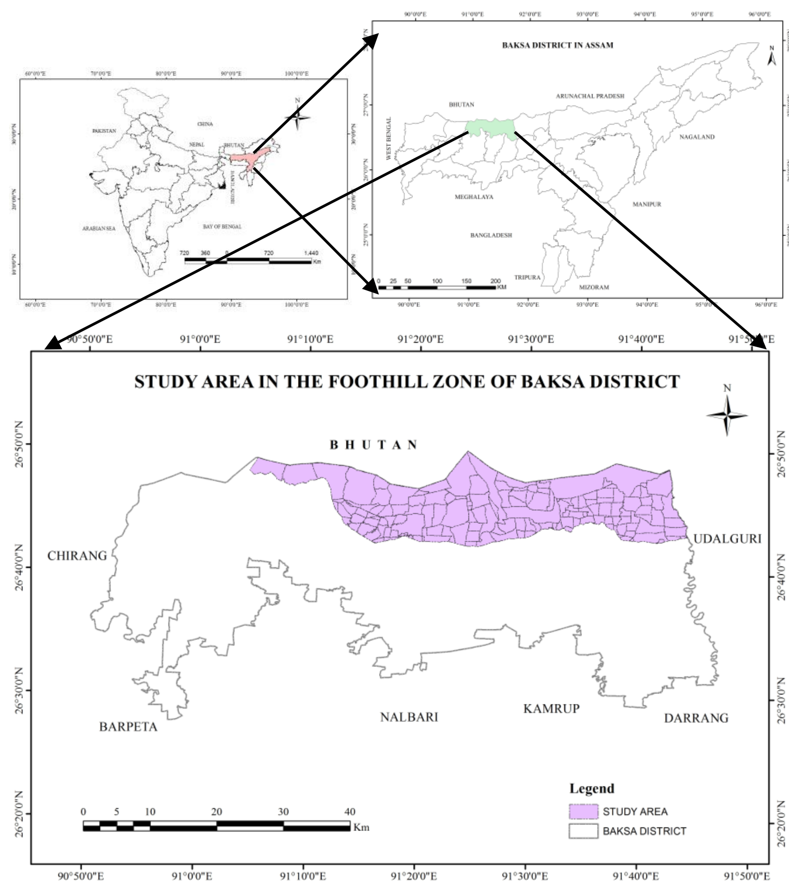


Fig. 1: Location of the study area.

MATERIALS AND METHODS

The study has been carried out in two different stages. First, personal field observation has been performed throughout the area in different seasons. After getting a general idea about the area, a total of 17 villages were selected randomly. One drinking water source from each village has been selected for collecting different information such as location, household dependency, management system, seasonal variation of water availability, and nature of water collection. PRA, focus group discussion (FGD), and interviews with the key informants and stakeholders were conducted to understand the status of drinking water availability and accessibility in the area.

In the second stage, we try to investigate the quality of drinking water. To study the status of water quality, 14 water samples (S1-S14) from both ground, as well as surface water, were collected from 14 randomly selected villages. The samples were collected during the pre-monsoon season. The water samples were collected in 1L high-density polyethylene bottles. Before collecting the sample, the bottles were rinsed thrice with the sample water (APHA AWWA and WEF 1992). Surface water samples were collected from the center of the canals at $1/3^{rd}$ depth from the surface water level where the velocity was sufficiently high (Khound & Bhattacharyya 2018). Two sets of samples were collected from each sample location. Untreated raw water was collected first and the second was acidified with nitric acid. Then the bottles were labeled with sample numbers and place names. The geographical coordinates of each sample site were recorded with GPS (GARMIN-GPSMAP 64s) (Table 1). Finally, the collected water samples were transported to the Northern Eastern Regional Institute of Water and Land Management (NERIWALM) in Tezpur, Assam (India) for analysis.

Measurement of Parameters

Selected parameters were measured for all the samples. The pH, electric conductivity, total dissolved solids (TDS), salinity, dissolved oxygen (DO), and turbidity were measured by using a water analyzer. The instrument was calibrated with standard solutions as per the Systronic Water Analyser 371 manual. The concentrations of sulfate and phosphate were determined by using a UV-Visible spectrophotometer. The amount of calcium, magnesium, chloride (Cl^-), total alkalinity, and total hardness were estimated by using titration. All the measurement was carried out in triplicate to minimize the errors. The concentration of iron, lead, cadmium, chromium, and arsenic was measured directly by using Atomic Absorption Spectrophotometer (AAS). All the measured parameters were analyzed and compared with standard limits of the Bureau of Indian Standards (BIS), Indian Council of Indian Medical Research (ICMR) and the World Health Organization (WHO) for drinking water quality. Finally, the water quality index (WQI) has been calculated by adopting the 'weighted arithmetic index method' (Brown et al. 1970).

$$\text{WQI}=\sum QnWn' \sum Wn$$

Table 1: Water sample collection sites.

Location	Village name	Coordinate		Elevation(M)	Types
		Latitude	Longitude		
S1	Dihira	26° 44' 17.49''N	91° 21' 26.64'' E	86	Surface
S2	Chaulkara	26° 45' 38.27'' N	91° 24' 6.38'' E	124	Ground
S3	Uttarkuchi	26° 46' 47.50'' N	91° 25' 32.28'' E	123	Ground
S4	No.1 Paharpur	26° 47' 42.96'' N	91° 26' 55.98'' E	149	Surface
S5	Jharbasti	26° 46' 18.54'' N	91° 26' 46.31'' E	124	Surface
S6	Moithabari	26° 43' 37.96'' N	91° 26' 21.26'' E	106	Ground
S7	Hatiduba	26° 45' 51.06'' N	91° 30' 26.62'' E	94	Ground
S8	Ganeshguri	26° 46' 32.20'' N	91° 33' 00.74'' E	165	Surface
S9	Unthaibari	26° 47' 44.28'' N	91° 35' 29.90'' E	180	Surface
S10	Manjurgaon	26° 48' 13.15'' N	91° 37' 30.02'' E	153	Surface
S11	No. 1 Dongargaon	26° 48' 4.78'' N	91° 37' 19.84'' E	156	Ground
S12	Guwabari	26° 47' 3.10'' N	91° 40' 40.73'' E	140	Surface
S13	Deuchunga	26° 46' 22.35'' N	91° 42' 49.37'' E	124	Ground
S14	No. 2 Dogargaon	26° 46' 17.77'' N	91° 41' 53.62'' E	125	Surface

Source: Field survey, 2020

Where Q_n refers to the quality rating scale of the n^{th} water quality parameter; W_n refers to the unit weight of the n^{th} water quality parameter.

For computing WQI, we first calculate the Q value by using the following formula-

$$Qn = 100 \{(Vn - Vi)'(Vs - Vi)\}$$

Where, V_n = the amount of n^{th} parameter present, Vi= ideal value of the parameter i.e. Vi=0, except P^H (vi=7) and DO (Vi=14.6 $mg.L^{-1}$); Vs= recommended standard value for n^{th} parameter

Unit weight (Wn) is calculated by the following equation-

$$W_n = K/Vs$$

Where k = proportionality constant and it is calculated by the following equation-

$$K = [1'\sum 1'Vs]$$

The status of water quality based on the water quality index (WQI) value and their possible uses are shown in Table 5.

Table 2: Selected drinking water sources and their supplies in sample villages.

Village	Location	Elevation [m]	Selected drinking water sources	Dependent households
Daragaon	26°46'54.93" N 91°23'1.79"E	171	Locally managed spring fed pipe line	60
Dihira	26°44'18.5" N 91°21'27" E	87	Community well	35
Bhangrikuchi Dimapur	26°46'47.60" N 91°23'41.04" E	154	Dong (traditional canal)	80
Ganeshguri	26°47'3.34" N 91°24'27.94" E	149	Chaulkara *dong* (traditional canal)	50
Chaulkara village	26°45'38.27" N 91°24'6.83" E	124	*Pani tanki* (Deep tube well)	65
Uttarkuchi village	26°46'47.50" N 91°25'32.28"E	106	*Pani tanki* (Deep tube well)	70
Dakhinkuchi	26°45'24.90" N 91°26'23.32" E	106	*Pani tanki* (Deep tube well)	120
Bhabanipur village	26°44'32.01"N 91°25'21.32" E	68	Community well	85
Jharbasti	26°46'18.54" N 91°26'46.31" E	124	*Pani tanki* (Deep tube well)	170
Jalah basti	26°46'34.13" N 91°27'9.38" E	111	Natural Spring	40
Moithabari village	26°43'52.64" N 91°26'17.27" E	96	*Pani tanki* (Deep tube well)	100
Hatiduba village	26°45'51.06" N 91°30'26.62" E	94	*Pani tanki* (Deep tube well)	70
Angarkata N.C	26°44'35.60"N 91°30'1.39"E	99	Community well	40
Unthaibari	26°47'44.28" N 91°35'29.90" E	180	Unthaibari *dong* (traditional canal)	65
No.1 Dongargaon	26°48'4.78" N 91°37'19.84" E	156	Natural Spring	240
No.2 Dongargaon	26°46'17.17" N 91°41'53.62" E	124	Garo *dong* (traditional canal)	250
Deuchunga	26°46'22.35"N 91°42'49.37" E	126	*Pani tanki* (Deep tube well)	180

Source: Field survey, 2020

RESULTS AND DISCUSSION

Drinking-Water Accessibility

Scarcity of drinking water is the most serious problem in the entire foothill region of the district and the problems become more acute during the winter and pre-monsoon season. Around 80-90% of villagers of this foothill region do not have a drinking water source on their premises. Only a small section of the villagers residing in the southern belt of this region have access to drinking water at their premises. The majority of the population of this entire zone collects their drinking water from the different locally invented sources, such as dong (canals), nijora (natural springs), ponds, small streams, and rivers (Table 2). Very recently, the government of Bodoland Territorial Council (B.T.C) has constructed a deep tube well and water tank, locally called 'pani tanki' in the villages of this area.

The existing drinking water source of this region forms a unique spatial pattern (Fig. 2). If we observe very carefully, we can classify the drinking water sources into five parallel belts. Natural spring, locally called Nijhora is the primary source of drinking water in the villages of the extreme northern belts of the foothill zone. Besides the natural springs, the villagers also collect their drinking water from nearby *dongs* (canals), streams, and rivers. Just south of this belt many villagers depend on traditional *dongs* for their drinking water. There is no community well or deep tube well in this zone. Few deep tube wells were installed by the government a few years back but most of these are now defunct. As the groundwater level is very low, a deep tube well could not work during the winter season. Thus, according to WHO's standard classification, the sources of drinking water in these two zones can be classified as the 'untreated surface water' category.

The villagers in the next zone were using locally managed traditional *dong* water for drinking purposes till recently. Very recently, the government installed a good number of deep tube wells and water tanks for drinking water supply. The installation of these deep tube wells and water tanks dramatically change the life of the villagers. Now the people of these belts are getting basic and limited water services. In every village, we found around 3-4 deep tube wells and water tanks. Around 50-120 households depend on one deep tube well. Every deep tube well has a pump machine for the withdrawal and storing of water. All the maintenance works are performed by the stakeholders. The local *Gaon Unnyan Samiti* (village development committee) makes a drinking water management committee under it and gives the responsibility of regulating and maintenance and fees collections. To fetch the drinking water, the villagers need to spend around 20-40 min for every round trip. It is noteworthy to mention that the responsibility of drinking water collection mainly relies on women and children. It has been estimated that the women of this area spend around 5-6 h per week on the collection of drinking water. Dug well and community well are the main source of drinking water in the villages in the fourth zone. As the construction of a well is very difficult and expensive, therefore, a well in every household

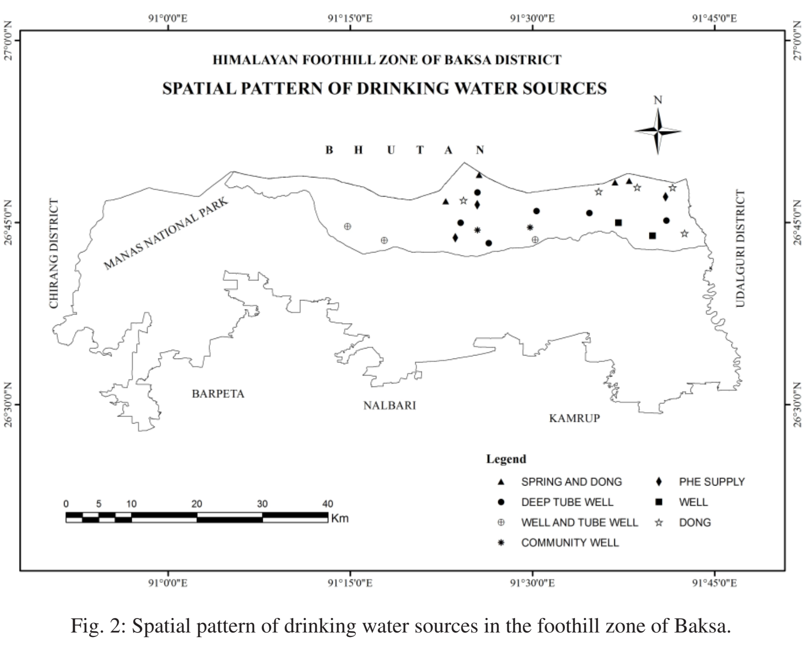


Fig. 2: Spatial pattern of drinking water sources in the foothill zone of Baksa.

premises is very rare. Community well is the primary source of drinking water. Like community deep tube well, around 50-60 households have to depend on one well. They need to walk around 200-500 m for collecting drinking water (Fig. 3). The majority of these wells are unprotected. Dug well and shallow tube wells are found in some villages in most southern belts of this region where the groundwater level is comparatively higher than in the northern part.

It is noteworthy here that the government has recently taken various projects to improve the drinking water supply in this entire foothill region. Public Health Engineering (PHE) water supply projects (pipe supply) have been taken in some villages such as Nikashi, Uttarkuchi, Subankhata, Chandranagar, and Guwabari, where the safely managed drinking water supply is available now. But the water supply is not available in the entire villages, some parts of these villages are receiving water supply from these PHE drinking water supply projects. Although the households under these water projects revive water supply through the pipeline in their home premises, the supply is only for specific time periods in a day. The drinking water supply project of the Uttrakuchi and Subankhata area is now almost defunct.

Seasonal Pattern of Drinking Water Accessibility

Focus group discussions (FGDs) with the local communities show that the drinking water accessibility of this region has been largely influenced by seasonal variation. A seasonal calendar- a widely used PRA tool- was applied to understand the seasonal variation in the reliability of drinking water. The participants reported that during the dry season (December-April) scarcity of drinking water becomes more acute because many of the traditional drinking water sources such as *dong* (canal), and natural springs become dry. Water availability in Community Well as well as in deep tubes is also reduced significantly due to the fall of the groundwater table. The villagers, particularly the women and children need to spend more time in water fetching. Fig. 4 represents the drinking water-related issues that the local communities of four selected villages are facing trough out the year.

It is seen that the drinking water source of Bhagrikuchi village is affected due to floods. During the rainy season, a large number of sediments and other eroded materials are mixed with *dong* water which makes the water undrinkable. The water fetching women and children of No.1 Dongargaon village reported that it becomes very difficult to access the natural spring during the rainy season due to flood water.

Status of Water Quality Parameters

Different parameters of selected water samples were tested to understand the general characteristics of drinking water in the Bhutan Himalayan foothill zone of Assam. The abstract results of the water sample test are presented in Table 3. pH indicates the acidity or alkalinity nature of water which plays a significant role in the quality of water. The pH value of natural water generally falls within the range of 6-8. The average P^H value of the water samples was found to be 7.98. Although the average P^H value is within the permissible limit of BIS' ICMR and WHO standards, the P^H value in one sample site i.e. 8.83 was found beyond the permissible limit. Generally, pure water is not a good conductor of

Table 3: Descriptive statistics of the physiochemical parameters of sample water.

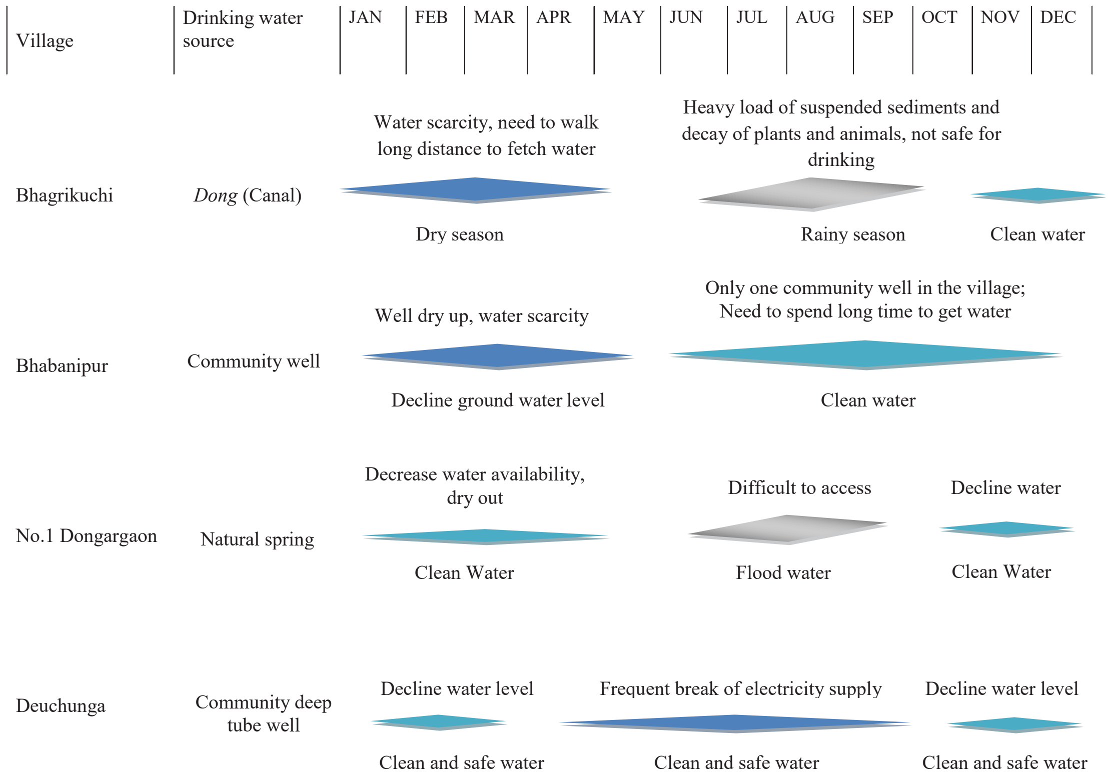
Parameter	Mean value	Median value	Standard deviation (SD)	BIS'ICMR Standard (2012)	WHO standard (1984)
pH	7.98 (7.12-8.83)	7.94	0.495	6.5- 8.5	6.5- 8.5
EC	283.64 (178-481)	264	81.94	300	300
TDS	177.37 (77.44-307.84)	168.96	58.33	500	1000
DO	4.72 (3.4-6.5)	4.6	0.960	5	-
Turbidity	19.96 (0.18-185)	1.25	49.64	5	5
Total hardness	187.4 (144-269.2)	176	36.49	200	500
Total Alkalinity	76.81 (42-238)	57	53.62	200	-
Chloride	2.85 (0.99-4.99)	2.74	1.08	250	250
Fluoride	0.06 (0.023-0.22)	0.05	0.04	1	1.5
Sulphate	11.45 (5.76-32.68)	10.22	6.73	150	400
Calcium	21.20 (8.83-36.84)	20.85	7.36	75	100
Magnesium	21.74 (13.73-34.67)	20.27	5.58	30	150

Note: The figure within parenthesis indicates the range of the value.

electricity but the presence of dissolved solids enhances the electric conductivity (Meride & Ayenew 2016). Electric conductivity (EC) measures the capacity of electric current transmission of water. It is also an indirect measurement of dissolved salts in a water sample. The electric conductivity (EC) value of water samples ranges between 178-481μS. P^H in most of the sites was found within the desirable limit of BIS and WHO standards except for three sites i.e. SI-4, SI-8, and SI-10. Measurement of TDS indicates the amount of total dissolved solids particles present in the water. TDS values of the sample water were found within the desirable limits of ICMR and WHO with a maximum record of 307.84 mg.L^{-1}. The amount dissolves oxygen present in water is called DO which is one of the major indicators of water quality. Good quality water must have more than 4mg'L dissolved oxygen (Lkr et al. 2020). The amount of dissolved oxygen (DO) across the foothill region was recorded within the range of 3.4-6.5 mg.L^{-1}. Turbidity is the measurement of water clarity. A higher level of turbidity adversely affects the aquatic life both plants and animals (Pant et al. 2017). There is a very significant variation of water turbidity values among the sample sites ranging from 0.18 NTU to 185 NTU. Although the turbidity values in the case of the majority of the sample sites are within the desirable limit i.e. 5 of BIS and WHO, few sample sites have excessive value. Turbidity in the water sample of the Paharpur-Lebra canal (sample site-4) was found extremely high (185 NTU) which is very harmful to aquatic plants and animals. Water hardness refers to the measure of divalent metal cation, mainly calcium and magnesium (Diggs & Parker 2009). The dissolve metallic ions from sedimentary rocks, surface runoff from the surrounding area, etc. are the major natural sources of water harness. The observed hardness values of the collected water sample of the area were range from 144 to 269.2 mg.L^{-1}.

Total alkalinity is the acid-neutralizing capacity of the water. The mean value of total alkalinity (76.81 mg.L^{-1}) was found within the desirable limit of BIS i.e. 200. The maximum concentration (238 mg.L^{-1}) was recorded at sample site-9 which exceeds the BIS standard limit. The concentration of chloride in all the water samples was found (between 0.99 and 4.99 mg.L^{-1}) within the BIS and WHO desirable limits. The mean concentration of fluoride was 0.06 mg'l with the values ranging from 0.023 to 0.22 mg.L^{-1}. Several minerals such as barite, gypsum, etc. are natural contributors to sulfate in water. A higher concentration of sulfate in drinking water causes different diseases such as diarrhea, dehydration, etc. The concentration of sulfate in the water sample varies between 5.76 and 32.68 mg.L^{-1}. Sulfate concentration values in all the sample sites under investigation were recorded within the desirable limits of BIS and WHO. Both calcium and magnesium dissolves are common minerals found in water that makes the water hard. These minerals are also essential nutrients for human health. The concentration of calcium was recorded within the range of 8.83 to 36.84 mg.L^{-1}. The mean magnesium value in the water sample was observed at 21.74 mg.L^{-1}. All the observed values of calcium and magnesium

Fig. 3: Scenario of drinking water sources in the Himalayan foothill zone of Baksa district, Assam, India.



Source: Based on focus group discussion, 2020

Fig. 4: Seasonality of drinking water status in the foothill region of the Baksa district.

for all the sample sites were found within the permissible limit of the World Health Organization (WHO).

Table 4 shows the concentration level of some selected heavy metals in the water sample sites. It is seen that the concentration of arsenic which is very hazardous to human health is below the detection level (BDL). Similarly, the concentration of cadmium (Cd) and lead (P) is also below the detection level. The following data reveals that the drinking water of this area is almost free from hazardous heavy metal contamination. But the mean concentration level of chromium (0.15ppm) and iron (1.03ppm) exceeds the BIS and WHO standard limits.

The water quality index is one of the most effective methods of water quality analysis which describe the overall quality of water in a single term (Akter et al. 2016, Tyagi et al. 2013). The method of water quality index was first formulated by Horton (1965) and Brown et al. (1970) and subsequently different modified WQI methods were developed by several scientists (Saeedi et al. 2009). The water quality index (WQI) has now been widely used throughout the world as an effective tool for evaluating the quality of ground and surface water (Ameen 2019, Bora & Goswami 2017, Samantray et al. 2009, Şener et al. 2017). 'Weighted Arithmetic Index' method was applied in the present study.

Table 4: Descriptive statistics of selected heavy metal concentration in sample water.

Parameter	Mean value	Median value	Standard deviation(SD)	BIS'ICMR Standard (2012)	WHO standard (1984)
Arsenic (As)	BDL	-	-	0.01	0.05
Chromium (Cr)	0.15	0.15	0.01	0.05	0.05
Cadmium (Cd)	BDL	-	-	0.003	0.003
Iron (Fe)	1.03	0.65	0.93	0.30	0.30
Lead (Pb)	BDL	-	-	0.01	0.01

Note: Concentration level is measured in ppm (parts per million)

Table 5: Range of water quality index, status, and possible uses (Brown et al. 1972).

Range of WQI	Water quality status (WQS)	Probable utility
<25	Excellent	Suitable for drinking, irrigation, and industrial uses
26-50	Good	Suitable for drinking, irrigation, and industrial purposes
51-75	Poor	Not suitable for drinking, only irrigation, and industrial use
76-100	Very poor	Irrigation purpose only
>100	Unsuitable for drinking and fish cultivation	Proper treatment is essential before any kind of use

The procedure for calculation of WQI applying weighted arithmetic index (WAI) starts with the estimation of 'unit weight' assigned for every physiochemical parameter considered for the study. By assigning the 'unit weight', the different dimensions and units of the selected parameters are converted into a common. Table 6 shows the drinking water quality standard (as per the BIS'ICMR) and the assigned 'unit weight' of every selected parameter for determining the water quality index (WQI).

The maximum 'unit weight' value is assigned to fluoride (0.627), DO (0.125), and turbidity (0.125) which indicates the importance of these parameters in the assessment of water quality. These parameters also play a very significant role in the computation of the water quality index (WQI). The measured values of all the twelve physiochemical parameters for all the sample sites and their corresponding WQI values are presented in Tables 7, 8, 9, 10, and 11. It is seen that the pH, DO, turbidity and fluoride are the most significant water parameters in determining the WQI score.

The overall water quality index value and water quality status of all the sample sites are presented in Table 12. The observed WQI values among 14 sample sites range from 21.75 to 502.38. It is seen that the WQI value in the majority of the sample sites falls under the category of good quality water status (25 < WQI < 50). The lowest WQI value i.e. 21.75 was found at Uttarkuchi village (S3), whereas the higher WQI value i.e. 502.38 was recorded at the village No.1 Paharpur (S4). The WQI values of the groundwater sample sites S2, S3, S6, and S7 are recorded as less than 30 except the sample site S11 which is a natural spring. WQI value of S11 is 34.26. The average WQI values of the surface water samples are found to be slightly higher than the groundwater sample. The sample sites S4 and S5 recorded unsuitable water quality status. The village Dihira (S1) recorded very poor quality water status with a WQI value of 87.63. The pollution level in the sample site S4 is extremely high. Electric conductivity (EC), turbidity, DO, total hardness, and magnesium level were recorded

Table 6: Relative weight of water parameters used for determination of water quality index.

Parameter	BIS' ICMR standard (2012) (V_S)	Unit Weight (W_n)
pH	6.5-8.5	0.077
Electric conductivity	300	0.002
TDS	500	0.001
DO	5	0.125
Turbidity	5	0.125
Total hardness	200	0.003
Total alkalinity	200	0.003
Chloride	250	0.002
Fluoride	1	0.627
Calcium	75	0.008
Sulphate	150	0.004
Magnesium	30	0.02
$\sum Wn$ =0.997(≅1.00)		

Table 7: Determination of WQI for sample sites 1, 2 and 3.

Parameter	Site -1			Site-2			Site-3		
	Vn	Qn	QnWn	Vn	Qn	QnWn	Vn	Qn	QnWn
P^H	8.03	85.83	6.61	7.75	62.50	4.81	7.82	68.33	5.26
Ec	212.00	70.67	0.14	330.00	110.00	0.22	291.00	97.00	0.19
TDS	77.44	15.48	0.02	211.20	42.24	0.04	186.24	37.25	0.04
DO	6.50	83.33	10.42	5.80	91.67	11.46	5.40	95.83	11.98
Turbidity	26.00	520.00	65.00	2.10	42.00	5.25	0.18	3.60	0.45
Total hardness	144.00	72.00	0.22	196.00	98.00	0.29	170.00	85.00	0.26
Total alkalinity	56.00	28.00	0.08	58.00	29.00	0.09	58.00	29.00	0.09
Chloride	1.50	0.60	0.00	4.00	1.60	0.00	5.00	2.00	0.00
Fluoride	0.05	5.26	3.30	0.03	3.32	2.08	0.03	3.01	1.89
Calcium	26.49	35.32	0.28	47.93	63.91	0.51	41.63	55.51	0.44
Sulphate	11.52	7.68	0.03	6.40	4.26	0.02	7.24	4.83	0.02
Magnesium	18.92	63.06	1.26	18.54	61.80	1.24	16.06	53.53	1.07
$\sum QnWn$ 87.36 WQI=87.63				$\sum QnWn$ 26.01 WQI=26.08			$\sum QnWn$ 21.69 WQI=21.75		

Table 8: Determination of WQI for sample sites 4, 5 and 6.

	Site-4			Site-5			Site-6		
Parameter	Vn	Qn	QnWn	Vn	Qn	QnWn	Vn	Qn	QnWn
P^H	8.53	127.50	9.82	8.25	104.17	8.02	7.12	20.83	1.60
Ec	481.00	160.33	0.32	242.00	80.67	0.16	213.00	71.00	0.14
TDS	307.84	61.57	0.06	154.88	30.98	0.03	136.32	27.26	0.03
DO	6.10	88.54	11.07	5.20	97.92	12.24	4.70	103.13	12.89
Turbidity	185.00	3700.00	462.50	50.00	1000.00	125.00	4.10	82.00	10.25
Total hardness	234.00	117.00	0.35	180.00	90.00	0.27	160.00	80.00	0.24
Total alkalinity	108.00	54.00	0.16	50.00	25.00	0.08	46.00	23.00	0.07
Chloride	3.50	1.40	0.00	2.00	0.80	0.00	3.50	1.40	0.00
Fluoride	0.22	22.00	13.79	0.05	4.74	2.97	0.02	2.31	1.45
Calcium	36.58	48.77	0.39	30.27	40.36	0.32	29.85	39.80	0.32
Sulphate	32.68	21.79	0.09	13.56	9.04	0.04	6.82	4.54	0.02
Magnesium	34.67	115.57	2.31	25.37	84.57	1.69	20.77	69.23	1.38
$\sum QnWn$ 500.87 WQI=502.38				$\sum QnWn$ 150.82 WQI=151.27			$\sum QnWn$ 28.40 WQI=28.49		

beyond the BIS standard limits at this site. Turbidity level at S4 was found to be 185 NTU which is higher than the permissible limit of BIS and WHO i.e. 5 NTU. A large number of waste materials from the recently developed coal mining and limestone quarrying sites in the Bhutan territory are mixing with the Lebra river water, which is the primary source of water pollution in this area. Besides, large-scale deforestation in the upper catchment area is also badly affecting the quality of water. The growing pollution level in the Lebra river has become a serious threat to the life and livelihoods of the villagers in Lebra-Santipur and No.1 Paharpur village. Water has become unfit

Table 9: Determination of WQI for sample sites 7, 8 and 9.

Parameter	Site -7			Site-8			Site-9		
	Vn	Qn	QnWn	Vn	Qn	QnWn	Vn	Qn	QnWn
P^H	7.44	36.67	2.82	8.83	152.50	11.74	7.85	70.83	5.45
Ec	178.00	59.33	0.12	351.00	117.00	0.23	311.00	1.04	0.00
TDS	113.92	22.78	0.02	224.64	44.93	0.04	199.04	39.81	0.04
DO	4.60	104.17	13.02	3.40	116.67	14.58	3.40	116.67	14.58
Turbidity	0.26	5.20	0.65	1.30	26.00	3.25	1.20	24.00	3.00
Total hardness	158.00	79.00	0.24	172.00	86.00	0.26	200.00	100.00	0.30
Total alkalinity	42.00	21.00	0.06	140.00	70.00	0.21	238.00	119.00	0.36
Chloride	4.00	1.60	0.00	2.50	1.00	0.00	2.00	0.80	0.00
Fluoride	0.07	6.65	4.17	0.07	7.22	4.53	0.03	3.19	2.00
Calcium	29.85	39.80	0.32	23.54	31.39	0.25	47.51	63.35	0.51
Sulphate	9.63	6.42	0.03	15.18	10.12	0.04	10.82	7.21	0.03
Magnesium	24.11	80.37	1.61	13.73	45.77	0.92	19.77	65.90	1.32
$\sum QnWn = 23.06$ WQI=23.13				$\sum QnWn = 36.06$ WQI=36.17			$\sum QnWn = 27.59$ WQI=27.67		

Table 10: Determination of WQI for sample sites 10, 11 and 12.

Parameter	Site -10			Site-11			Site-12		
	Vn	Qn	QnWn	Vn	Qn	QnWn	Vn	Qn	QnWn
P^H	8.32	110.00	8.47	7.36	30.00	2.31	8.30	108.33	8.34
Ec	213.00	71.00	0.14	286.00	95.33	0.19	241.00	80.33	0.16
TDS	136.32	27.26	0.03	183.04	36.61	0.04	154.24	30.85	0.03
DO	4.00	110.42	13.80	4.60	104.17	13.02	4.10	109.38	13.67
Turbidity	2.20	44.00	5.50	0.40	92.00	11.50	1.20	24.00	3.00
Total hardness	150.80	75.40	0.23	236.00	118.00	0.35	166.80	83.40	0.25
Total alkalinity	65.40	32.70	0.10	47.40	23.70	0.07	62.00	31.00	0.09
Chloride	3.00	1.20	0.00	3.00	1.20	0.00	2.50	1.00	0.00
Fluoride	0.06	5.63	3.53	0.07	6.76	4.24	0.05	5.44	3.41
Calcium	32.80	43.73	0.35	47.93	66.57	0.53	37.02	49.36	0.39
Sulphate	5.76	3.84	0.02	8.22	5.48	0.02	12.02	8.01	0.03
Magnesium	16.74	55.80	1.12	28.27	94.23	1.88	18.08	60.27	1.21
$\sum QnWn = 33.28$ WQI=33.38				$\sum QnWn = 34.16$ WQI=34.26			$\sum QnWn = 30.59$ WQI=30.68		

for drinking, therefore they need to walk a long distance for fetching water. Cultivation of fish in their household ponds is destroyed and ponds have become abundant (Fig. 5). Irrigation fields are also adversely affected due to high levels of pollution and siltation.

CONCLUSION

The present study gives an account of the status of water accessibility and the quality of the existing drinking water sources. The physiochemical analysis of water quality reveals that the majority of the values are within the drinking water

Table 11: Determination of WQI for sample sites 13, and 14.

Parameter	Site -13			Site-14		
	Vn	Qn	QnWn	Vn	Qn	QnWn
P^H	7.67	55.83	4.30	8.50	125.00	9.63
Ec	380.00	126.67	0.25	242.00	80.67	0.16
TDS	243.20	48.64	0.05	154.85	30.97	0.03
DO	4.22	108.13	13.52	4.10	109.38	13.67
Turbidity	0.50	10.00	1.25	0.47	9.40	1.18
Total hardness	269.20	134.60	0.40	186.80	93.40	0.28
Total alkalinity	50.60	25.30	0.08	54.00	27.00	0.08
Chloride	3.00	1.20	0.00	1.00	0.40	0.00
Fluoride	0.04	3.71	2.33	0.05	5.03	3.15
Calcium	64.13	85.51	0.68	35.32	47.09	0.38
Sulphate	8.50	5.67	0.02	12.09	8.06	0.03
Magnesium	25.36	84.53	1.69	23.97	79.90	1.60
$\sum QnWn = 24.57$ WQI=24.64				$\sum QnWn = 30.19$ WQI=30.28		

Table 12: Water quality index value and water quality status.

Sampling site	Village	Water quality index (WQI)	Water quality status (WQS)
S1	Dihira	87.63	Very poor
S2*	Chaulkara	26.08	Good
S3*	Uttarkuchi	21.75	Excellent
S4	No.1 Paharpur	502.38	Unsuitable
S5	Jharbasti	151.27	Unsuitable
S6*	Moithabari	28.49	Good
S7*	Hatiduba	23.13	Excellent
S8	Ganeshguri	36.17	Good
S9	Unthaibari	27.67	Good
S10	Manjurgaon	33.38	Good
S11*	Manjurgaon	34.26	Good
S12	Guwahati	30.68	Good
S13*	Deuchunga	24.64	Excellent
S14	No.2 Dogargaon	30.28	Good

Note: Sample site with * sign indicates the groundwater source

standard limits of WHO and BIS. From the calculated water quality index (WQI) values of all the sample sites, it can be concluded that the quality of water is good in all the sites except No.1 Paharpur (site 4) and Jharbasti village (site 5). Deforestation, open cast coal and limestone mining in the hilly region of Bhutan territory are mainly responsible for the degradation of water quality of this region. As the local communities of this entire foothill region have been using the surface water (through the *dong-bandh* irrigation system) for drinking as well as irrigation purposes, therefore government intervention is very essential to overcome these issues.

Fig. 5: Coal mining waste mixed with the water of Lebra-Santipur and No.1 Paharpur village.

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