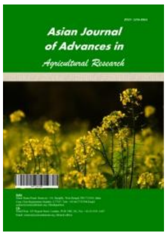

Asian Journal of Advances in Agricultural Research

16(4): 18-27, 2021; Article no.AJAAR.75120
ISSN: 2456-8864

Quality Assessment of Groundwater of Barind Area, Bangladesh using Integrated Hydrochemical Method

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJAAR/2021/v16i430181
Editor(s):
(1) Dr. Rajesh Kumar, College of Veterinary Science & A.H, Lala Lajpat Rai University of Veterinary and Animal Sciences, India.
Reviewers:
(1) Mamdouh Salama Morsi, Egypt.
(2) Pale Sié, Centre Universitaire de Gaoua, Université Nazi Boni, Burkina Faso.
Complete Peer review History: https://www.sdiarticle4.com/review-history/75120

Original Research Article

Received 09 August 2021
Accepted 19 October 2021
Published 25 October 2021

ABSTRACT

The study was conducted for assessing water quality for drinking and irrigation purposes of groundwater sources. Total 50 water samples were collected from different locations of Nachol and Niamatpurupazilla of Chapainawabgonj and Naogaon district in January 2019 and January 2020. Water quality parameters like pH, electrical conductivity (*E*c), iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg), zinc (Zn), copper (Cu), sodium (Na), potassium (K), total hardness (TH), alkalinity, sulphate (SO4), nitrate (NO3), nitrite (NO2), ammonia (NH4), phosphate (PO4), chloride (Cl), dissolved oxygen (DO), and total dissolved solids (TDS) were analyzed in the laboratory. All the analyzed parameters were compared with national and international drinking and irrigation water quality standards to understand the overall groundwater quality status of the study area. The study showed that the water samples of almost all the locations were suitable for consumption and irrigation.

Keywords: Water quality; water quality index; chemical parameters; irrigation.

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1. INTRODUCTION

Groundwater is withdrawn approximately 32 km^3annuallyin Bangladesh of which 90% is used for irrigation, and 10% for domestic and industrial purposes combined that is equivalent to ~4% of global groundwater withdrawal [1]. About 98% of drinking and 80% of dry-season irrigation water supplies come from groundwater at shallow depths (<150 m below ground level, bgl) [2]. Groundwater is found throughout Bangladesh but its quality and quantity vary across hydrological environments,posing unique challenges to certain geographical areas and population groups [3]. Water quality depends on water composition influenced by natural processes and human activities. Water quality is characterized on the basis of water parameters (physical, chemical, and microbiological), and human health is at risk if values exceed acceptable limits [4].The concentration and composition of the dissolved constituents in water determine its suitability for irrigation purposes. Moreover, the suitability of water for irrigation depends on the total concentration of the soluble salts, the relative proportion of the major constituents (that is sodium, calcium, and magnesium), and the effect of some mineral constituents on both the soil and plants [5]. Among soluble constituents in water, common major and secondary constituents are Ca, Mg, Na, Fe, B, MO3, HCO3, SO4, and Cl but minor or trace constituents are As, Cd, Cr. Cu, Mn, P and Zn [6]. Sarkar *et al.*[7] investigated the suitability of groundwater for irrigation sampled water before irrigation pumping started (Nov.) and during the peak pumping period (Feb.) at Magura, Bangladesh. Almost all samples were found good to excellent except for slightly increased iron and chloride in two locations. They observed no distinct variation in the chemical composition due to the pumping effect except the Magnesium content, which showed slightly increased value during the pumping period. The poor or marginal quality water has effects on health and life expectancy, and also on soil and crop [8]. In the Barind region, farmers use the water withdrawn from a deep tube well for irrigating the crops, drinking, and household consumption. The study was led to evaluate the chemical quality and suitability of water for drinking and irrigation at starting and peak pumping period of Dry season.

2. MATERIALS AND METHODS

In this study, physical and chemical analyses of water samples were performed taken from 50 locations (Fig.1). The analysis results were compared with maximum permissible limit values recommended by the World Health Organization [9], Food and Agricultural Organization [10] of the United Nations, and [11], Bangladesh drinking water standards. The water quality for drinking purposes was also evaluated using the Water Quality Index (WQI) method.

2.1 Description of Study Area

Barind Tract largest Pleistocene physiographic unit of the Bengal basin, covering an area of about 7,770 sq km. Geographically this unit lies roughly between latitudes 24°20´N and 25°35´N and longitudes 88°20´E and 89°30´E. The study area is located in the Level Barind Tract (AEZ 25).This tract covers area of 5,049km^2. This region is almost level, with 60–90cm local differences in elevation. All soils become very dry in the surface during the dry season. The predominant soils have a grey, silty, puddled topsoil with plough pan. Shallow grey terrace soil and deep grey terrace soils are the major components of general soil types of the area. The soils are low in available moisture holding capacity and slightly acidic to acidic in reaction. Organic matter status is very low and most of the available nutrients are limiting. Twenty-five samples were collected from different locations of Nachol upazilla of Chapainawabgonj and the rest of 25 samples were from the Niamatpur upazilla of Naogaon district. GPS data of the sampling locations were recorded using Samsung smart-phone (J7) device and location maps were generated through Arc GIS and Google map.

2.2 Sampling and Sample Preparation

Water samples were taken from 50 sites. Samplings of water were in January, 2019 and in January, 2020. All measurements were carried out in triplicate, and the results were expressed as averages. Before collecting water samples and data collection all pumps were run for minimum 15 minutes. The measurement at the sampling site, Dissolved oxygen, Electric conductivity, pH, and water temperature were recorded. The water samples were taken in ice boxes and immediately transported to Water Quality Lab, Agricultural Engineering Division, BINA, Mymensingh for analysis of water quality following common protocols. Samples were collected in polyethylene bottles of 250ml capacity. Prior to their filling with sampled water, these bottles were rinsed to minimize the chance of any contamination. The samples were stored in the refrigerator at 4^0C up to the time of analysis.

2.3 Sample Analysis

Different water quality parameters like iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), potassium (K), total hardness (TH), alkalinity, sulphate (SO4), nitrate (NO3), phosphate (PO4), chloride (Cl) and dissolved oxygen (DO) were determined by COD Multi-parameter Photometer. The EC, pH, total dissolved solids (TDS) were determined by a water testing Kit (Lovibond Tintometer). Sodium (Na), calcium (Ca), magnesium (Mg) was determined by standard lab method using a spectrophotometer.

2.3.1 Statistical analysis

The statistical analysis was done for correlation using Statistix 10.0. The Water quality index was calculated from the point of view of the water suitability for human consumption as seen below.

2.4 Calculation of Water Quality Index (WQI)

Water Quality Index, a technique of rating water quality, is an effective tool to assess the quality and ensure sustainable safe use of water for drinking. In computing WQI two steps are followed. In the first step, Quality rating (qn) for the water quality parameters is calculated followed by the equation of Brown *et al.,* 1972[12]. In the Second step, Unit weight (*W*n) for various water quality parameters are calculated which is inversely proportional to the recommended standards value ***Sn*** of the corresponding parameters. The computation of the WQI was done for observed data by the weighted arithmetic index method for different parameters. This method has been implemented by many researchers [13] [14][15][16].

2.5 Calculation of Sub Index of Quality Rating (*qn*)

Let there be ***n***-water quality parameters, where the quality rating or sub-index (***qn***) corresponding to the ***nth*** parameters is a number reflecting the relative value of these parameters in the polluted water with respect to its standard permissible value. The value of ***qn***is calculated using the following expression.

$$qn = \frac{100\,[Vn - Vio]}{[Sn - Vio]} \qquad (1)$$

Where,

qn= Quality rating for the *nth* water quality parameters
Vn= Estimated value of the *nth* parameter at a given sampling station.
Sn= Standard permissible value of the *nth* parameters
Vio= Ideal value of an / the *nth* parameter in pure water. *(i.e., 0 for all other parameters except the parameter pH and dissolved oxygen (7.0 and 14.6 mg l-1 respectively)*[17]

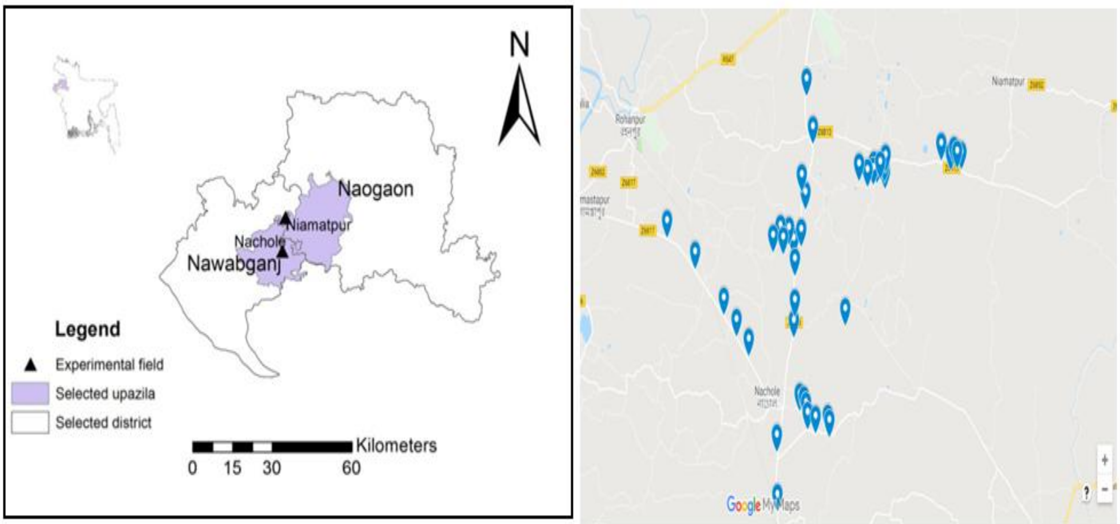

Fig. 1. Location map of sampling wells

2.6 Calculation of Quality Rating for pH

For pH, the ideal value is 7.0 (for natural water) and a permissible value is 8.5 (for polluted water).

Therefore, the quality rating for pH is calculated from the following relation:

$$qpH = \frac{100\,(VpH - 7.0)}{\mathrm{Sn}(8.5 - 7.0)} \quad (2)$$

Where *VpH*= observed value of pH during the study period.
If quality rating *qn*= 0 means the complete absence of pollutants,
While 0 <*qn*< 100 implies that, the pollutants are within the prescribed standard.
When *qn*>100 implies that, the pollutants are above the standards.

2.7 Calculation of Unit Weight (*Wn*)

Calculation of unit weight (*Wn*) for various water quality parameters is inversely proportional to the recommended standards value *Sn* of the corresponding parameters.

$$Wn = \frac{\mathrm{K}}{\mathrm{Sn}} \quad (3)$$

Where *Wn*= Unit weight for the *nth* parameters.
Sn= Standard value for *nth* parameters.
K = Proportional constant, this value considered (1) here, also can calculate using the following equation:

$$\mathrm{K} = \frac{1}{\Sigma\,(1/Sn)} \quad (4)$$

The overall Water Quality Index was calculated by aggregating the quality rating with the unit weight linearly.

$$\mathrm{WQI} = \frac{\boldsymbol{\Sigma\, qnWn}}{\boldsymbol{\Sigma\, Wn}} \quad (5)$$

The overall Water Quality Index was calculated by aggregating the quality rating with the unit weight of parameters pH, Cl, TDS, TH, Ca, Mg, NO_3, SO_4, K, Fe, bicarbonate, PO_4 for the samples of the year 2020. For 2019, water parameters pH, Fluoride, Zn, NO_3, SO_4, bicarbonate, PO_4were considered for WQI calculation (as all parameters were not determined).

The maximum weight of 5 has been assigned to the parameters due to their major importance in water quality assessment [18]. The HCO^{3-} is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment. Other parameters were assigned weights between 1 and 5 depending on their importance in water quality determination.

2.8 Correlation Analysis

To observe the significant relationship between the hydro-chemical parameters, Karl Pearson's correlation matrix was used. The level of significance was considered at >0.05 to identify the positive correlation Statistical software "Statistix 10" was used to measure the minimum, maximum, mean, and standard deviation (SD) of the data.

3. RESULTS AND DISCUSSION

3.1 Water Quality Index (WQI)

WQI ranges were demonstrated in Table 1. The computed WQI values range from 7.62 to 67.03 in 2019. Among all the groundwater samples, 70% were Excellent, 30% were Good in 2019.

For 2020, 100% were Excellent and WQI values range from 2.3 to 12.1. Water samples of most of the locations fall within the Excellent to Good category. None of the samples fall in the class of"poor water", "very poor water" and "Water non-suitable for drinking".

3.2 Groundwater Quality Status of Nachol and Niamatpur in 2019

3.2.1 Nachol' 2019

Water Samples of Nachol upazila were collected from 25 locations of ground sources. pH, Ec, NO_3, Fluoride, PO_4, Zn, SO4, Cr were tested from the samples, and found data were compared with GoB, WHO, and ESB, USA (for irrigation). Fluoride level is higher in 6 locations than the recommended values (1) of GOB (DPHE 2020), but the values are within the permissible limit (1.5) of WHO. Others parameters are within the permissible limit.

3.2.2 Niamatpur' 2019

The quality parameters are summarized in Table 2. The results revealed that the water samples of all the locations of Niamatpur upazila were found within the permissible limits for irrigation and drinking purposes.

Table 1. Water quality classification based on WQI value

Water quality class	WQI Range	Water samples (%) for 2019	Water samples (%) for 2020
excellent	<50	70 % (35 samples)	100% (50 samples)
good water	50-100	30% (15 samples)	-
poor water	100-200	-	-
very poor water	200-300	-	-
Water non suitable for drinking	>300	-	-

Table 2. Groundwater quality status of 2019

Upazila	Calc.	pH	Ec us/m	NO3 (mg/L)	Fluride (mg/L)	PO4 (mg/L)	Zn (mg/L)	SO4 (mg/L)	Cr (mg/L)
Nachol	Mean	8.2	628.1	0.0	0.8	0.3	0.0	3.6	0.1
	STD	0.16	80.60	0.02	0.23	0.11	0.00	4.21	0.60
	Max	8.48	803.4	0.06	1.1	0.67	0	15	3
Niamatpur	Mean	8.1	583.4	0.0	0.2	0.3	0.0	3.2	0.0
	STD	0.10	126.17	0.02	0.13	0.08	0.06	3.95	0.00
	Max	8.24	840.7	0.06	0.54	0.61	0.3	10	0.009
ESB for irrigation		6.0-8.5	1200			15	2		
GOB for drinking			600-1000	10	1	6	5	400	
WHO (drinking)		6.5-8.5			1.5				
FAO (Irrigation)		6.5-8.4	<0.7ds/m				<2		

3.3 Groundwater Quality Status of Nachol and Niamatpur in 2020

3.3.1 Nachol'2020

The quality parameters are summarized in Table 3. All the analyzed parameters are compared with national and international drinking and irrigation water quality standards, and the water samples of the tested DTWs of Nachol are found suitable for drinking and irrigation purposes.

3.3.2 Niamatpur in 2020

The quality parameters are summarized in Table 3. The results reveal that the water samples of all the locations of Niamatpur upazilla are found within the range of permissible limit of GoB, WHO (for drinking), ESB (USA), and FAO (1985) (for irrigation).

3.4 Interpretation for Drinking

3.4.1 Classification according to WHO guideline

In the present WHO guideline (WHO, 2011; fourth edition), the guideline values have not been established for the following naturally occurring chemicals: Br, Cl, H_2S, Fe, Mn, Mo, K, Na, SO_4, PH, TSS (total dissolved solids) and Hardness. The WHO mentioned the reason for not establishing a guideline value that, the elements occur in drinking water at concentrations well below those of health concern and may affect the acceptability of drinking water if guideline values are established.

In 2019 and 2020, the values of the parameters for the water samples were within the permissible limit according to the provisional guideline value of WHO (2011) (Table2& 3).Considering the other given guideline values of WHO, the water for all locations are safe for drinking.

3.4.2 Classification according to GOB guideline

Year 2019

When we consider the guideline values of GOB (DPHE 2020), the Fluoride level is slightly higher than the permissible limit (1 mg/L) in some (6) locations. Other's parameters are within the permissible limits.

Year 2020

In 2020, all parameters are within the permissible limits at all locations.

3.5 Interpretation for Irrigation

3.5.1 Classification according to Environmental Studies Board permissible limit for irrigation guideline (USA)

All parameters are within the permissible limit at all locations for irrigation for 2019 and 2020 samples according to the Environmental Studies Board permissible limit for irrigation guideline.

3.5.2 Interpretation based on FAO guideline

The values of the parameters for the water samples were within the permissible limits according to the provisional guideline value of WHO (1985).

3.6 Comparison of Indices of Water Samples

Comparison of pH, NO_3, and PO_4 of water samples of Niamatpur and Nachol of 2019 and 2020 is depicted in Figs 2, 3, and 4.

3.7 Correlation

Results are presented in Tables 4 and 5. A highly positive correlation was noticed among the parameters. Negative correlations were found among the hydro-chemical parameters.

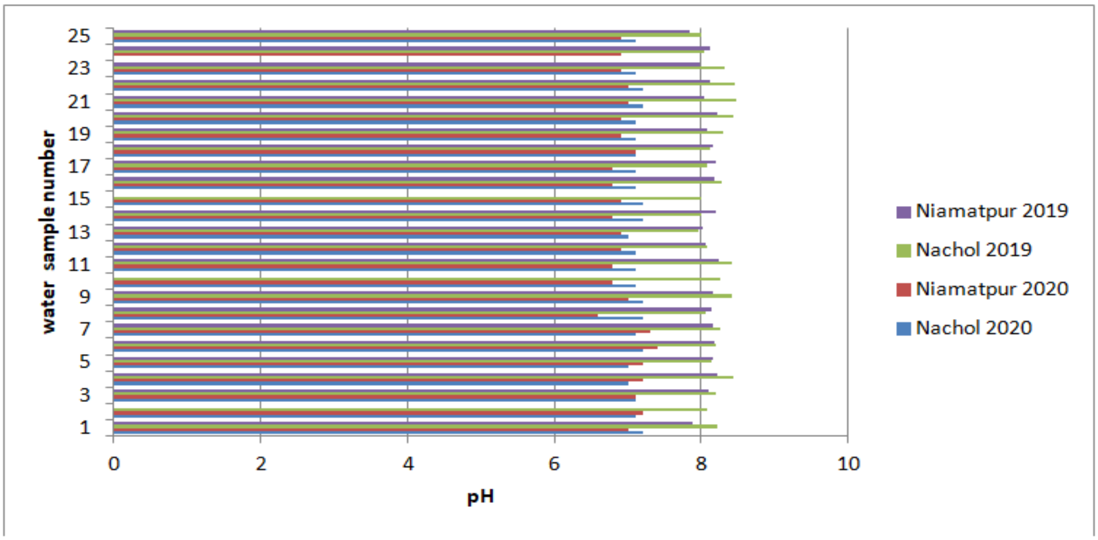

Fig. 2. Comparison of pH of water samples of Niamatpur and Nachol of 2019 and 2020

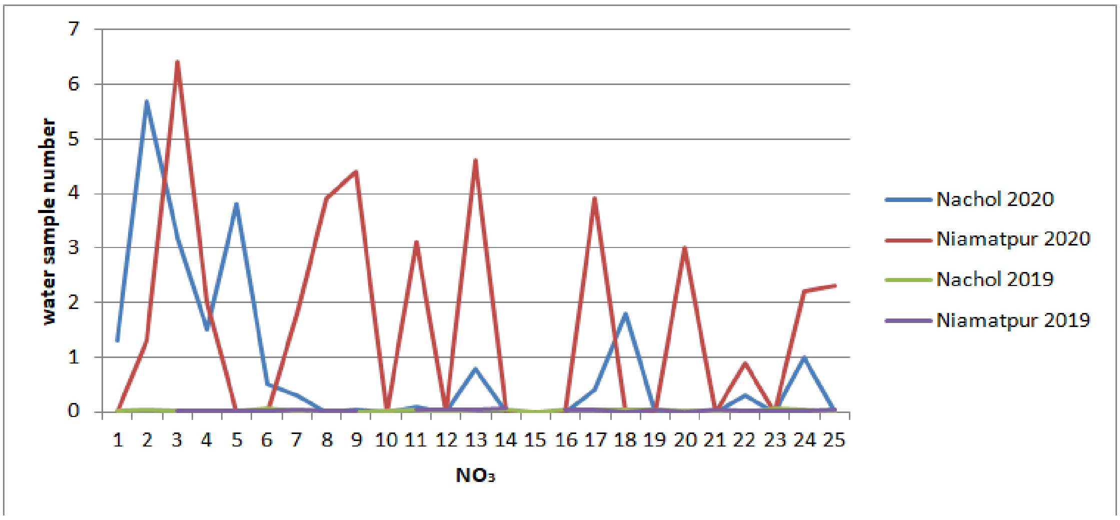

Fig. 3. Comparison of NO_3 of water samples of Niamatpur and Nachol of 2019 and 2020

Table 3. Groundwater quality status of Nachol in 2020

Upazila	Calculation	pH	EC (µs/m)	Fe ppm	Total Cl ppm	Mg ppm	NO3 ppm	TDS ppm	PO4 ppm	Zn ppm	SO4 ppm	Cr ppm	Mn ppm	Ca ppm	Ag ppm	Al ppm	K ppm	Ni ppm	Cu ppm	Mo ppm	Br ppm
Nachol	Mean	6.8	452.6	0.1	0.0	17.6	0.8	226.3	0.5	0.0	8.1	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.1	0.1
	STD	1.43	130.82	0.06	0.04	7.79	1.43	65.69	0.35	0.04	5.44	0.01	0.00	0.00	0.00	0.00	0.91	0.00	0.03	0.09	0.12
	Max	7.2	735	0.32	0.12	35	5.7	367	1.23	0.11	20	0.03	0	0	0	0	4.2	0	0.1	0.2	0.45
Niamatpur	Mean	6.97	574	0.13	0.02	19.4	1.71	470	0.69	0.03	5.2	0.01	0	0	0.01	0	2.2	0	0.03	0.08	
	STD	0.18	229	0.11	0.03	9.17	2.01	114	0.42	0.03	5.49	0.01	0	0	0.02	0	0.48	0	0.04	0.08	
	Max	7.4	987	0.4	0.08	35	6.4	688	1.37	0.1	25	0.05	0	0	0.09	0	3.2	0	0.15	0.2	0.32
ESB (Irrigation)		6.0-8.5	1200	5	-	-	-		15	2	-	0.1	0.2	-	-	5	-	0.2	0.2	-	-
GOB (Drinking)			600-1000	0.3-1	150-600	30-35	10	1000	6	5	400		0.1	75	0.02	0.2	12	0.1	1		
WHO (Drinking)		6.5-8.5	<0.7 ds/m	-	-	-	50 as N	-		-	-		-	-	-	-	10	.02 (p)	2		
FAO (Irrigation)		6.5-8.4	<0.7 ds/m	<5	<92			*<450		<2			<0.2					0.2	<0.2		

**Degree of Restriction: None <450 mg/l or ppm; Slight to moderate 450-2000 mg/l or ppm;*

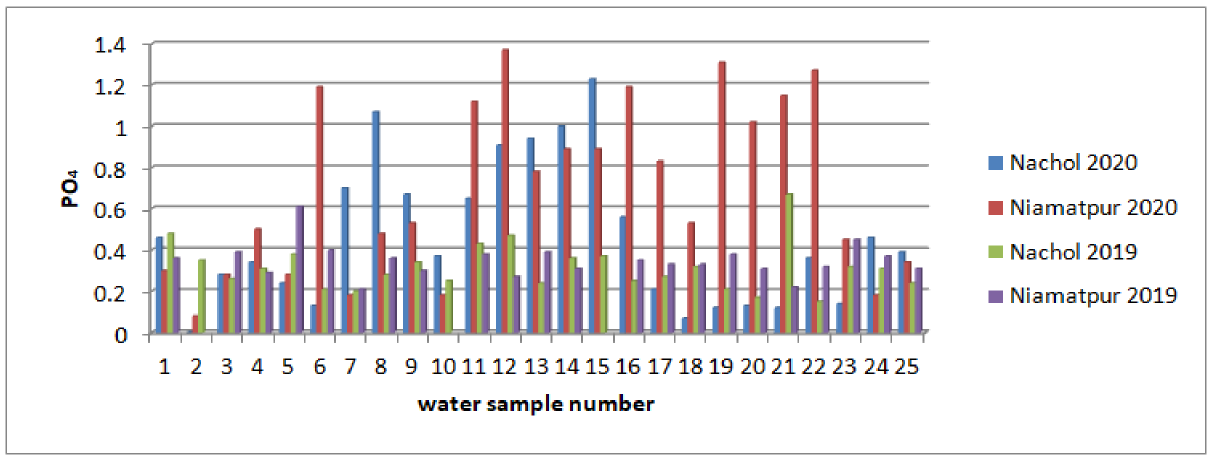

Fig. 4. Comparison of PO_4 of water samples of Niamatpur and Nachol of 2019 and 2020

Table 4. Karl Pearson's correlation matrix between the hydro-chemical parameters for the sample of 2020 Data January, 2020

	pH	Ec	Fe	Total	Mg	NO3	TDS	PO4	Zn	SO4	Cr	K	Cu	Mo	Br
pH	1.0000														
Ec	0.2634	1.0000													
Fe	0.0619	-0.0123	1.0000												
Total	0.1213	-0.1363	-0.1207	1.0000											
Mg	0.1069	0.1310	-0.0982	-0.0303	1.0000										
NO3	0.0169	0.2447	-0.0948	-0.0431	-0.0153	1.0000									
TDS	0.2695	0.9341	-0.0328	-0.1513	0.2176	0.2578	1.0000								
PO4	0.0032	0.3083	0.0292	-0.1702	-0.2875	-0.0546	0.2182	1.0000							
Zn	0.1187	-0.0271	-0.0964	-0.1406	-0.1432	0.0274	0.0077	-0.1890	1.0000						
SO4	-0.3295	-0.2372	-0.0379	0.0079	-0.2439	0.2869	-0.2409	0.0512	-0.0953	1.0000					
Cr	-0.2911	0.0552	-0.1158	0.1137	0.0201	0.0562	0.0734	0.1512	-0.0004	-0.0343	1.0000				
K	-0.3963	-0.1396	-0.0259	-0.0027	-0.2031	-0.1441	-0.1565	0.0404	-0.1847	0.1773	0.0195	1.0000			
Cu	0.0210	-0.1266	-0.0224	-0.0842	0.0156	0.0303	-0.1333	-0.0984	-0.1009	-0.0355	-0.0756	-0.0972	1.0000		
Mo	-0.2775	0.3079	-0.1683	-0.2251	0.1249	0.0835	0.3313	0.0158	-0.1481	-0.0201	0.0985	0.0358	-0.1089	1.0000	
Br	0.0780	-0.0019	-0.1582	0.1930	0.0061	-0.0841	0.0070	0.0131	-0.0103	-0.0095	0.1575	-0.0704	-0.0019	0.827	1.0000

Table 5. Karl Pearson's correlation matrix between the hydro-chemical parameters for the sample of 2019

	pH	Ec	NO3	Fl	PO4	Zn	SO4	Cr
pH	1.0000							
Ec	0.1309	1.0000						
NO3	-0.1479	0.0448	1.0000					
Fluoride	0.4570	0.1250	-0.0691	1.0000				
PO4	-0.0219	-0.0792	-0.2041	-0.1195	1.0000			
Zn	-0.0214	0.0696	-0.1250	-0.1624	0.4184	1.0000		
SO4	-0.2400	0.3007	-0.1918	0.0444	-0.1305	0.0694	1.0000	
Cr	0.0084	0.0442	-0.0933	-0.0495	0.0326	-0.0605	0.0692	1.0000

All the analyzed parameters were found safe and suitable for drinking. Rahman et al also found that groundwater of this region is suitable for drinking and use in domestic purpose [19].

4. CONCLUSION

All the analyzed parameters were compared with national and international drinking and irrigation water quality standards to understand the overall groundwater quality status of the study area. The study showed that the water samples of almost all the locations were suitable for consumption and irrigation. The groundwater at the study areas is safe for drinking and irrigation according to GoB, WHO, and Environmental Studies Board (USA) standards. It is anticipated that this study provides adequate primary information on physico-chemical parameters, water quality indices of Nachol and Niamatpur upazila in Bangladesh. This study will be a useful guide for policy makers to take appropriate initiatives for sustainable ground water quality management.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

ACKNOWLEDGEMENT

The project from which these findings were reported was funded by the PBRG-002, NATP-2 (BARC) project. Their assistance is gratefully acknowledged. The staffs of Agril.Engg. Division of BINA are gratefully acknowledged for their assistance in carrying out laboratory work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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