

HYDROGEOLOGICAL INVESTIGATIONS OF CHAPAI NAWABGANJ TOWN OF NAWABGANJ DISTRICT, NORTH-WEST BANGLADESH USING ISOTOPE AND OTHER TECHNIQUES

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ABSTRACT

Groundwater of Chapai Nawabganj town has been studied using hydrogeological, hydrochemical and environmental isotope ($\delta^{18}\text{O}$, $\delta^2\text{H}$, $\delta^{13}\text{C}$, ^3H and ^{14}C) data. Aquifer underneath the study area is divided into unconfined to semi-confined Holocene alluvial floodplain aquifer and confined Plio-Pleistocene Dupi Tila sandstone aquifer. Chemical composition of groundwater is characterized by high concentrations of Mg^{2+} , Na^+ , Ca^{2+} , HCO_3^- , Fe^{Total} , and low concentrations of Mn^{2+} , NO_3^- and PO_4^{3-} . Groundwater samples are mainly Mg-Ca- HCO_3 and Na-Mg-Ca- HCO_3 types and Na-Mg-Ca-Cl- HCO_3 type of water is also found at some places. Based on Cl⁻ and SO_4^{2-} concentrations groundwater is normal chloride and normal sulphate water, respectively. In terms of SAR and EC values water is excellent for irrigation purpose. The isotopic composition also suggests some segregation of groundwater from the different aquifers and indicates different ages of recharge.

Key words: EC, Global meteoric water line, Hydrochemistry, Stable and radioactive isotopes

INTRODUCTION

Chapai Nawabganj town is situated in the north-western part of Bangladesh. The study area lies between $88^\circ 13' 10''$ and $88^\circ 18' 50''$ E longitude and $24^\circ 33' 25''$ and $24^\circ 37' 40''$ N latitude covering an area of about 33 km^2 (Banglapedia 2003 and BBS 2010) under Chapai Nawabganj district. The study area is situated close to the present course of the river Mahananda flowing through the northern and south-eastern part of Chapai Nawabganj Town (Fig. 1).

In the study area, the recent floodplain comprises predominantly of fluvial deposits. The Barind tract is composed of well-oxidized alluvial sediment, which is reddish brown in color with the presence of ferruginous and calcareous nodules. The objectives of this study include the comparing of groundwater quality with national and international water

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quality standard for justifying its use for domestic, industrial and irrigation purposes. The study also involved use of an isotope approach with naturally occurring isotope tracers ^2H , ^{18}O and ^3H to characterize the aquifers for identifying origins of groundwater and possible, recharge sources.

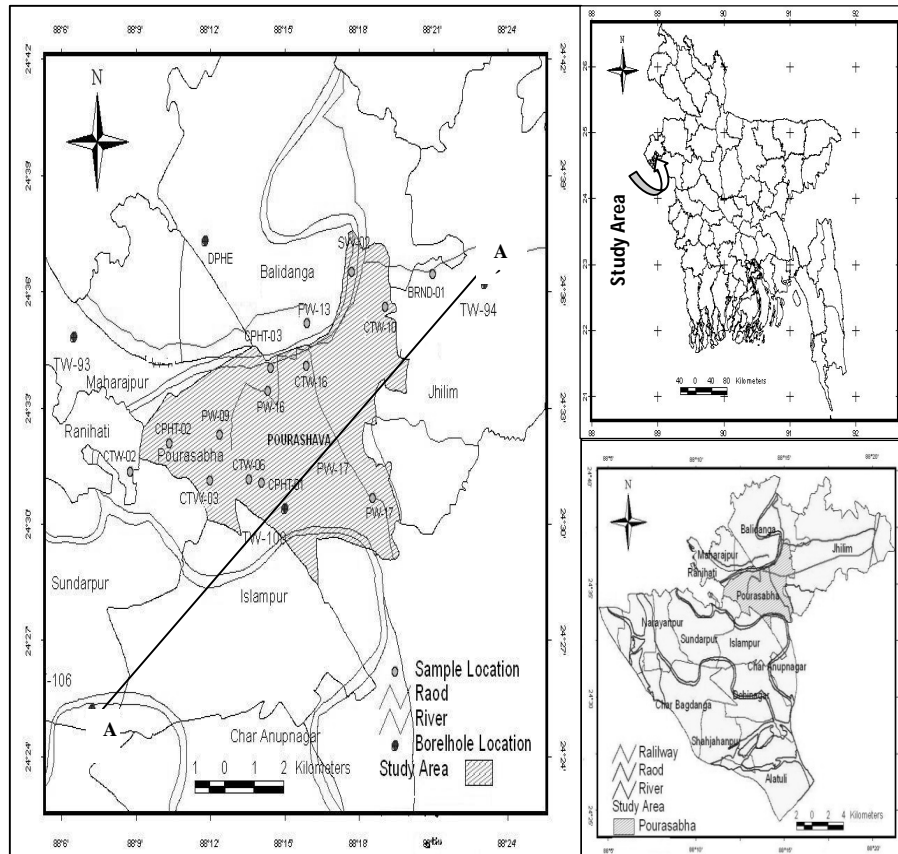


Fig. 1. Location, water samples and bore log position map of the study area.

Hydrostratigraphy of the study area up to 100 m depth was established from the analysis of the bore logs. A generalized subsurface lithological cross section AA' (Fig. 2) was drawn based on available borelog data. From this cross-section, the aquifer system of the study area can be divided into upper aquitard, middle aquifer and lower aquitard. The single aquifer in this zone is different in both geometry and permeability; which causes complex groundwater flow in the aquifer. The aquifer varies widely in depth and thickness, reflecting mainly unconfined to confined in nature. The thickness of the aquifer is much higher in the central and southern part of the study area in comparison to the eastern part.

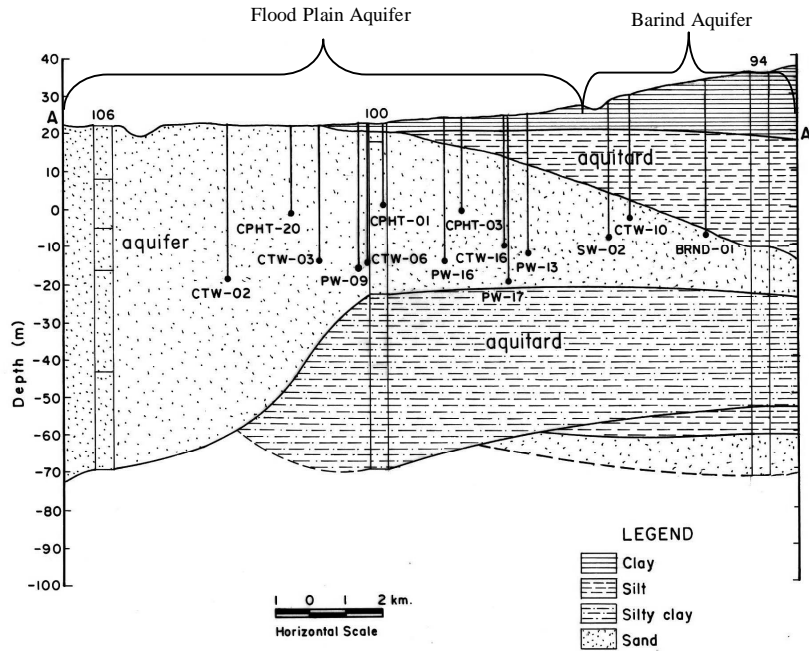


Fig. 2. Lithological cross-section along the line AA'.

Groundwater level data of 1988 - 2008 for seven observation wells were used to study the piezometry of the study area. Groundwater level rises with the initiation of monsoonal rainfall in the month of June whereas little contribution of rainfall is observed in river water level (Fig. 3a, b). In addition it has been concluded that the influence of river stage is very significant regarding the recharge and discharge of the aquifer, nearer to rivers.

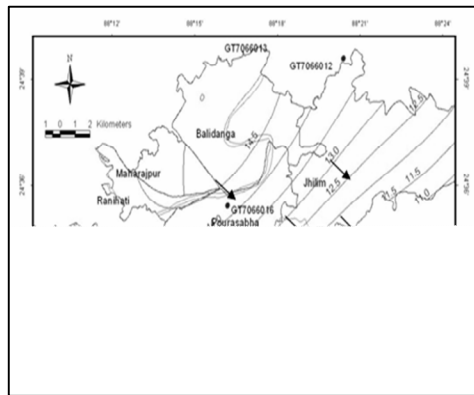


Fig. 3a. Contour map of minimum groundwater elevation (mPWD) in 2005.

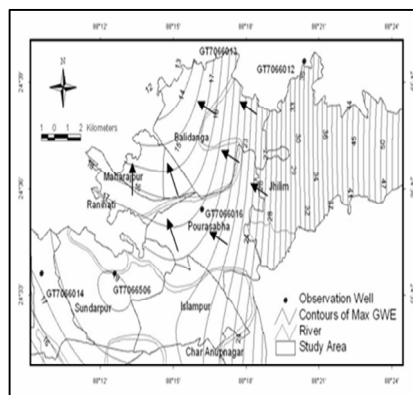


Fig. 3b. Contour map of maximum groundwater elevation (mPWD) in 2005.

MATERIALS AND METHODS

Hydrogeological, hydrological and climatic data; previous reports, maps and images were collected from different organizations such as Bangladesh Water Development Board (BWDB), Bangladesh Meteorological Department (BMD) and Department of Public Health Engineering (DPHE).

Field work was mainly done for collection and field measurement of physico-chemical parameters of water samples. Ground- and surface water samples were collected following sampling techniques standard of the USGS (1998) water chemistry sampling protocol from 1 to 3 June, 2008. Groundwater samples were collected from 14 hand tube wells and the depth varies from 21 m to 46 m. The geographical locations of the tube wells were determined with a GARMIN handheld global positioning system (GPS). The approximate depth of each well was noted from the record preserved and described by the well owners. The samples were collected in 500 ml HDPE bottles, after pumping continuously 15 - 30 minutes until the temperature, electrical conductivity (EC) and pH reading had stabilized. Standard procedure of filtering inorganic constituents in whole water samples through a 0.45 μm pore-size disposable capsule filter has been used during sampling. All the samples are acidified in the field for the determination of cations. The environmental sensitive physical parameters like temperature, redox potential (Eh), pH, EC, DO were determined in the field by portable pH meter (Sension1, HACH Company, USA), EC meter (Sension-5, HACH Company, USA), DO meter (Sension-6 HACH Company, USA). HCO-3 was determined by digital titrator (Model 16900, HACH Company, USA).

The hydrochemical analysis has been carried out in the different laboratories of Atomic Energy Research Establishment (AERE), Ganakbari, Savar, Dhaka following the standard procedures recommended by APHA (1995). CL, SO_4^{2-} , NO_3^- , SiO_2 were determined by UV-VIS Spectrophotometer (Model-DR/4000U, Version-2.42, HACH, U.S.A), Na^+ and K^+ were determined by Digital Flame Photometer (Model 381), Ca^{2+} , Mg^{2+} , and Fe_{Total} , Mn^{2+} were determined by Atomic Absorption Spectrophotometer (Shimadzu Company, Model AA 6800, Japan) and the arsenic was determined by Atomic Absorption Spectrophotometer using hydride generator (Shimadzu Company, Model-HVG-1). The accuracy and precision of the above mentioned analyses were tested through running duplicate analyses on selected samples. Standard reference materials (SRM-1640 and SRM-1643e of National Institute of Scientific and Technology, USA) were used to check accuracy of the methods. The relative standard deviation for all the samples was within $\pm 5\%$. All samples were diluted several times to adjust for the operating range and were analyzed.

The stable isotopes ($\delta^2\text{H}$ and $\delta^{18}\text{O}$) and tritium analyses were performed using the CO_2 equilibrium method and the chromium reduction method for 2H/1H ratios, followed by analysis with an Isotope Ratio Mass Spectrometer (IRMS) using the conventional method (Coplen 1996) at the Isotope Hydrology Laboratory of International Atomic Energy Agency (IAEA) in Vienna, Austria.

The sodium adsorption ratio (SAR) values for each water sample were calculated by using following equation (Richard 1954), where the concentrations are reported in meq/l.

$$\text{SAR} = \frac{\text{Na}}{\sqrt{\frac{\text{Ca} + \text{Mg}}{2}}}$$

Arc GIS 9.2 was used for the preparation of different maps and graphical interpretation of water level data and AquaChem4.0 software was used for graphical analysis of water chemistry data.

RESULTS AND DISCUSSIONS

Concentrations of different physico-chemical parameters, major and minor constituents of groundwater are given in Tables 1 and 2, respectively. On site measurement of EC of groundwater ranges from 450 to 1706 $\mu\text{S}/\text{cm}$ and most of the floodplain aquifer water samples show negative Eh value which indicates relatively reducing condition whereas the Barind aquifer water samples show positive Eh value indicating oxidizing condition. The Barind aquifer water samples are characterized by slightly acidic pH (average 6.96), DO (average 0.20 mg/l) and temperature (average 25.98°C). Floodplain aquifer samples show higher values of pH (average 7.18), DO (average 0.28 mg/l) and temperature (average 26.57°C), than the Barind aquifer water samples.

Chemical composition of the Barind aquifer water is characterized by high concentrations of Mg^{2+} (average 48.65 mg/l), SiO_2 (average 50.02 mg/l) and low concentrations of Fe (average 0.90 mg/l), Mn^{2+} (average 0.12 mg/l), SO_4^{2-} (average 17.53 mg/l) and NO_3^- (average 1.31 mg/l).

Floodplain aquifer water are also characterized by high concentrations of HCO_3^- (average 412 mg/l) and Ca_{2+} (average 42.71 mg/l), Fe (average 3.63 mg/l), Mn_{2+} (average 0.33 mg/l), NO_3^- (average 8.15 mg/l), SO_4^{2-} (average 39.40 mg/l) and As (average 67.05 $\mu\text{g}/\text{l}$) and low concentrations of Mg^{2+} (average 33.92 mg/l). High concentrations of Ca^{2+} and HCO_3^- occur in the central part of pourashava, which indicate current recharge of groundwater (Azad *et al.* 2000).

Table 1. Concentrations of physico-chemical properties of groundwater samples.

Sample ID		Longitude (E)	Latitude (N)	Well depth (m)	pH	Eh (mV)	Temp (°C)	EC (μ S/cm)	DO (mg/l)
BRND-01	Barind aquifer	88.31998	24.61219	35	6.78	14.6	25.7	811	0.13
CTW-10		88.30545	24.60600	34	7.02	0.6	25.8	578	0.04
PW-17		88.30177	24.56891	46	7.01	1.3	26	496	0.06
SW-02		88.29540	24.61266	37	7.03	0.2	26.4	789	0.58
PW-13		88.28175	24.60269	38	7.09	-3	26.6	510	0.51
PW-16		88.26998	24.58963	38	6.93	6.2	26.8	579	0.05
CTW-02	Flood plain aquifer	88.22831	24.57394	40	7	1.9	26.2	513	0.18
PW-09		88.25536	24.5812	39	7.12	-4.8	26.6	1209	1.41
CTW-16		88.28152	24.59452	35	7.36	-18.9	26.4	450	0.09
CTW-06		88.26422	24.57248	38	7.23	-11.3	27.4	1706	0.11
CPHT-01		88.26806	24.57183	21	7.15	-6.8	26.8	959	0.04
CTW-03		88.25233	24.5723	37	7.23	-11.2	26.7	554	0.12
CPHT-02		88.24010	24.57948	23	7.25	-12	25.7	513	0.14
CPHT-03	88.27071	24.59397	24	7.45	-23.7	26.5	1167	0.15	

Table 2. Concentrations of major cations and anions in groundwater samples.

Sample ID	Na ⁺ (mg/l)	K ⁺ (mg/l)	Ca ²⁺ (mg/l)	Mg ²⁺ (mg/l)	Fe ⁺ (mg/l)	Mn ²⁺ (mg/l)	As (μ g/l)	SiO ₂ (mg/l)	HCO ₃ ⁻ (mg/l)	Cl ⁻ (mg/l)	NO ₃ ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)
BRND-01	68.63	12.34	53.34	35.22	0.7	0.05	0.08	55.56	355	188.24	3.646	26.8
CTW-10	48.02	8.75	38.62	25.61	0.01	0.05	0.08	49.59	378	17.39	0.726	8.132
PW-17	70.57	4.21	29.77	26.38	0.01	0.325	0.08	49.14	439	47.62	0.115	13.569
SW-02	40.38	12	26.9	107.37	2.88	0.05	10.99	45.77	440	19.66	0.753	21.609
PW-13	23.12	6.77	29.69	28.83	0.56	0.373	17.94	45.0	420	38.93	1.779	18.871
PW-16	54.32	13.84	43.9	35.05	6.87	0.133	112.88	34.44	486	142.3	8.056	51.158
CTW-02	7.83	7.6	32.22	26.77	14.77	0.518	167.73	41.48	447	3.14	9.65	0.166
PW-09	40.33	21	60.95	42.37	9.26	0.361	180.34	30.31	494	175.81	5.099	51.267
CTW-16	9.53	5.89	21.96	18.83	1.58	0.181	62.73	35.51	268	14.38	2.754	1.209
CTW-06	146.75	25.88	82.45	52.84	0.21	0.602	17.68	40.41	490	392.37	4.253	227.31
CPHT-01	44.58	18.27	63.23	35.49	0.01	0.698	44.45	46.23	466	88.81	6.646	17.703
CTW-03	20.28	11.16	26.62	20.68	1.02	0.289	22.11	42.25	255	28.69	5.031	10.124
CPHT-02	10.51	7.56	23.5	43.61	0.01	0.05	24.51	42.09	305	9.84	5.211	2.442
CPHT-03	175.88	24.82	42.55	34.69	0.01	0.133	20.12	27.09	489	157.18	33.039	13.722

The chemical characteristics of water quality data have been illustrated in the Piper (Piper 1944) Trilinear diagram (Fig. 4). Interpretation of the hydrochemical data implies that the groundwater samples PW-13, SW-02, PW-16, CTW-02, PW-09, BRND-01, CTW-16, CPHT-01, CTW-03, CPHT-02, and CTW-10 belong to Ca-Mg-HCO₃ type water and is the region of water of temporary hardness. Sample CTW-06 belongs to saline (Na⁺ + K⁺ and Cl⁻ + SO₄²⁻) type water. PW-17, CPHT-03 belongs to mixing type water (Ca-Mg-Na-HCO₃-Cl). All of these samples have low to negligible chloride content and secondary alkalinity exceeds 50%. These are all pure meteoric waters, which have not undergone any specific chemical changes. From the observation of Piper diagram, it is concluded that water of the study area is Ca-Mg-HCO₃ type.

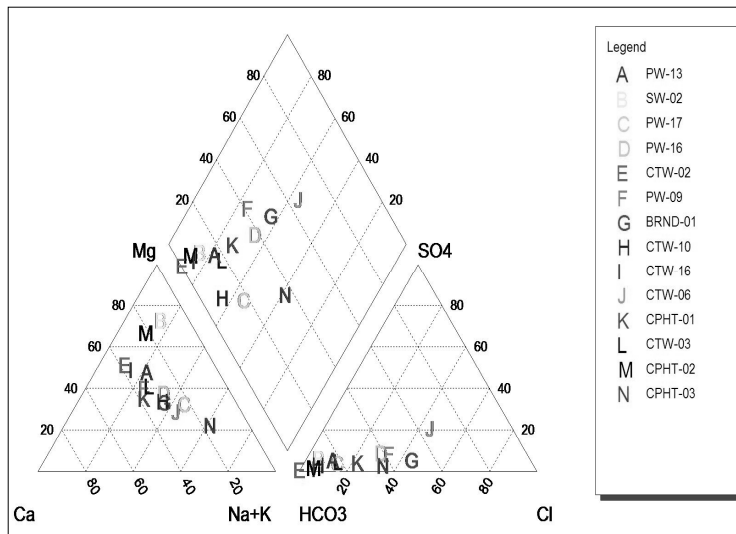


Fig. 4. Piper trilinear diagram of the groundwater samples.

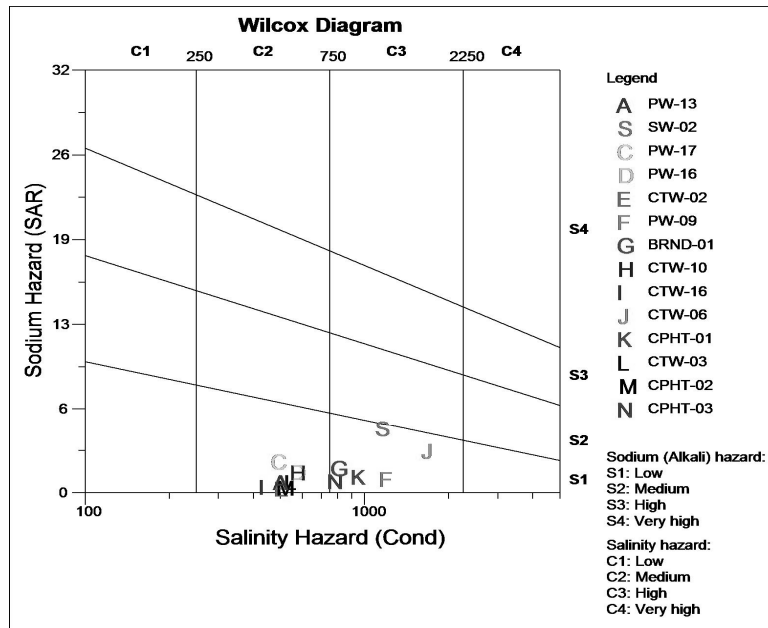


Fig. 5. Simple water classification for irrigation according to US Salinity Laboratory’s diagram.

In terms of drinking water quality standard (Table 3), most of the ions of groundwater are within the limit of drinking water quality standard of both DoE (1997) and WHO (2008) but in some samples K^+ , Fe , Cl^- and As concentrations exceed the drinking water quality standard. Water from the floodplain aquifer exhibits higher arsenic

concentrations. All of the floodplain aquifer samples exceed WHO (2008) standard and four samples exceed DoE (1997) standard. In the Barind aquifer, all water samples show concentrations of As below the WHO (2008) standard and only one water sample (SW-02) exceeds WHO (2008) but below DoE (1997) standard. Most of the groundwater samples of Chapai Nawabganj Pourashava are arsenic contaminated. The highest concentrations (180.34 µg/l) present in PW-09 in floodplain aquifer at a depth of 39 m in production well of Pourashava, Nama Sankar Bati (Natun Hat), Ward No. 11. The severely arsenic contaminated groundwater is dominantly Mg-Ca-HCO₃ type water with neutral to basic pH, often moderately hard to very hard hardness with much bicarbonate concentrations. As the reducing condition is prevailing in groundwater it is likely to be the reason of arsenic mobilization. Groundwater of the study area is suitable for industrial purposes except few groundwater samples that are not maintaining conformity with the recommended concentration.

Table 3. Comparison of groundwater quality parameters with WHO (2008) guideline values for chemicals that are of health significance in drinking-water and DoE (1997) standards for drinking water.

Water quality parameters	WHO standard (2008)		Bangladesh standard (DoE, 1997)	Study area		
	Max. acceptable	Max allowable		Range	Average	
Physical parameter	pH	6.5	8.5	6.5-8.5	6.78-7.5	7.12
	TDS (mg/l)	1000		1000	307-1232	575.36
	Hardness	100	500	200-500	132-509	259.66
Major cations	Na (mg/l)	200		200	7-175	54.34
	K "	-	-	12	4-25.8	12.87
	Ca "	-	-	75	21.9-82	41.12
	Mg "	50	150	30-35	18.8-107	38.12
	HCO ₃ "	-	-	-	255-494	409.43
Major anions	Cl' "	200	600	150-600	3-392	94.60
	SO ₄ ²⁻ "	-	250	400	0.1-227	33.15
	NO ₃ ²⁻ "	50	-	10	0-33	6.20
Minor & trace element	Fe "	0.3	3	0.3-10	0-14	2.79
	Mn "	0.5	-	0.1	0-0.7	0.27
	As µg/l	10	-	50	0-180	67.05

In terms of SAR (Raghunath 1990) and EC values (Wilcox 1967) it is observed that groundwater is satisfactory for irrigation purposes but it is doubtful for using irrigation purposes because of high arsenic concentration. From the observation of both SAR and EC value it is found that most of the water samples in the study area are belonging to C2 field and rest of the groundwater samples belong to C3 field (Fig. 5).

The water samples for environmental isotopic analyses (^{18}O , ^2H , ^{13}C , ^3H and ^{14}C) were conducted and collected from the IAEA, Vienna, Austria. The result of environmental isotopic analyses is given in Table 4.

Table 4. Concentrations of environmental isotopes of groundwater samples.

Sample ID	Well depth (m)	$\delta^{18}\text{O}$ (‰VSMOW)	$\delta^2\text{H}$ (‰ VSMOW)	$\delta^{13}\text{C}$ ‰ (14C)	3H (TU)	^{14}C (pMC)
PW-13	38	-4.72	-32.7	-11.91	3.82	98.15
SW-02	37	-4.13	-29.1	-8.08	1.05	81.38
PW-17	46	-3.62	-28	-10.26	1.15	78.33
PW-16	38	-4.3	-31.4	-11.91	3.64	99.62
CTW-02	40	-5.3	-37.3	-	3.2	-
PW-09	39	-4.99	-36.8	-14.18	2.59	95.58
BRND-01	35	-3.44	-25.1	-	0.32	-
CTW-10	34	-3.56	-25.6	-8.75	0.42	82.24
CTW-16	35	-3.92	-28.4	-	4.26	-
CTW-06	38	-5.37	-35	-	3.73	-
CPHT-01	21	-4.96	-33.1	-	5	-
CTW-03	37	-5.04	-32.3	-	3.53	-
CPHT-02	23	-4.02	-26.6	-	4.42	-
CPHT-03	24	-5.68	-37.7	-	1.25	-

Results of stable isotope analysis for $\delta^{18}\text{O}$ and $\delta^2\text{H}$ are plotted in Fig. 6. The plot presents data in relation to the Global Meteoric Water Line (GMWL) of Craig (1961). This line represents the results of world-wide precipitation measurements of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ and is defined by the following equation:

$$\delta^2\text{H} = 8\delta^{18}\text{O} + 10.$$

For the present study the local meteoric line (for Shillong, India) is also drawn. The local meteoric line is very similar to the WML and is defined by the equation:

$$\delta^2\text{H} = 8\delta^{18}\text{O} + 12$$

The results of stable isotopic compositions for $\delta^{18}\text{O}$ and $\delta^2\text{H}$ are plotted in Fig. 6 and the WML is drawn on the plot. Most of the sampled water depart significantly from this line, indicating an origin from rain and local rivers; and it represents that some evaporative fractionation has occurred before infiltration.

Groundwaters in the study area show some spatial variation with the most depleted (range -5.04 to -5.68 ‰) and also with a few slightly enriched (range -3.44 to -4.99 ‰) compositions of $\delta^{18}\text{O}$ in the Holocene aquifer that lies in the central part of Pourashava. Most likely, it relates to increased inputs of rain and river recharge locally during flood time. The isotopic distinctions in groundwater in this study area suggests some

segregation of groundwaters from the different aquifers and may indicate different ages of recharge. Groundwater from the two aquifers are therefore likely to have been recharged at different periods. This is to some extent confirmed by radioactive isotope (tritium) data for groundwaters from this study area.

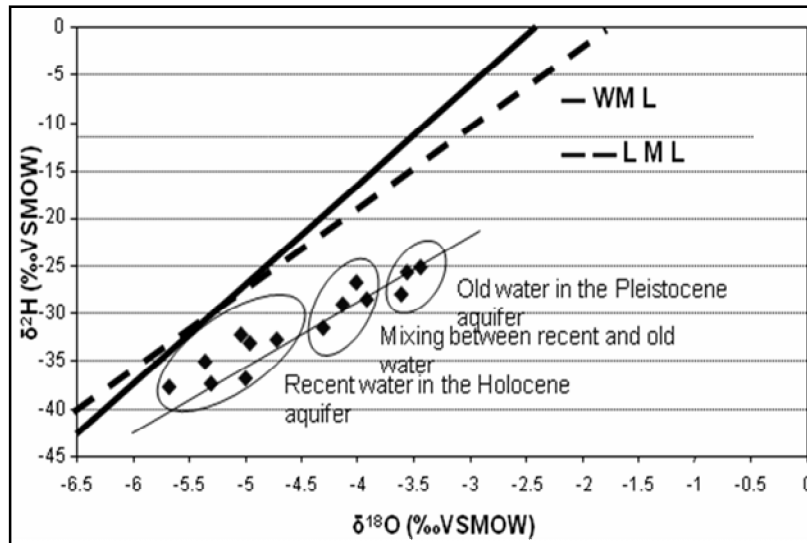


Fig. 6. Relationship between oxygen-18 and deuterium in the groundwater of the study area and Mahananda river.

It is seen from the tritium distribution plot, the samples with very low tritium (<1 TU) are mostly from the eastern part of town. These samples have a $\delta^{18}\text{O}$ value of between about -4 and -5 ‰. Two samples in the eastern part (SW-13 and PW-17) have slightly higher tritium values (1.05 and 1.15 TU), but these samples have very high $\delta^{18}\text{O}$ values, indicating draw down of water from a nearby waterbody or pond. Based on the tritium and stable isotope values, it can be concluded that the source of water in this arsenic-free reservoir is likely from recharge much to the east and/or north (could include river recharge). Low tritium values in the eastern side samples indicate the presence of predominantly older (pre-1960s) water at depth. It is unlikely that this water is much older than 100 years, as the older waters in other regions that had previously been seen at depth of about 100 m had a $\delta^{18}\text{O}$ value of about -5 ‰. This aquifer may continue to provide safe water. Samples with low tritium in the western part of town have a much lower $\delta^{18}\text{O}$ value of about -5.5 ‰ or so and likely have a different source of water, but not from the Pleistocene aquifer of eastern side.

C-14 activity of the analyzed groundwater varies from 99.62 to 81.38 pMC in the study area. The result indicates that the groundwater residence times in ~ 30 to 1700 years

BP. Shallow groundwater collected from the study area show relatively high ^{14}C values which indicate modern recharge from precipitation or river waters.

CONCLUSION

The general trend of groundwater flow is towards the south-east direction in dry season and north-west direction in wet season. The fluctuation of groundwater level ranges from 7.58 to 18.12 mPWD. The average EC of the Barind aquifer and floodplain aquifer is 668.33 and 816 $\mu\text{S}/\text{cm}$, respectively. The average pH of floodplain aquifer is about 7.18 which are a bit higher than the Barind aquifer. Groundwater is mainly Mg-Ca- HCO_3 and Ca-Mg-Na- HCO_3 type of water. Water samples from floodplain area contain high arsenic and exceed drinking water quality standard of Bangladesh. From the above observations, it can be concluded that most of the groundwater samples are suitable for drinking and minor treatment may be required except arsenic. In terms of SAR and EC values it is observed that the water of the study area is excellent quality water for irrigation purpose. The spatial variation of $\delta^{18}\text{O}$ in groundwaters of Chapai Nawabganj town shows mostly depleted and a few slightly enriched compositions in the Holocene flood plain aquifer, indicating the inputs of rain and river recharge locally during flood time. Two subsystems could be identified in the study area based on hydrochemical, stable isotope and tritium data. Subsystem A with low arsenic content and pre-1960s water was formed in the eastern part of the study area. Sub-system B is consisted of arsenic rich and recent recharge water in the central part of the study area. Therefore water in the eastern part of the study area is safe for drinking purpose and continue to be so in near future.

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