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Use of hydrochemistry and stable isotope techniques in investigating seepage/leakage in Gumti flood dyke, Comilla

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Abstract

Water seepage/leakage and slope failures are the major issues in Gumti earthen dyke. The distinct seepage and slope failure zones were observed at three places (Farizpur, Kathalia and Ebdarpur) along the countryside of left dyke. Two sampling campaigns were conducted near the seepage site for collection of water samples from the river and the country side hand tubewell. Both samplings were done after recession of peak water level in the Gumti river. The chemical and stable isotope parameters support the statement that the hydraulic connection exists between the river and shallow aquifer. The high EC values of groundwater from the nearby private shallow wells clearly show that these groundwater flows were influenced by the river water during peak water level in the river Gumti. The chloride contents of both groundwater and river water are found mostly similar, indicating mixing between the two water systems. The results of stable isotopes (^{2}H and ^{18}O) reflect the hydraulic connectivity between the river water and groundwater through the base of dyke.

Keywords: Stable isotopes, meteoric water line, hydraulic connectivity, electrical conductivity, chloride

1. Introduction

Gumti Embankment/Dyke is vital for flood control, leading to the protection of vital installations (such as cantonment, Comilla city, industries, Asian highway, national highway and growth centers), protection of agricultural land and protection of human lives and livelihood. During the year 1964-65, Gumti Flood Control and Irrigation Project was undertaken by the government and construction work was completed by 1978. Under this project, 32 km of dyke on left bank from Katak bazar to Jafarganj and on the right to Bishnapur were constructed. Later on under Flood Control and Drainage (FCD)-3, the length of the dyke was extended upto Elliotganj on left bank and Puniaton on right bank in 1991-92 (Mott MacDonald Ltd. et al., 1993). Now, the total length of the dyke is about 70 km. The height of dyke varies from 10.0m to 5.0m in the direction upstream to downstream of the Gumti river. Due to the construction of dyke on both banks covering almost the whole length of the Gumti river, there created a severe confinement effect on flash flood. This became more critical due to construction of several bridges by different agencies at different locations across the Gumti river. The bed and flood plains of the Gumti river also gradually started rising because of heavy siltation. As a result, serious confinement of floodwater within the dyke took place. For this reason, each and every year, the dykes are threatened by the floods. Due to flashy nature, the peak water level of the Gumti river exists for short period, such as two or three days, following the high monsoon rainfall in the months of June-July. During the flash flood time, the Gumti dyke experiences a serious leakage/seepage problem through the body and foundation of the dyke in some particular locations. As a consequence, slope failures occur in some locations of the country side of the dyke.

The investigation of origin and dynamics of groundwater in the vicinity of dyke is a major requirement to identify the leakage/seepage problems. Seepage/leakage of water from dykes may occur through the foundation, body, or through natural geologic formations in which these rivers/reservoirs lie. The losses may be in the form of general seepage usually covering a wide area or they may be due to specific leakage flowpaths. In most cases, local groundwater and river water related to the leakage/seepage emerge in the country side of dyke with a complex mixing pattern. In consultation with Bangladesh Water Development Board (BWDB), the Gumti Flood Control Embankment/Dyke of Comilla has been taken up as a case study to find out the leakage/seepage or slope failure zones of the dyke by applying environmentally safe stable isotope techniques along with contemporary conventional hydrochemical methods. Integration of isotope techniques in the hydrogeological characterization work in the study area provides the required information rapidly and at a much lower cost than possible with the non-isotopic techniques alone. The isotope methodology works essentially by developing a characteristics pattern of the isotopic composition to identify the sources and flow dynamics of seeping/leaking in the dykes. The isotopic technique has been integrated in the conventional hydrologic investigations.

The following works were carried out in the three distinct locations of seepage and slope failure zones of the dyke, namely, Farizpur, Kathalia and Ebdarpur; (i) on-site measurement of physio-chemical properties and (ii) hydrochemical and stable isotopic (^{2}H and ^{18}O) analyses of groundwater and river water near the seepage/leakage site in the dyke.

2. Study area and hydrology

The study area is located some 60 km east of the Dhaka city. It is roughly a square of 50 x 50 km lying between longitude 90º45´E to 91º15´E, and latitude 23º28´N to 23º38´N. The area is bounded by the Meghna river to the west, the Indian border and Tripura Hills to the east, and the Dhaka-Chittagong national highway to the south. The Gumti embanked from upstream of Comilla, almost to its confluence with the Meghna. The location map of study area is shown in Figure 1.

The Gumti, a perennial river and flashy in nature, originates from the Tipperan hilly region of India and flows into territory of Bangladesh through Katak Bazar border. The river has its course on the northern side of Daudkandi-Comilla road. The Gumti carries the direct precipitation runoff to the Meghna from the catchments on both sides of the border. In the western part, the rivers generally have flat slopes and come under tidal influence. In the eastern part, the channels draining the Tripura hills (e.g. Gumti and Salda) are steeper and more liable to flash flooding. The Gumti river is embanked on both banks from the Indian border (Chainage 0.0 km) to 70 km downstream at Gouripur near its outfall.

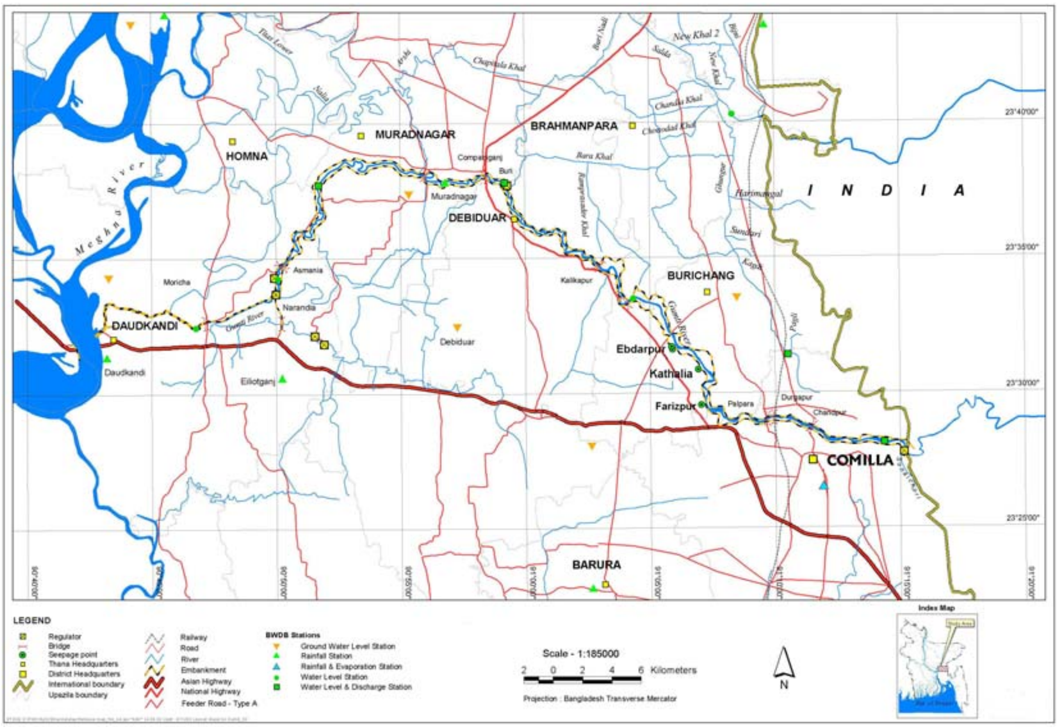

Fig. 1. Location map of the study area

3. Field reconnaissance survey and observations

During 28–29 September 2002, the reconnaissance survey and surface investigation of leakage/seepage points in Gumti Flood Dyke were performed. The reconnaissance survey was carried out along the left bank dyke of Gumti river starting from Katak Bazar to Jafarganj having a length of about 37 km. The height of the dyke varies from 10.0m to 5.0m in the direction upstream to downstream of the Gumti river. Typical cross section of the Gumti dyke is given in Figure 2. The distinct seepage and slope failure zone were observed at three places (Farizpur, Kathalia and Ebdarpur) along the countryside of dyke. All the observed seepage zones are protected by providing gunny bags with sand filling on the slope and bamboo piling on the toe of dyke.

At Farizpur area (23°29.565′ N & 91° 07.028′ E), the seepage zone is about 120 ft long and at the seepage zone, a portion of soil has been eroded and slightly soggy. The height of the dyke at the seepage zone is about 30 ft with distinct berm. There are borrow pits adjacent to the toe of the dyke. Kathalia seepage zone (23°30.853′ N & 91°06.917′ E) is about 100 ft long along the country-side of the dyke. At this seepage zone the height of the dyke is about 25 ft and this zone is about 200 ft of setback distance from the river. Ebdarpur (23°31.607′ N & 91°05.882′ E) seepage zone is about 140 ft long along the country-side of the dyke. A localized slope failure line is observed at this seepage. The slope failure line is crescent shaped and more or less 25 ft long and 1 ft wide. There is a private pond close to the dyke. At this point, the dyke is about 300 ft of setback distance from the river.

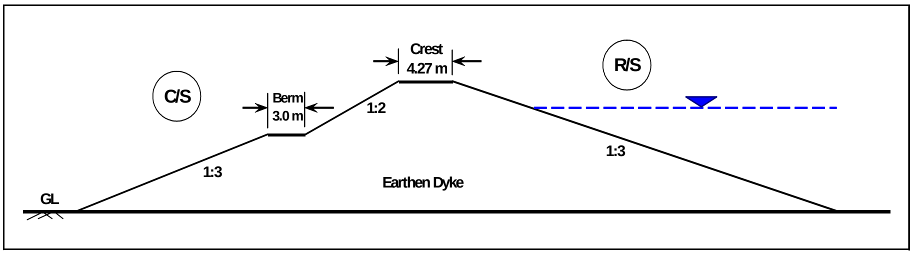

Fig. 2. Typical cross section of the Gumti Dyke

4. Methods and materials

4.1 Using stable isotopes to determine the recharge and mixing pattern

Analysis of oxygen-18 (^{18}O) and deuterium (^{2}H) involves measuring the fractionization (isotope partitioning) of these stable isotopes that has occurred as a result of natural meteorological (meteoric) processes. Hydrogen and oxygen each have two stable (non-radioactive) isotopes (^{1}H, ^{2}H and ^{16}O, ^{18}O respectively) whose ratios are characteristic of the geographic location and climatic conditions where precipitation reaches the ground surface (Clark and Fritz, 1997). On a global scale, the stable oxygen (^{18}O) and hydrogen (D or ^{2}H) isotope ratios in surface precipitation are found to form a "Global Meteoric Water Line" (Craig, 1961) that is defined as:

$$\delta\,^{2}H = 8 \times \delta^{18}O + 10 \qquad (1)$$

where, $\delta\,^{2}H$ = isotopic ratio of deuterium
$\delta^{18}O$ = isotopic ratio of oxygen-18

The stable isotope ratios are conventionally reported in delta notation (δ), which compares the ratio between heavy and light isotopes of a sample to that of a reference standard (seawater is used as the standard for isotope measurements, its isotopic ratios, by definition, are zero). Delta values are expressed as *per mil* (parts per thousand or ‰) differences relative to the standard known as Vienna Standard Mean Ocean Water (VSMOW). Except for evaporation before or during infiltration, the stable oxygen and hydrogen isotope ratios remain mostly unchanged as surface water percolates down to become groundwater. Evaporation increases the oxygen and hydrogen isotopic ratio of the residual water and this residual water no longer follows the trace of the Global Meteoric Water Line (IAEA, 1983).

4.2 Sample collection and analysis methods

The first field sampling was carried out jointly by Bangladesh Atomic Energy Commission (BAEC) and BWDB on 30 September – 01 October 2002 (especially the post-monsoon period). The second field sampling was conducted on 22 July 2003 (especially the monsoon period). Groundwater and surface water sampling were performed close to the seepage zones of the three detected areas as mentioned earlier. Global Positioning System (GPS) readings (latitude and longitude) were recorded at each sampling point. Field meters were calibrated using appropriate pH standards. On-site measurements of physio-chemical properties (such as pH, electrical conductivity, and temperature) of water samples were done. Alkalinity (HCO_3^-) was determined on-site by end-point titration. Six samples were taken from each site, four for chemical analyses (major cation and anion) and two for stable isotopes (^{18}O and ^2H) analyses. So, in total 18 water samples were collected during both sampling campaigns. The groundwater samples were collected from the tubewells located near the seepage zone. For cation analysis, samples were filtered using membrane filters (0.45µm pore size and 47mm diameter). The samples were collected in 500 mL polyethylene bottles for both cation and anion analyses. The samples for cations were acidified (using HNO_3) to pH≈2 in the field in order to avoid any precipitation of trace elements (APHA, 2003). Unfiltered samples were collected for analysis of anions. For stable isotope (^2H and ^{18}O) analysis, water samples were collected in a pre-cleaned, leak tight, double stoppered, high density polyethylene (HDPE) bottle (size: 50 mL). As the river water was not clean, it was filtered in the field (without evaporation losses) prior to collection.

Major cation concentrations (Na^+, K^+, Ca^{+2} and Mg^{+2}) were analyzed using atomic absorption spectrophotometer (AAS) in the Nuclear and Radiation Chemistry Division (NRCD) laboratory, Institute of Nuclear Science and Technoloy (INST), Savar, Dhaka. Anion concentrations were determined for Cl^-, SO_4^{-2} and NO_3^- using UV-VIS spectrophotometer in the same laboratory. Stable isotopes (^{18}O and ^2H) analyses were done in the laboratory of the Radiation and Isotope Application Division, Pakistan Institute of Nuclear Science and Technology (PINSTECH), Pakistan. The description of sample collection with physio-chemical parameters of groundwater and river water samples are presented in Table 1.

Table 1
Description of field sampling and physio-chemical properties of water samples

Sample ID	Sampling Location	Description of Samples	Date of Sampling	Temp. ^0C	pH	EC (µS/cm)	HCO_3^- (mg/L)
GUM-1G	Farizpur (Mirpur)	Hand Tubewell near guard shade. Depth=160 ft.	30/09/2002	26.4	6.44	185.4	85
GUM-1R	- do -	Gumti riverside and sample from shallow depth of river	01/10/2002	30.1	7.42	88.8	20
GUM-2G	Vill.-Kathalia Union-Mainamati	Darul Para, Hand Tubewell at house of Kamal Chowdhury. Depth=150 ft.	01/10/2002	26.1	7.43	355	150
GUM-2R	- do -	Gumti riverside and sample from shallow depth of river	01/10/2002	30.3	7.47	89.4	60
GUM-3G	Vill.-Ebdarpur Union-Bherellah	Tara pump at house of Ali Azam Bhuiyan. Depth=130 ft.	01/10/2002	26.4	7.20	451	202
GUM-3R	- do -	Gumti riverside and sample from shallow depth of river	01/10/2002	30.7	7.44	89.7	44
GUM-4G	Vill.-Ebdarpur Union-Bherellah	Hand tubewell at house of Khokan Miah. Depth=120 ft.	22/07/2003	26.4	6.85	315	139
GUM-4R	- do -	Gumti riverside and sample from shallow depth of river	22/07/2003	30.6	7.32	94.3	63
GUM-5G	Farizpur (Mirpur)	Hand Tubewell near guard shade. Depth=160 ft.	22/07/2003	26.6	6.43	185.6	85
GUM-5R	- do -	Gumti riverside and sample from shallow depth of river	22/07/2003	31.3	7.25	96.4	37
GUM-6G	Vill.-Kathalia Union-Mainamati	Darul Para, Hand Tubewell at house of Kamal Chowdhury. Depth=150 ft.	22/07/2003	26.0	7.15	356	146
GUM-6R	- do -	Gumti riverside and sample from shallow depth of river	22/07/2003	31.0	7.39	94.6	65

Note: G=Groundwater, R=River Water

The groundwater temperature ranges from 26.0°C – 26.6°C and river water temperature ranges from 30.1°C – 31.3°C with an average temperature difference of about 4.40°C. The average pH value of groundwater samples is about 6.92 whereas the average pH value of river samples is about 7.38. The electrical conductivity (EC) value of groundwater at different seepage locations varies from 185 - 451 μS/cm with an average value of about 308 μS/cm. The river water EC value ranges from 88.8 - 96.4 μS/cm with an average value of about 92.2 μS/cm. Both the groundwater and river water EC values gradually increases from upstream to downstream part of the Gumti River. But the average groundwater EC value is nearly 3.5 times higher than the river water average EC value. The high EC values of groundwater from the nearby private shallow wells clearly show that these groundwater flows were influenced by the river water. Apart from the EC values, other chemical and isotopic parameters support the statement that the hydraulic connection exists between the river and shallow aquifer.

5. Results and discussion

5.1 Hydrochemistry

The summary of chemical analyses of the collected samples is given in Table 2. The chemical characteristics of water quality data are illustrated in the Piper Trilinear diagram (Fig. 3). Interpretation of the hydrochemical data implies that the groundwater in the vicinity of the seepage zones is of Na-Ca-HCO_3 type and for the river water is of Ca-Mg-HCO_3 type.

Table 2
Summary of chemical analyses of water samples

Sample ID	Sampling Location	Major Cations (mg/L)				Major Anions (mg/L)		
		Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	SO_4^{-2}	NO_3^-
GUM-1G	Farizpur (Mirpur)	71.232	1.915	32.406	8.252	4.534	<0.4	6.147
GUM-1R	- do -	8.432	1.182	10.125	8.129	3.089	<0.4	5.826
GUM-2G	Vill.-Kathalia Union-Mainamati	63.214	2.389	17.784	8.275	4.808	<0.4	9.369
GUM-2R	- do -	7.754	1.068	32.486	7.813	2.137	<0.4	8.178
GUM-3G	Vill.-Ebdarpur Union-Bherellah	88.089	2.170	33.576	8.446	19.233	<0.4	8.561
GUM-3R	- do -	7.076	1.068	35.112	8.261	26.045	1.04	9.944
GUM-4G	Vill.-Ebdarpur Union-Bherellah	58.850	2.280	28.460	5.260	1.720	0	2.210
GUM-4R	- do -	5.860	2.730	33.440	4.080	2.009	3.00	3.597
GUM-5G	Farizpur (Mirpur)	71.120	1.740	28.030	7.110	6.573	1.00	3.503
GUM-5R	- do -	6.920	2.010	18.530	3.110	4.763	1.00	3.300
GUM-6G	Vill.-Kathalia Union-Mainamati	63.110	2.130	11.250	4.660	2.735	0	6.905
GUM-6R	- do -	7.270	2.830	27.560	4.150	2.333	0	6.135

Note: G=Groundwater, R=River Water

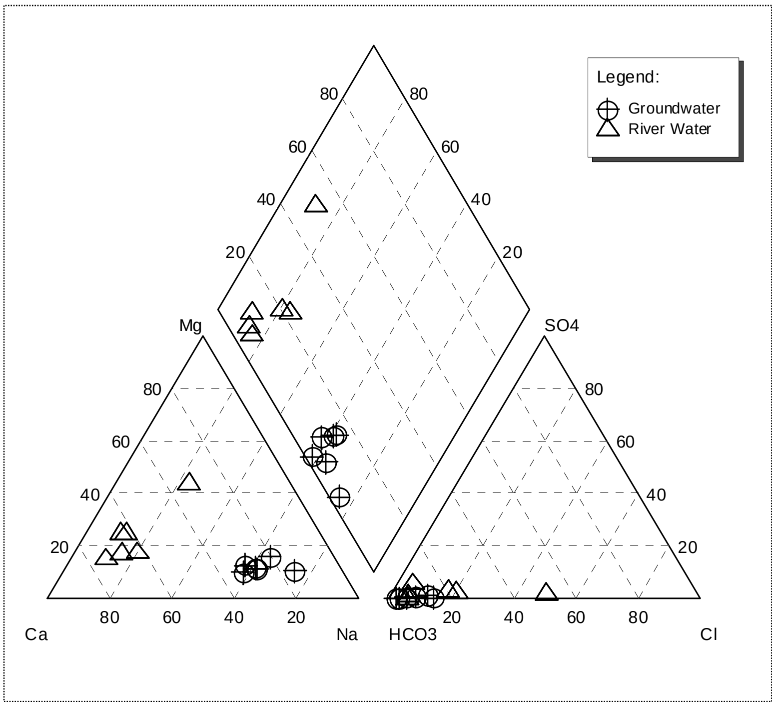

Fig. 3. Piper trilinear diagram for water samples of groundwater and river water

The chemical constituents of the collected groundwater and river water samples are described as below. The sodium (Na^+) content in groundwater collected adjacent to the seepage zones varies from 58.85 – 88.09 mg/L, but in river water it varies from 5.86 – 8.43 mg/L. The average Na^+ concentration (69.27 mg/L) in groundwater is nearly 10 times the Na^+ concentration(7.22 mg/L) in river water. The average K^+ (2.10 mg/L), Ca^{+2} (25.25 mg/L) and Mg^{+2} (7.00 mg/L) concentration in groundwater are more or less similar to that of river water. So, the Na^+ concentration of river water decreases from upstream to downstream direction of the Gumti River. The average SO_4^{-2} and NO_3^- contents in both groundwater and river water are more or less the same. But the average bi-carbonate concentration (135 mg/L) in groundwater is higher than that of river water (48 mg/L).

The chloride (Cl^-) content in groundwater varies from 1.72 – 19.23 mg/L, but in river water it varies from 2.01 – 26.05 mg/L. The average Cl^- concentration(6.60 mg/L) in groundwater is mostly similar to the average Cl^- concentration(6.73 mg/L) in river water. It is very important to point out that among all major ions usually dissolved in water, chloride is the most conservative ion. This behavior indicates that it is a good tracer of water, i.e. the behavior of water and that of the chloride ion are very similar (Drever, 1988). In most of the cases for both groundwater and river water samples, the chloride concentration shows a similar pattern. It suggests the possibility of a hydraulic connection/mixing between these two water bodies.

5.2 Stable isotopes of water

An integrated interpretation of hydrogeologic and isotopic data has been performed. The results for the two sampling campaigns are given in Table 3. Measurements of environmental stable isotope composition of water have been carried out as a complementary tool for this kind of investigation. Differences in the content of D and ^{18}O in groundwater and surface water are used to determine mixing processes between the two water systems in the three distinct locations of seepage. The stable isotope composition of water provides information which cannot be obtained by other methods (Bedmar and Araguás, 2002). The important information based on stable isotope analyses of the Gumti river water as well as groundwater in the vicinity of the seepage/leakage points of Gumti dyke show sufficient differences in the existence of δD and $\delta^{18}O$.

The stable isotopes (^2H and ^{18}O) data of both groundwater and river water are plotted in the same X-Y graph (as shown in Fig. 4). The groundwaters sampled near the seepage zone area have stable oxygen and hydrogen isotope ratios ranging from –4.98 to –5.46 ‰ and –30.0 to –33.6 ‰, respectively. Mostly all groundwater samples fall on the meteoric water line, indicating an origin of recharge from river without evaporation before infiltration (IAEA, 1981). It focuses that the recharge of groundwater is influenced by the river water during peak water level in the river Gumti.

Table 3
Summary of stable isotope analyses of water samples

Sample ID	Sampling Location	Notes	Date of Sampling	$\delta^{18}O$ (‰ VSMOW)	δ^2H (‰ VSMOW)
GUM-1G	Farizpur (Mirpur)	Hand Tubewell near guard shade	30/09/2002	-5.04	-30.04
GUM-1R	- do -	Gumti riverside and sample from shallow depth of river	01/10/2002	-4.26	-28.09
GUM-2G	Vill.-Kathalia Union-Mainamati	Darul Para, Hand Tubewell at house of Kamal Chowdhury	01/10/2002	-4.98	-30.00
GUM-2R	- do -	Gumti riverside and sample from shallow depth of river	01/10/2002	-4.39	-28.43
GUM-3G	Vill.-Ebdarpur Union-Bherellah	Tara pump at house of Ali Azam Bhuiyan	01/10/2002	-5.23	-32.22
GUM-3R	- do -	Gumti riverside and sample from shallow depth of river	01/10/2002	-4.427	-28.48
GUM-4G	Vill.-Ebdarpur Union-Bherellah	Hand tubewell at house of Khokan Miah	22/07/2003	-5.46	-33.60
GUM-4R	- do -	Gumti riverside and sample from shallow depth of river	22/07/2003	-3.93	-22.39
GUM-5G	Farizpur (Mirpur)	Hand Tubewell near guard shade	22/07/2003	-5.43	-32.36
GUM-5R	- do -	Gumti riverside and sample from shallow depth of river	22/07/2003	-3.61	-22.39
GUM-6G	Vill.-Kathalia Union-Mainamati	Darul Para, Hand Tubewell at house of Kamal Chowdhury	22/07/2003	-5.13	-31.00
GUM-6R	- do -	Gumti riverside and sample from shallow depth of river	22/07/2003	-3.78	-22.30

Note: G=Groundwater, R=River Water

On the otherhand, the stable isotopes for river water show some enriched and evaporative values, ranging from –3.61 to –4.43 per mil and values from –22.30 to –28.48 per mil respectively. The samples for both sampling campaign were collected after the recession of peak flow in the Gumti river. Due to flashy nature of the Gumti river, the peak flow having velocity exists only for two or three days. As soon as the river water recedes, the river flow decreases with time. As a result, the stable isotopes of the

Gumti river show some evaporation effect, which might have occurred due to the stagnation of flowing water in the river.

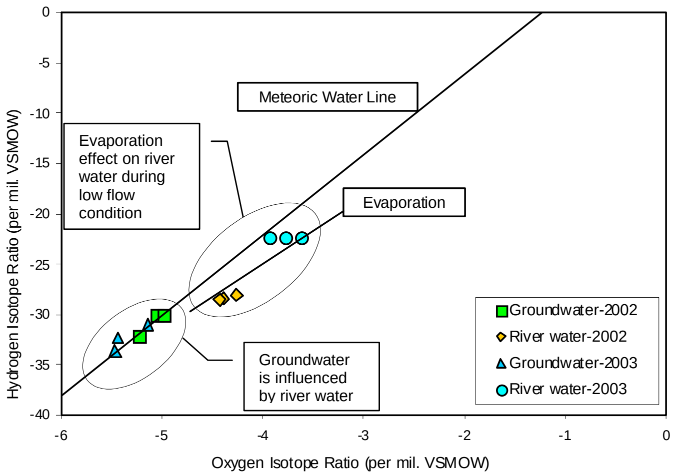

Fig. 4. Stable oxygen and hydrogen isotope compositions of groundwater and surface water adjacent to seepage zones

Evaporation is frequently responsible for important differences in isotopic composition of river water with respect to local groundwater. Due to stagnation of flowing water, when evaporation takes place to sufficient degree, the river water becomes enriched in stable isotopes. Usually the δD and δ^{18}O of the river are more depleted compared to that of the local aquifer. But in this case, the groundwater shows depleted values of stable isotope. This can help in calculating the contribution of river water in the groundwater when mixing takes place. These stable isotopes likely indicate the migration of river water to the groundwater of country side through the base of dyke during the peak flow time. The δD and δ^{18}O contents are thus an ideal tool for the evaluation of groundwater flow along the dyke created by the leakage coming from the river. These isotope results reflect the hydraulic connectivity between the river water and groundwater through the base of dyke. Geologic relationships are consistent with the observation that hydraulic interconnections with the groundwater are induced by the peak flow of the Gumti river.

6. Conclusions

Gumti Flood Control Dyke is identified as having the problem of piping through the foundation and body of the dyke, sloughing at the toe of the dyke, slope failure, siltation in the canals etc. Each and every year, the dykes are threatened by flash floods originated from the Tipperan hilly region of India.

Isotope techniques are among many available technical tools and considered unique and have the potential to solve certain types of problems common in dam safety activities, which could complement existing conventional problem solving techniques. Chemical and isotope are used in this way to prove the degree of hydraulic interconnection and mixing between two water bodies, as has been shown previously. Electrical conductivity (EC) of river water showed reasonably good contrast with the EC of local groundwater, i.e. the groundwater average EC value is about 3.5 times the river water average EC value. These high EC values of groundwater suggest that the groundwater flow is influenced by the river water. Apart from the EC value, similar concentration of chloride ion found in river water and groundwater reflects the possibility of a hydraulic connection/mixing between these two water bodies.

The stable isotope results reflect the hydraulic connectivity between the river water and groundwater through the base of dyke. It indicates the recharge of groundwater from the river water during peak water level in monsoon. On the otherhand, the stable isotopes of the Gumti river show some evaporation effect, which are thought to have occurred due to stagnation of flowing water in the river. The general conclusions drawn from this study are as follows:

– Soggy soil conditions found at some points on countryside of the dyke are due to presence of seepage and capillary rise of local shallow groundwater when the river water level reaches to the peak.

– The source of seepage water is likely from the river but believed to have mixed with local shallow groundwater along its pathway towards lower elevation surrounding the dyke toe.

– Uplift pressure develops at the river bed during peak water level is likely to cause seepage flow paths, followed by some evidence of piping through the dyke body and sloughing at toe of the dyke.

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References

APHA (2003). Standard methods for the examination of water and wastewater, American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), Washington D. C., USA.

Bedmar, A. Plata and Araguás, Luis (2002). Detection and prevention of leaks from dams, A. A. Balkema Publishers, Lisse, the Netherlands.

Clark, I. D. and Fritz, P. (1997). Environmental isotopes in hydrogeology, Lewis Publishers, New York, USA.

Craig, H. (1961). "Isotopic variations in meteoric water", Science; 133, 1702-1703.

Drever, I. J. (1988). The geochemistry of natural waters, Prentice Hall, New Jersey, USA.

International Atomic Energy Agency (1981). Stable isotope hydrology: deuterium and oxygen-18 in the water cycle, Technical Reports Series, No. 210, IAEA, Vienna, Austria.

International Atomic Energy Agency (1983). Guidebook on nuclear techniques in hydrology, Technical Reports Series, No. 91, IAEA, Vienna, Austria.

Mott MacDonald Ltd., Nippon Koei Comp. Ltd., House of Consultants Ltd. and Desh Upadesh Ltd. (1993). Gumti phase-II sub-project feasibility study, Final report (World Bank), Dhaka.