Identification of river water and groundwater interaction at central part of the Kathmandu valley, Nepal using stable isotope tracers

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ABSTRACT

The groundwater and surface water are two interrelated systems of the water resources and belong to one of the processes of hydrologic cycle. If the interconnectivity between these two systems can be recognized and established for particular rivers, the probable contamination of any one of the systems caused by anthropogenic activities can be indicated and suggested for necessary mitigative measures. Thus, this study was focused on identifying the interconnection of groundwater and river water using hydrogen (δD) and oxygen ($\delta^{18}O$) stable isotopes of water. Monthly water samples (June 2010 to March 2011) collected from shallow groundwater and river water were used for this research. The river water samples were collected from the Bagmati River (3 locations), the Bishnumati River (2 locations), the Dhobi Khola (2 locations) and the Manahara River (1 location) whereas some groundwater samples (from 7 locations) were collected from these river corridors (2 samples from 35 to 60 m and 4 samples from 90 to 200 m from the river channel) and three samples were collected far from the river channel.

The concentration of chemical parameters, especially Na^+ and Cl^- from the river water, was higher in the dry season (Dec-Jan), which decreased to nearly half in the wet season (July-Sep). The values of $\delta^{18}O$ and δD show significant temporal variation ranging from -6.4‰ to -9.3‰ and -43.3‰ to -64.5‰, respectively. The concentration of Na^+ and Cl^- of groundwater varied with the distance from the river channel. Significant temporal variation of stable isotopes and Na^+ and Cl^- was observed in that groundwater which was collected from 35 to 60 m from river channel whereas constant values were measured in water samples taken from 90 to 200 m. Similarity in isotopic composition of groundwater and river water in dry season conforms the recharge of the river water from nearby groundwater (GW1, GW3 and GW6). Contrarily, GW2 and GW4 (located within 35– 60 m) have higher probability of recharge from the river water.

Key words: Stable isotopes, Chemical ions, Groundwater- Surface water, interaction, Kathmandu Valley

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INTRODUCTION

The groundwater and surface water are two interrelated systems of the water resources. It is one of the processes of hydrologic cycle. The relationship of these two water systems can observe in all landscapes such as pond, lake, and reservoir but is commonly researched at the river reach scale to classify as connected (losing and gaining) and disconnected system. Some of research also focused on the stream to classify as losing-connected and losing-disconnected reach of the river [1]. Different methods had been applied to study about interaction of groundwater and surface water such as direct measurement of water flux, heat tracer methods, environmental tracer methods (isotope and geochemical), solute tracer methods, methods based on Darcy's Law [2] and geophysical methods [3][4][5]. Among these methods, stable environmental isotopes (hydrogen and oxygen) and hydrochemistry are widely applied for such study [6][7][8][9][10][11][12][13][14][15][16][17][18][19].

The interconnection of groundwater and surface water can affect the quantity and quality of both water systems. But in the context of Nepal, such studies has just started in few areas [13]. Earlier studies had only focused on quality of groundwater [20][21][22][23][24][25] as well as of surface water. Previous studies based on quality of groundwater of Kathmandu valley have reported high value of chloride, nitrate and coliform in shallow groundwater. Nitrate level at shallow depth is higher as compared with high depth in urban areas due to anthropogenic sources such as poorly managed septic tanks, sewer pipes and solid waste disposal [26].

Previous researches on river water quality of the Kathmandu valley have reported that the downstream segments which travelled through urban areas has more contaminated than the upstream segments [27][28]. The Bagmati River and its tributaries were classified into distinct zones according to water quality classes as defined by the "extended biotic index". The river segments are classified as heavily polluted to very heavily polluted [29]. Low dissolved oxygen with high coliform is noted in all downstream section of the Bagmati River and its tributaries. This deteriorating quality of river water has caused frequent cases of water borne diseases such as diarrhea, dysentery, cholera, and skin diseases among people living in riverside areas [30].

The earlier research related with interconnection of groundwater and surface water has also indicated that the northern part of the Bagmati river and the Bishnumati river are connected with surrounding groundwater [13]. Concentration of chemical parameters is decreased as the distance from the Bagmati river channel has increased. The higher contamination of groundwater along river banks towards urban river corridor indicate the intrusion of nearby polluted river water [31]. Thus the purpose of this study is to identify connecting condition of groundwater and river water at the central part of the Kathmandu valley. Specific objectives of this study is to 1) investigate spatial and temporal variation of water chemistry and environmental isotope in river water and groundwater and 2) relationship between river water and groundwater along the Bagmati river, the Bishnumati river and the Dhobi khola.

STUDY AREA

The study area covers major river corridors of central part of the Kathmandu Valley. The valley is extended about 30 km towards EW direction and 25 km towards NW covering about 650 km² areas. The valley is surrounded by the Shivapuri, Chandragiri and Phulchauki mountain range from north, south and west respectively. The Bagmati River is the only one outlet drainage of the valley. The major Bagmati River has many tributaries such as the Bishnumati and the Dhobi Khola flowing from north, the Manahara flowing from northeast, the Hanumante from east, the Godawari and the Kodku from southeast and the Nakhhu from south direction.

The surrounding mountain ranges are composed of sedimentary and metamorphic rock with gneiss and migmatites [32] whereas the valley consist Plio-Pleistocene fluvial, fluvial lacustrine and fluvio-deltaic sediments [33]. The study area is dominated by three major sedimentological formations such as the Patan Formation, the Thimi Formation and the Lower Terrace deposit [34]

(Fig 1). The Thimi Formation contains sand, silt, clay, peat and gravel composed of granite and gneiss derived from the Shivapuri Range. Similarly the Patan formation is composed of fluvio-lacustrine deposits containing sand, silt, clay and peat. The Lower Terrace deposit consist micaceous sand, pebbles and granules.

Fig 1: Sampling point on geological map of the Kathmandu Valley (compilation of Yoshida & Igarashi, 1980, Sakai et al, 2008 and Dhital, 2015)

METHODOLOGY

Monthly collected samples from June 2010 to March 2011 of groundwater and river water by International Research Centre for River Basin Environment- University of Yamanashi (ICRE-UY), Japan was used for this research. These samples were stored in low temperatures at the lab of UY. Water samples were collected from 17 different locations among which 8 were from river and 9 from shallow groundwater (Fig 1 & Table1). The river samples included the Bagmati River (RW1, RW2 & RW3), the Bishnumati River (RW4 & RW5), the Dhobi Khola (RW6 & RW7) and the Manahara River (RW8). Similarly seven groundwater samples were taken from these river corridors (2 samples from 35 to 60 m and 4 samples from 90 to 200 m from the river channel) and three samples were collected far from the river channel. These samples were analyzed for chemical parameters and stable hydrogen and oxygen isotope in the laboratory of ICRE-UY, Japan.

In chemical analysis, concentration of major cation (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , $\text{NH}_4^+\text{-N}$) and anion (SO_4^{2-} , Cl^- , $\text{PO}_4^{3-}\text{-P}$, $\text{NO}_3^-\text{-N}$) were measured using ion chromatography (ICS-1100, Dionex, USA).

The stable isotope of hydrogen (δD) and oxygen ($\delta^{18}\text{O}$) were analyzed using an isotope ratio mass spectrometer (IRMS) (Sercon, Hydra 20-20). The results were reported in per mill deviation with respect to VSMOW (Vienna Standard Mean Ocean Water) standards with precision 0.1 ‰ for $\delta^{18}\text{O}$ and 1 ‰ for δD . The isotopic ratios of hydrogen and oxygen are calculated by using the formula given by [35]:

$$\delta = \frac{R_{\text{sample}} - R_{\text{V-SMOW}}}{R_{\text{V-SMOW}}} \times 1000\text{‰}$$

Where R is defined as D/H for δD and $^{18}\text{O}/^{16}\text{O}$ for $\delta^{18}\text{O}$.

Table1: Information on water sampling location

Sample type	Sample ID	Latitude	Longitude	Elevation (m)	Distance from river (m)
River water	RW1	27°41'2.1"	85°17'58.25"	1284	
	RW2	27°41'0.86"	85°20'33.87"	1293	
	RW3	27°42'41.99"	85°21'14.39"	1311	
Groundwater	GW1	27°41'16.4"	85°18'11.6"	1279	230
	GW2	27°41'24.1"	85°18'51.4"	1285	60
	GW3	27°41'43.5"	85°21'12.7"	1312	218
River water	RW4	27°41'32.5"	85°18'4.0"	1287	
	RW5	27°43'32.69"	85°18'20.21"	1303	
Groundwater	GW4	27°42'5.3"	85°18'10.3"	1281	40
	GW5	27°42'50.3"	85°17'50.4"	1305	395 (90 m from tributary)
River water	RW6	27°41'22.37"	85°19'41.84"	1292	
	RW7	27°43'23.96"	85°20'46.32"	1311	
	GW6	27°41'47.4"	85°19'45.9"	1306	90
River water	RW8	27°40'28.75"	85°20'25.46"	1293	
Groundwater	GW7	27°42'8.6"	85°17'22.8"	1304	500
	GW8	27°43'57.5"	85°19'43"	1341	1720
	GW9	27°39'55"	85°18'50.2"	1319	670

RESULTS

Chemical concentration of groundwater and river water

The chemical parameters of groundwater and river water were summarized in Table 2 and Table 3 respectively. All chemical parameters in both water sources showed significant temporal as well as spatial variation.

Chemical concentration of river water

Na⁺ and Cl⁻ were dominant cation and anion in all river water. The mean value of Na⁺ and Cl⁻ in river water ranged from 11 to 88.9 mg/l and 8.2 to 87.1 mg/l respectively. The higher concentration was observed in downstream of the Bishnumati River (RW4) and the Dhobi Khola (RW6) where as lower value was obtained from the upstream of the Bagmati River (RW3). The concentration of other chemical ions such as NH₄-N⁺, K⁺, Mg²⁺ and SO₄²⁻ were also higher in these two downstream water samples (Table 2). The dominance of Na⁺ together with Cl⁻ in all downstream section of rivers reflects anthropogenic activities such as effluent from industrial wastes, solid wastes and human urine.

The ion concentration also shows distinct seasonal variation. Most chemical ions were higher in dry season (Dec-Jan) which was decreased to more than half in wet season (July-Sep). The minimum values indicate concentration of wet season whereas maximum was from dry season in Table 2. Decreased in concentration of all chemical ions in wet season may be due to surface runoff through precipitation.

Chemical concentration of groundwater

The chemical concentration shows wide spatial variation in groundwater. Most of chemical ions were higher in such groundwater which was collected from nearby (35 to 250m) river channels as compared with those collected far from river channel (Table 3). As same as in river water, Na⁺ and Cl⁻ with additional as SO₄²⁻ were dominant cation and anions in groundwater. Mean values of Na⁺ and Cl⁻ ranged from 14.9 to 104 mg/l and 13.5 to 129.7 mg/l respectively whereas SO₄²⁻ mean value

ranged from 11.5 to 174.2 mg/l. Except GW8, all groundwater were collected from the Lower Terrace Deposit [34] (Fig 1) but have distinct variation in chemical ions indicate effects of human activities. The higher concentration of ions towards river channel as compared with those of far from river channel may also indicate higher anthropogenic activity near river corridor.

Value of Mg^{2+} and K^{+} show least seasonal variation but Na^{+} , Ca^{2+} , Cl^{-} and SO_4^{2-} show more fluctuation in groundwater. GW6 shows more or less similar values of all ions throughout the year but other all groundwater samples show seasonal variation.

Isotopic composition

Isotope composition of River water

The composition of $\delta^{18}O$ and δD in water samples from four different rivers has least spatial variation (Fig 2). These values have similar trend of temporal variation throughout the collected months. Heavy isotopic concentration of $\delta^{18}O$ and δD were observed in June 2010 ranging from -6.4 to -7.7‰ and -43.3 to 52.9‰ respectively which was decreased in July and September ($\delta^{18}O$ -8.1 to -9.3‰ and δD -57.3 to -64.5‰) and then again slightly increased from November to March indicating wet seasons has lighter isotopic value (Fig 2).

Table 2: Chemical variation in river water

Parameters (mg/l)	Bagmati River			Bishnumati River		Dhobi Khola		Manahara River
	RW1	RW2	RW3	RW4	RW5	RW6	RW7	RW8
Na^{+}	Min	28.8	17.9	5.8	43.7	24.6	47.1	26.3
	Max	107.3	87.4	16.5	136.6	74.9	101.2	111.5
	Average	60.2	48.4	11.0	88.9	49.6	71.4	65.6
	SD	24.9	23.4	3.8	31.1	16.5	18.1	28.7
NH_4-N^{+}	Min	3.3	2.4	0.6	4.0	2.2	5.7	2.5
	Max	20.0	21.1	2.4	25.1	11.6	16.7	9.4
	Average	9.7	9.2	1.2	13.4	6.5	11.5	5.5
	SD	6.2	7.0	0.5	9.1	3.4	4.5	2.2
K^{+}	Min	7.8	4.6	1.5	11.1	6.7	13.5	6.3
	Max	25.3	21.5	3.7	37.2	16.8	39.1	26.6
	Average	14.9	12.1	2.6	22.7	12.5	22.0	14.9
	SD	5.5	5.5	0.7	8.3	3.2	7.4	6.0
Mg^{2+}	Min	4.3	2.5	1.4	5.4	4.8	5.9	4.2
	Max	10.4	7.8	4.0	13.0	8.8	9.9	9.9
	Average	7.1	5.1	2.6	8.9	6.8	7.6	6.9
	SD	2.1	1.9	0.9	2.4	1.5	1.3	1.9
Ca^{2+}	Min	7.8	8.1	4.2	11.4	11.4	12.1	11.1
	Max	26.6	20.0	10.1	28.5	32.1	24.8	21.2
	Average	17.1	13.9	6.7	19.8	19.2	17.8	16.8
	SD	5.9	4.5	1.8	5.9	6.6	3.4	3.5
Cl^{-}	Min	27.3	15.3	3.8	45.1	21.7	46.6	25.8
	Max	101.5	87.8	13.6	141.6	72.3	102.5	98.9
	Average	58.1	46.3	8.2	87.1	47.4	71.4	59.8
	SD	24.2	24.0	3.2	31.2	16.1	17.2	24.9

NO ₃ -N	Min	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.3
	Max	0.2	0.4	0.8	0.3	0.5	0.3	0.9	0.6
	Average	0.2	0.2	0.5	0.2	0.4	0.3	0.5	0.4
	SD	0.0	0.1	0.1	0.0	0.1	0.0	0.3	0.1
PO ₄ -P	Min	0.8	0.8	0.4	3.8	0.8	4.3	2.8	1.0
	Max	9.8	9.7	2.1	10.6	9.1	11.3	10.4	9.1
	Average	5.5	5.4	1.3	7.5	4.6	8.8	6.9	3.0
	SD	3.0	3.3	0.8	2.4	3.0	2.1	2.8	2.5
SO ₄ ²⁻	Min	2.7	7.1	3.6	0.9	1.5	1.9	6.2	9.7
	Max	25.4	26.5	9.9	33.4	25.0	28.3	37.0	21.4
	Average	15.6	15.7	6.2	20.4	16.2	18.4	21.5	14.7
	SD	6.6	6.6	1.9	9.0	6.6	6.8	9.7	3.4

Table 3: Chemical variation in groundwater

Parameters (mg/l)		Along Bagmati River			Along Bishnumati		Along Dhobi	Away from river		
		GW1	GW2	GW3	GW4	GW5	GW6	GW7	GW8	GW9
Na ⁺	Min	32.4	49.6	42.9	72.6	55.2	34.0	14.0	12.1	5.9
	Max	41.2	187.5	86.2	101.1	123.8	36.1	35.7	17.9	38.2
	Average	35.7	104.0	71.9	85.4	83.8	35.2	24.5	14.9	18.8
	SD	3.2	43.5	12.6	8.9	18.9	0.7	8.9	1.6	10.3
NH4-N ⁺	Min	3.5	0.0	6.6	2.2	7.2	2.5	4.0	0.7	1.2
	Max	5.8	0.0	9.7	4.7	9.1	2.8	12.5	0.7	4.2
	Average	4.5	0.0	8.6	3.4	8.2	2.6	6.8	0.7	2.3
	SD	0.8	0.0	1.1	0.9	0.8	0.1	3.1	0.0	0.9
K ⁺	Min	3.7	12.8	9.6	46.1	12.0	7.7	4.0	1.4	2.0
	Max	4.7	22.6	17.0	52.2	25.9	8.2	6.0	2.3	19.8
	Average	4.2	18.1	15.1	49.4	20.0	7.9	5.0	1.8	8.2
	SD	0.3	2.7	2.3	2.0	5.0	0.1	0.6	0.2	6.2
Mg ²⁺	Min	24.4	15.7	5.8	17.6	23.3	9.6	17.4	14.4	4.1
	Max	31.9	30.8	8.9	23.8	30.8	10.8	21.3	17.3	11.7
	Average	28.3	22.1	7.5	20.7	27.3	10.1	19.3	15.9	6.7
	SD	2.5	4.6	0.8	2.1	2.6	0.3	1.2	1.0	2.6
Ca ²⁺	Min	19.4	27.0	6.2	18.1	6.1	9.4	6.6	7.2	12.1
	Max	51.5	61.3	13.1	32.8	72.5	18.2	20.3	23.7	48.7
	Average	36.0	40.5	9.8	24.3	38.0	13.7	12.1	13.5	26.0
	SD	10.3	10.8	2.3	4.2	21.5	2.7	3.9	5.1	10.3
Cl ⁻	Min	38.6	66.6	31.0	101.3	122.9	45.1	30.9	7.2	17.2
	Max	50.5	183.8	60.0	142.2	174.0	48.4	50.1	23.7	79.3
	Average	43.5	129.7	50.3	123.5	145.4	47.0	40.4	13.5	45.5
	SD	4.5	43.2	8.3	14.9	17.9	1.0	7.0	5.1	20.2
NO3-N ⁻	Min	0.3	2.2	9.0	10.3	0.2	0.0	0.2	1.9	0.3
	Max	0.3	20.5	21.7	26.2	1.8	0.0	3.4	2.4	1.5

	Average	0.3	8.9	13.8	15.0	0.8	0.0	1.5	2.2	0.8
	SD	0.0	5.2	5.0	5.0	0.6	0.0	1.2	0.6	0.4
PO ₄ -P	Min	0.0	2.1	0.0	1.0	0.0	0.0	0.5	0.0	0.6
	Max	0.0	2.1	0.0	4.0	0.0	0.0	0.5	0.0	2.0
	Average	0.0	2.1	0.0	2.5	0.0	0.0	0.5	0.0	1.3
	SD	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.7
SO ₄ ²⁻	Min	118.5	80.3	31.6	51.2	24.7	24.6	0.9	13.8	5.1
	Max	238.4	135.0	49.1	73.0	212.4	28.5	26.8	16.8	126.2
	Average	174.2	99.3	42.0	61.1	134.3	26.5	11.5	15.3	40.7
	SD	36.1	17.5	5.1	6.7	61.2	1.4	11.2	1.3	37.2

Fig. 2: Temporal and spatial variation of δD in river water (RW)

Isotopic composition of groundwater

The isotopic composition of groundwater near to river and far from river channel was very different. The $\delta^{18}O$ and δD values of groundwater was not much temporally variable except in GW2, GW4 and GW5 (Fig 3). GW2 has lighter isotopic value in September to November. The maximum value of variation was 1.7‰ in $\delta^{18}O$ and 14.2‰ in δD . Except in GW8 and GW9, other groundwater has similar values of $\delta^{18}O$ (-7.8 to -8.1‰) and δD (-53.5 to 55.4‰). The GW8 shows heavier isotopic composition as $\delta^{18}O$ is -7.1‰ and δD is -47.6‰ where as GW9 has least $\delta^{18}O$ (-9.0‰) and δD (-63.5‰). These two groundwater were collected away from river channel have significant isotopic variation.

Fig. 3: Temporal and spatial variation of δD in groundwater (GW)

Comparison of isotopes in river water and groundwater

The relation between $\delta^{18}\text{O}$ and δD of river water and groundwater for dry and wet season were presented in Fig 4 with GMWL. Except GW8 and GW9, all groundwater isotopic values were overlapped with river water samples in dry season. Groundwater which showed similar isotopic values with river samples were collected from nearby river channel (within 200 m) and remaining two which has different isotopic value was located far away from river channel (500 and 1500 m). This plot indicates that there is most probability of interaction between river water and groundwater which was located nearby river channel.

But in the case of wet season, the isotopic composition of river water was slightly lighter than dry season but groundwater has similar isotopic composition as in dry season. The lighter isotopic value of river water may be resulted by addition of surface runoff through precipitation as rainfall has lighter isotopic value [36][37][38]. As all water samples are closer to GMWL (Global Meteoric Water Line), there is less chances of evaporation in both seasons. Previous report also finds that Kathmandu Valley rivers have no evidence of evaporation [36].

Fig 4: Plot of $\delta^{18}\text{O}$ and δD for groundwater and river water a) dry season and b) wet season

DISCUSSION**Interconnection between river water and groundwater**

River water from the Bagmati, Bishnumati and Dhobi Khola with groundwater nearby these rivers was used to identify interconnection of groundwater and river water. One sample from the Manahara River and three samples from groundwater (away from river channel) were excluded for this.

Bagmati river corridor

The values of $\delta^{18}\text{O}$, δD , Na and Cl were plotted against month from river water (RW1, RW2 and RW3) and groundwater (GW1, GW2 and GW3) for comparison of river and groundwater (Fig 5 & 6). The plots against $\delta^{18}\text{O}$ and δD verses months clearly show that the isotopic composition is only similar in dry season in GW1 and GW3 and has heavy isotope in wet season as compared with river isotope. But in the case of GW2, the wet season has also somehow similar trend of decreasing value as in river water. Similarly in the plot of Na^+ and Cl^- , GW1 and GW3 do not show seasonal variation but in the case of GW2, it shows significant variation with months. Based on these isotopic and chemical parameters (Na^+ and Cl^-), it can be said that the groundwater can discharge to the river water during dry season but the chances of groundwater recharge from river water and rainfall infiltration is very low in GW1 and GW3 [11]. But in the case of GW2, there is possibility of recharge from river water.

Bishnumati River Corridor

As same in the Bagmati River, plots of $\delta^{18}\text{O}$, δD , Na^+ and Cl^- verses months were used to compare river water (RW4 & RW5) and groundwater (GW4 & GW5) (Fig 5 & 6). GW5 shows different isotopic data as well as chemical ions as compared with river water which may indicate less probability of interaction. But in the case of GW4, it has similar isotopic composition as in RW5 in dry season (Dec-March) and also has same decreasing value trend in September. Na^+ and Cl^- were also diluted in wet season. Dilution in ions and similar isotopic value trend in GW4 indicate the possibility of recharge of groundwater from river water.

Fig 5: $\delta^{18}\text{O}$ and δD verses month plots of the Bagmati River, the Bishnumati River and the Dhobi Khola

Dhobi Khola Corridor

The uniform isotopic composition and constant chemical concentration (Na^+ and Cl^-) in GW6 show that the absence of chances of recharge of groundwater from river water. But the similar isotopic composition in dry season reveals the possibility of recharge of river water from groundwater (Fig 5 & 6).

Fig 6: Na^+ and Cl^- verses month plots of a) the Bagmati River, b) the Bishnumati River and c) the Dhobi Khola

CONCLUSIONS

The present research is basically focused on study of chemical parameter and stable water isotopes of river water and groundwater (nearby river channel) of the Kathmandu Valley. Chemical analysis of water of river gives the information that all the major rivers of the valley are deteriorating towards downstream possibly by anthropogenic activities. Concentration of chemical ions is decreased nearly to half from dry season to wet season. Isotope of all rivers has similar variation trend indicating similar type of recharge source.

Groundwater near to river channel (within 200 m) has higher chemical concentration as compared with those which located far away from river channel (greater than 500 m). The relation of $\delta^{18}\text{O}$ and δD also shows cluster of river water and groundwater (near to river) in dry season. Similarity of isotopic data in GW1, GW3, GW6 (90 to 230 m) river water in dry season conform that the groundwater recharges river. But in the case of GW2 and GW4 (35 to 60 m), isotopic value was decreased in September as in river water indicating probability of recharge from river through bank infiltration.

In overall condition, there exist interaction between river water and that groundwater which is near to river channel but the condition of recharge and discharge to river water from groundwater or vice-versa is changed in location. Thus the interconnectivity not only can change water quantity but also on quality of both water systems. In present research, fewer water samples were used to analyze chemical and environmental isotope; it has lack of data on water table depth of wells, subsurface lithology and these layer inclination. Thus for further detail study of interaction, it need larger number of water samples from river as well as from groundwater with detail subsurface lithology, water table depth of wells, elevation of water level in river with river sediments which will help to verify chemical and isotopic analysis.

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