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Assessment on connection between shallow and deep aquifers using isotope analysis of surface water and groundwater in Sunsari and Morang Districts

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ABSTRACT

The Sunsari and the Morang Districts confine the eastern region of the Koshi River and are considered as a huge potential of groundwater zones. The study mainly focuses on the concept of delineation of recharge source of groundwater and connection between aquifer system through isotopic analysis. Altogether 33 samples are collected from surface and groundwater for the isotopic analysis. Majority of the samples of flowing artesian wells are encountered under the range of -7.03‰ to -6.53‰. The shallow aquifers fall under the range of -5.94‰. to -5.34‰ and deep aquifers fall over a wide range of -7.13 ‰. to -6.53‰ for $\delta^{18}O$. Clustering of samples from isotopic analysis gives idea of surface water and groundwater interconnection along with the recharge source identification. Isotopic variation of majority of samples ranges from -7.34‰ to-4.74‰ while depleted value for $\delta^{18}O$ is -10.16‰ in shallow aquifer of Jamungachhi, which indicates that the recharge source is precipitation at higher elevation. The d excess (greater than 10‰) concluded that the aquifer system in the study area is complex and recharged from various sources. The range of enrichment is measured as 2.6‰< 1.96‰<1.87‰<1.55‰ for shallow aquifers, rivers, deep aquifers and flowing artesian well. The significant increase in coarse particle towards the norther part reveals the good aquifer sequence in the northern zone and proves the best recharge area. The overall aquifer system in the study area is complex and recharged from various sources. Most of the aquifers are recharged from the rivers and precipitation at higher altitude.

Keywords: Stable isotopes, Groundwater recharge, Connectivity assessment, Flow path

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INTRODUCTION

The Terai Plain that marks the northern fringe of the Into-Gangatic Plain is the major groundwater potential zone in Nepal. The continuous deposition of sediments from the Himalayas makes it more porous hence, exploration of groundwater makes feasible. Understanding of aquifer's recharge process and their linkage with surface water is essential for integrating water resources all over the earth. Several quantitative databases have been developed encountering perspective of the arsenic contamination of water in aquifer of the Terai region, however no study has been undertaken to understand the details of groundwater flow system, recharge source and geochemical approaches in this area. The study mainly focuses on the concept of delineation of recharge source of groundwater through isotopic analysis of surface water and groundwater. To establish the interrelationship between aquifer system through stable isotopes of $\delta^{18}O$ and $\delta^{2}H$ plot, $\delta^{18}O$ and $\delta^{2}H$ are chosen to trace the groundwater and surface water flow and to identify the recharge source.

Craig (1961) has identified the isotopic contents of Oxygen and Hydrogen are linearly related worldwide, introducing Global meteoric water line that provide empirical relationship describing precipitation, isotopic content collected worldwide.

Winter et al. (1998), has established the fact that range of topographic, geologic and climatic landscape play significant role to groundwater and surface water interconnection. Groundwater discharge is more in low lying areas where several rivers profoundly dominate their flow regimes with different origin. Jenkins et al. (1987) had conducted, in a study on "A stable isotope reconnaissance of groundwater resources in Kathmandu Valley, Nepal", the isotopic signature, flow regimes, and possible dynamics of the valley from the sample collected from groundwater, surface water spring water and precipitation during monsoon season. Samples were analysed for environmental isotopes Oxygen-18 and Deuterium, and concluded that the stable isotope signatures of the valley groundwater were useful to identify the source and to differentiate between various groundwater flow regimes. Gajurel et al. (2006) published some findings on isotopic composition and its variability with elevation and meteoric water. According to their study, isotopic signature of $\delta^{18}O$ was around -18%o to the north of the High Himalayan range and those up to -8%o to -4%o in the Indo-Gangatic Plain, while $\delta^{18}O$ of river were seasonally

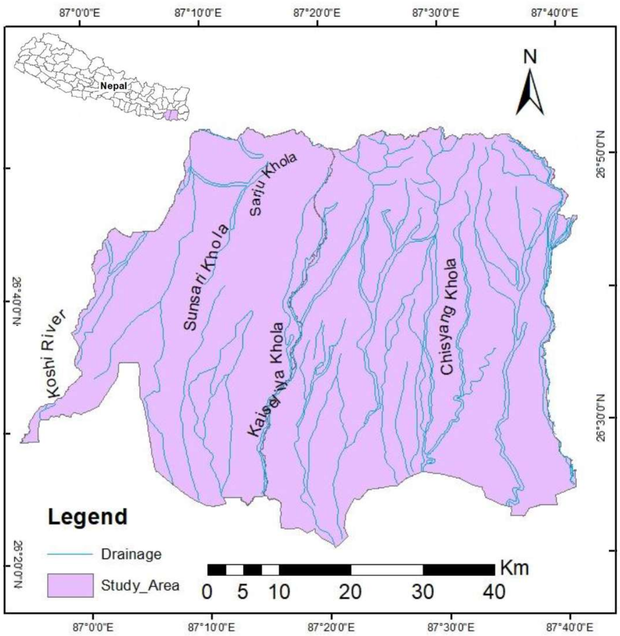

Fig. 1: Location Map of Study Area

variable and monsoon rain could bear 4%o lower than precipitation during the dry season as were observed. The isotopic variation in the foothill rivers ranged from -11%o to -7%o for wet and -8%o to -5%o for dry seasons.

Viava (2015) has documented, for the surface water and groundwater connectivity, that compositional difference of less than 20% between surface water and groundwater samples would indicate high connectivity, 20% and 40% a moderate connectivity; and higher than 40% to low connectivity condition. These percentages were obtained under comparison I the central rhombus of the piper diagram. Based on the water stable isotopes, the range (difference between the lowest and highest value) of the recorded isotopic signature was determined for both δ^2H and δ^{18}O and same criteria (20% and 40% based on range) were considered.

STUDY AREA

The study area covers two districts of Eastern Development Region, which incorporates the Koshi River basin. The Sunsari and Morang Districts confine the eastern region of the Koshi River and are of huge potential of groundwater zones. The Sunsari District is bounded by the Koshi River in the west and the Morang District in the east. To the west of the Sunsari District, the Morang District is bounded by the Jhapa District in the east. The study area is easily assessed by all means of road transportation through the East-West Highway, and lies in the middle and the southern Terai, where good gravel aquifers can be found at shallow depth. The plain land featured with valley is bordered by several river channels and canals, of which the Koshi River is the major river drained by numerous tributaries: Kaiseliya Khola, Sunsari Khola, Chisyang Khola, Lohandra Khola, Sarju Khola, etc. (Fig. 1).

Sampling and analytical methods

Altogether 33 samples were collected from surface water and groundwater from different locations (Fig. 2). Special attention was taken to avoid any contamination and effect of exchange with atmosphere while sampling. The sample taken for isotopic analysis was filtered by using filter to avoid any suspended sediments. Before sampling, all bottles were rinsed with sampling water 3 to 4 times for better in-situ sample. To maintain the accuracy, groundwater from shallow and deep tube wells were left for sufficient time, so that the sample represent the groundwater of aquifer.

Stable isotopic ratio of Oxygen and Hydrogen were analysed at ETH lab, Zurich of Switzerland and results were expressed in ä‰ with respect to Vienna Standard Mean Ocean (VSMOW).

RESULTS

Isotopic Composition

The analysis of ä18O and ä2H is based on the isotopic ratio of the collected sample of surface water and subsurface water. The statistical results are discussed considering ±0.25‰ and ±4‰ as the limiting range for δ^{18}O and δ^2H.

The range of δ^{18}O varies from -10.16 ‰ to -4.74 ‰. Highest depletion (-10.16‰) is noticed in shallow well of Jammungachhi while the highest enrichment is observed (-4.74‰) in the shallow hand pump of Tankesinwari (Table 1). δ^2H values range from -66.36‰ to 26.94 ‰ with average of -40.35‰. The distribution of isotopic composition of sample is presented in the histogram. The graphical representation shows that the isotopic ratio of δ^{18}O has the highest frequency for -5.5 ‰to -5‰ and that for δ^2H is -44‰ to -41‰ (Fig. 3).

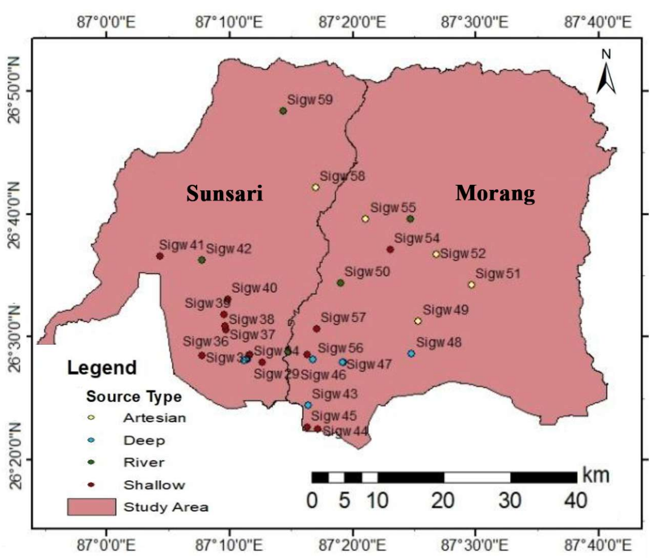

Fig. 2: Sampling Stations

Table 1: Isotopic ratio of collected sample

Sample ID	Easting	Northing	Elv. (m)	District	Location	δ18O (‰)	δ2H (‰)	d excess (‰)
Sigw27	87.27	26.48	70	Morang	Jamungachhi	-10.16	-66.36	14.91
Sigw28	87.25	26.48	61	Sunsari	Ramgunj,Belbachhiya	-5.42	-33.15	10.25
Sigw29	87.21	26.47	62	Sunsari	Amaibela	-6.72	-42.19	11.60
Sigw30	87.19	26.47	60	Sunsari	Eastern sugar mill	-7.42	-47.94	11.41
Sigw31	87.19	26.47	59	Sunsari	Eastern sugar mill	-7.40	-46.96	12.23
Sigw32	87.19	26.47	69	Sunsari	Eastern sugar mill	-7.34	-46.79	11.90
Sigw33	87.19	26.47	" "	Sunsari	Eastern sugar mill	-4.91	-29.59	9.71
Sigw34	87.19	26.48	59	Sunsari	Amaibela	-5.20	-31.93	9.67
Sigw35	87.13	26.48	71	Sunsari	Madhyaharsahi	-7.01	-45.44	10.65
Sigw36	87.16	26.51	63	Sunsari	Rashi	-5.61	-33.30	11.60
Sigw37	87.16	26.52	65	Sunsari	Satyajhora	-5.79	-36.28	10.04
Sigw38	87.16	26.52	59	Sunsari	Satyajhora	-5.95	-37.14	10.46
Sigw39	87.16	26.53	101	Sunsari	Satyajhora	-5.72	-35.62	10.15
Sigw40	87.16	26.55	64	Sunsari	Hattimoda	-5.65	-36.59	8.59
Sigw41	87.07	26.61	75	Sunsari	Pachhim Kusaha	-6.94	-45.35	10.20
Sigw42	87.13	26.60	82	Sunsari	Sunsari Khola	-6.53	-42.56	9.70
Sigw43	87.27	26.41	54	Morang	Rani	-7.69	-49.68	11.85
Sigw44	87.29	26.37	54	Morang	Buddhanagar	-5.74	-35.71	10.23
Sigw45	87.27	26.38	56	Morang	Bhediyari	-5.37	-33.55	9.45
Sigw46	87.32	26.47	59	Morang	Katahari	-7.06	-42.61	13.89
Sigw47	87.32	26.47	59	Morang	Katahari	-6.65	-42.00	11.18
Sigw48	87.41	26.48	65	Morang	Karsiya	-6.97	-42.18	13.61
Sigw49	87.42	26.52	70	Morang	Babiyabirta	-5.73	-34.61	11.21
Sigw50	87.32	26.57	81	Morang	Chisan Khola	-5.89	-37.07	10.08
Sigw51	87.49	26.57	84	Morang	Kerung	-6.82	-41.82	12.77
Sigw52	87.45	26.61	105	Morang	Dangighat	-7.28	-44.29	13.98
Sigw53	87.41	26.66	134	Morang	Lohandra Khola	-6.22	-39.63	10.16
Sigw54	87.38	26.62	110	Morang	Sisaugau Sundarharaicha	-6.72	-41.16	12.56
Sigw55	87.35	26.66	109	Morang	Gothgau	-6.86	-42.05	12.86
Sigw56	87.28	26.47	57	Morang	Munalpath	-5.55	-34.19	10.17
Sigw57	87.28	26.51	71	Morang	Tankeshwori	-4.74	-26.94	11.02
Sigw58	87.28	26.70	125	Sunsari	NARC,	-6.69	-40.54	12.98
Sigw59	87.24	26.81	234	Sunsari	Sarjukhola	-7.38	-46.26	12.80

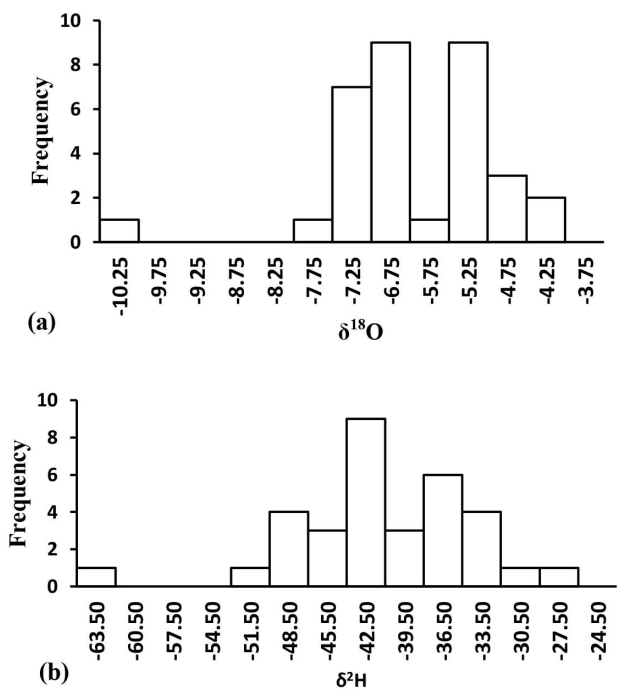

Fig. 3: Histogram (a) $\delta^{18}O$ (b) δ^2H

Deuterium Excess

The calculated d excess value (Table 1) varies from 8.59‰ in shallow aquifer to 14.91‰ in shallow aquifer situated at Jamungachhi. The intercept (d excess) varies from 9.71‰ to 13.89‰, with average value of 11.76‰ for deep aquifer while it varies from 8.59‰ to 14.91‰ with an average of 10.87‰. for shallow aquifer and the value of intercept for the case of artesian well ranges from 11.2‰ to 13.28‰.

Spatial distribution

Majority of the samples of flowing artesian wells are encountered under the range of -7.03‰ to -6.53‰. The shallow aquifers fall under the range of -5.94‰.to-5.34‰ and deep aquifers fall over a wide range of -7.13‰.to -6.53‰ for $\delta^{18}O$ (Fig. 4).

Isotopic characteristics of Surface water and subsurface water

From the plot of $\delta^{18}O$ vs. δ^2H, four rivers clustered the samples including shallow and a deep aquifer based on the isotopic signature shown by collected sample (Fig. 5). The clustering is done limiting the range ±0.25‰ for $\delta^{18}O$ to show

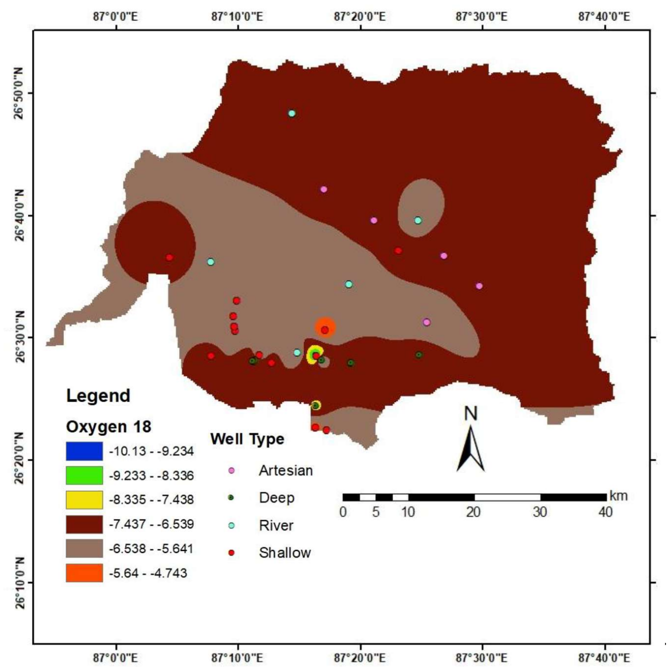

Fig. 4: Spatial Distribution of $\delta^{18}O$

the connectivity between surface water and groundwater. Among four clusters shown in Fig. 5, the Chisyang Khola (sigw 50) with isotopic composition -5.89‰ for $\delta^{18}O$ consisted 6 samples of five shallow and a flowing artesian well. The shallow aquifers have -5.65‰, -5.72‰, -5.74‰ and -5.95‰, and the flowing artesian well has -5.79‰ to -5.73 ‰. The Kaiseliya Khola has isotopic ratio -5.42‰: with 3 shallow aquifers with isotopic ratio -5.20‰, -5.61‰ and -5.37‰, and a deep aquifer with

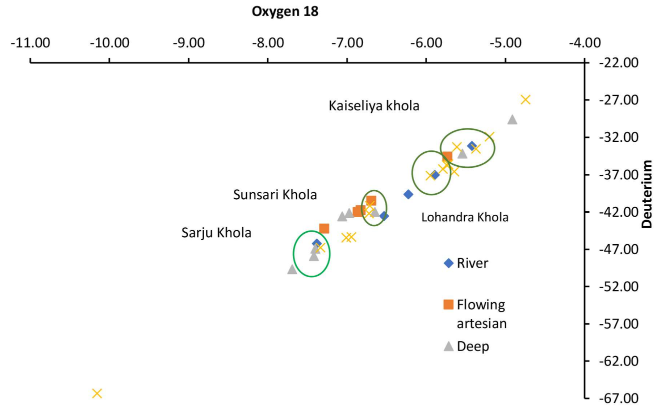

Fig. 5: Isotopic Composition in Surface water and Groundwater

isotopic composition of -5.55‰. The Sunsari Khola whose isotopic ratio is -6.53‰ consisted the sample of shallow aquifers with isotopic ratio -6.72‰, deep aquifer of isotopic ratio -6.65‰ and flowing artesian well with isotopic composition -6.69‰. Likewise, the Sarju Khola that shows the isotopic ratio -7.38‰ is clustered with two deep aquifers with isotopic ratio -7.40‰ and -7.42‰, a shallow aquifer with isotopic ratio-7.34‰ and a flowing artesian well with composition -7.28‰. The Lohandra Khola doesn't group any other aquifer.

Subsurface geology

Thirteen lithologs were considered to make a 3-D correlation (Fig. 3; Table 2). Gravel type materials are abundant in the northern parts and degradation of coarse particle in the southern part occurs (Fig. 6). This imply that the river originating at the higher altitude and presence of porous materials at the

Table 2: Location of representative lithologs

Location	District	X	Y	Altitude (m)	Total Depth (m)	Aquifer materials
Tarahara	Sunsari	528125	2953375	145	44.5	Gravel and pebble
Inarwa	Sunsari	515125	2943625	83.1	50.9	Gravel Sandy
Lauki	Sunsari	506500	2941875	80.5	36.9	sand and Gravel
Satyajhoda	Sunsari	516000	2936375	77.3	16.8	sand and Gravel
Amahibela	Sunsari	518125	2927750	69.8	24.4	Sand
Shankarpur	Morang	528125	2928125	70.2	126.2	Gravel and Sand
Biratnagar Hospital	Morang	528375	2928250	72.95	75.9	Garvel with Sand
Salakpur	Morang	535125	2949250	135.5	36	Gravel fine angular
Karsiya	Morang	541563	2926375	67	36.6	Sand fine to Coarse
Karoon	Morang	548500	2938563	93	30.5	Sand and Gravel
Tankesinuwari	Morang	527875	2934000	82.5	102.4	Gravel
PTC. Biratnagar	Morang	526250	2922250	68	92	Gravel and Sand
Dangihat	Morang	544375	2943500	107	128.2	Sand and Gravel
Indrapur	Morang	540875	2951125	141.6	123.1	Gravel

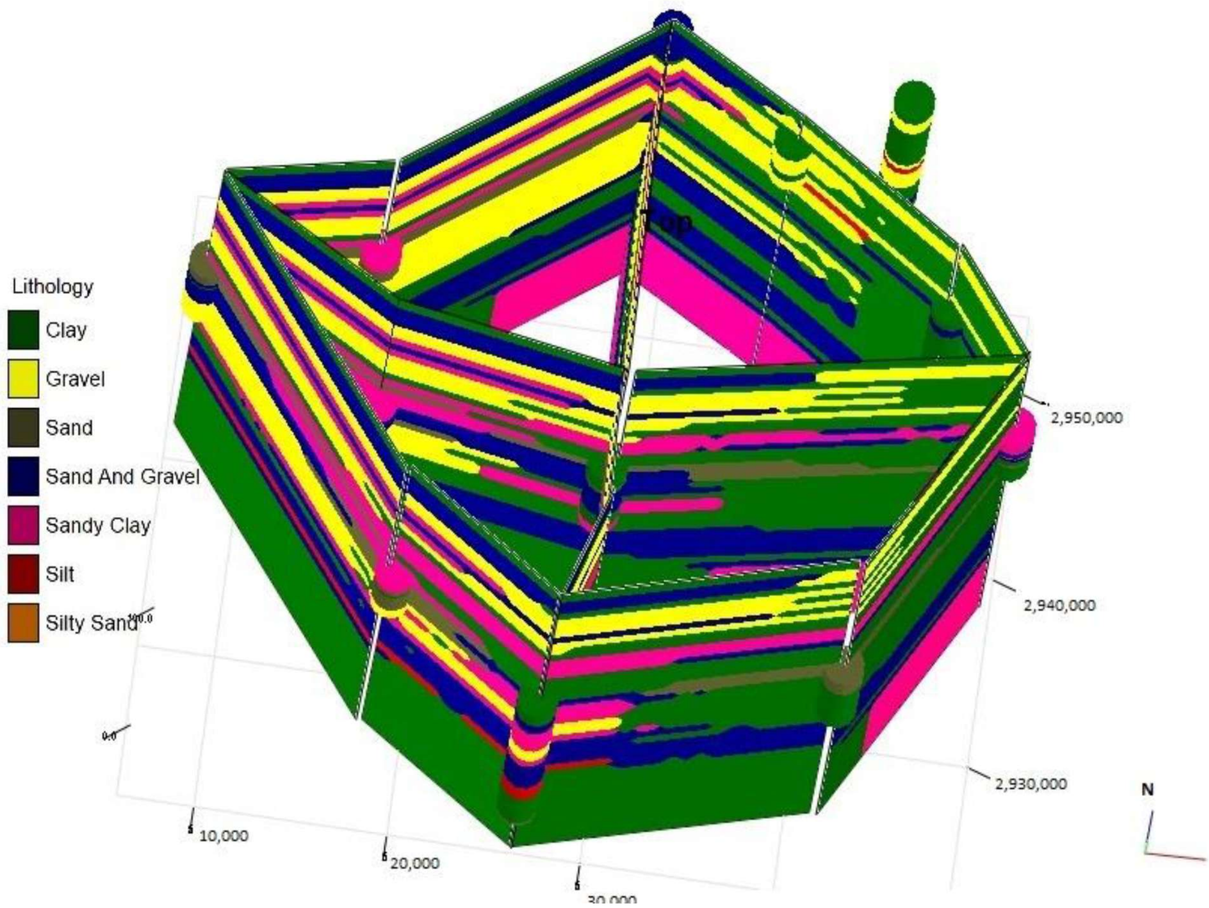

Fig. 6: 3-D subsurface correlation of lithology from logs

northern fringe has major role for the availability of groundwater in study area (Winter et al., 1998).

DISCUSSIONS

The connectivity between the aquifer system in the study area is primarily based on the isotopic composition of the collected sample. The sample that falls under the same range in isotopic composition are correlated to establish the connectivity between the surface water and groundwater (Fig. 5). The Chisyang Khola (sigw50) shows the connectivity with the shallow aquifer of Satyajhoda (sigw37 and sigw39), Hattimoda (sigw40), Buddhanagar (sigw44) and flowing artesian well of Babiyabirta (sigw49). Similarly, the Sunsari Khola establishes the connectivity with shallow aquifer at Amahibela (sigw29), sisgaun (sigw54), deep aquifer at Tankisinwari (sigw57) and flowing artesian well of National Agriculture and Research Center (sigw58). The Kaiseliya Khola (sigw28) shows the same range of isotopic ratio with shallow aquifer at Amahibela (sigw34), Bhediyari (sigw45), Rashi (sigw36) and deep aquifer at Munalpath (sigw56). The Sarju Khola (sigw59) exhibits the connection with shallow aquifer (sigw32) and deep aquifer (sigw30 and sigw31) of eastern sugar mill, Amahibela at the southern zone.

The interconnection established by isotopic analysis of shallow and deep aquifers in the study area implies that the groundwater system in the area is recharged by major and minor river system. The range of enrichment is measured as 2.6‰< 1.96‰<1.87‰<1.55‰ for shallow aquifers, rivers, deep aquifers and flowing artesian well also established the interconnections between surface water and sub-surface water. Hence on the basis of water stable isotopes, the range (difference between the lowest and highest value) of the recorded isotopic signature was determined for both δ^2H and $\delta^{18}O$ and same criteria (20% and 40% based on range) indicate the highest connectivity (Viava, 2015).

The enriched value of isotopic ratio ($\delta^{18}O$ -4.74‰ to -6.74‰) shows that the majority of the shallow and deep aquifers are recharged from the local rivers distributed in the area as, the isotopic signature of $\delta^{18}O$ in groundwater showed that the shallow and deep aquifer fall along the same range. Jamungachhi (sigw27) with isotopic ratio ä18O (-10.16‰) indicates depleted recharge source like precipitation at higher altitude (Trinid et al., 2017).

The slope greater than 8 in all samples implies less or no evaporation effect (Clark and Firtz, 1997) and intercept (d-excess) value greater than 10‰ in most of the samples suggests that the probable input to the recharge is recycling water vapor contributed by the possible surface flows (Fynn, 2016). The wide variation in isotopic signature (ä18O: -10.16‰ to -4.74‰) might be the reflection of multiple recharge source (Keesari et al., 2017). Dominance of coarse particles increasing towards the northern part reveals the good aquifer sequence in the northern zone and hence proves the best recharge area.

CONCLUSION

Lithological analysis of shallow and deep aquifers from the representative data indicates material at shallow zone with high potential of groundwater exploration. The groundwater and surface water in the study area show the high connectivity on the basis of isotopic signature and its range. The isotopic signature of the collected sample determines the major and minor rivers as recharge source of the groundwater system in the study area. The overall aquifer system in the study area is complex and recharged from various sources. Most of the aquifers are recharged from the rivers and precipitation at higher altitude.

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