Isotope studies to identify the origin and recharge area of Himalayan Springs as a climate change adaptation initiative: a case study from Sikkim, Eastern Himalaya

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Abstract: *Springs originating naturally from unconfined aquifers are the primary source of water for both rural and urban communities in the Sikkim Himalaya. Several factors such as changes in climatic conditions, landuse, demography, etc are affecting the discharge of springs in this region. We undertook a study to identify the springs' origin and their recharge area using isotopic methods in the Central Pandem region of East Sikkim. Twelve micro springs having an average household dependency of thirty per spring were studied. In order to identify the recharge area and to understand the spring's dynamics, we performed environmental isotope studies on the collected spring water samples. The initial results reveal that the spring discharges are strongly dependent on the rainfall pattern. The concentration of the stable isotopes of Hydrogen (^2H) and Oxygen (^{18}O), is been analysed for the spring water samples along with the field parameters like pH, Electrical Conductivity, discharge, rainfall etc. This study has resulted in a better understanding of the basic characteristics of the springs and their recharge. The stable isotope studies of the spring samples show that the spring samples fall above the global meteoric water line as shown by Himalayan aquifers and evaporation enrichment during recharging process. Electrical conductivity analysis shows that the aquifers are recharged on a local level. Revival of these springs using this scientific knowledge can help in enhancing the climate change resilience of the local communities.*

Keywords: *Atmospheric Precipitation; Ground Water; Isotopes; Electrical Conductivity; Aquifer; Eastern Himalaya.*

1. Introduction:

Water is an essential resource for human life. Hydrosphere is estimated to have 1.4×10^9 km^3 of water; of which about 0.008×10^9 km^3 is stored as groundwater [1] which forms a key source of drinking water on Earth. Springs are important component of the hydrosphere where the groundwater flows onto the surface. For sustainable groundwater resource management the understanding of mechanism for groundwater recharge is required. Various techniques for such investigation are available but the environmental isotopes of oxygen and hydrogen are widely used to identify the source and groundwater recharge path [2,3,26]. Oxygen and Hydrogen, being building blocks of water molecule and hydrological cycle, show a characteristic isotope signature in water which can be taken as tracers of groundwater recharge [4,5,6] and its signature is not modified by other biosphere factors like rock-water interaction [7,8].

In mountainous areas $\delta^{18}O$ and δ^2H is used to distinguish precipitation derived groundwater as a result of altitude effect[9]. In this paper, the spring water samples are analysed for $\delta^{18}O$ and δ^2H data for the dry and monsoon season from March to August 2013. The determination of the source and origin of the springs will further help in designing artificial ground water recharge projects for their revival.

2. Background of the study Area:

2.1. Location and Climate

Based on the climate change related vulnerability assessment done earlier [10] Central Pandem was found to be one of the most vulnerable regions of East Sikkim district. The present study hence focuses on the Central Pandem watershed of River Teesta located between 27.20 and 27.22 °N latitude and 88.55 and 88.53 °E longitude (see fig I). The elevation in the watershed ranges from 650 m at Kameray to 1850 m at Karmithang Ghari. The study area experiences a temperate climate with temperature ranging between 4-30°C at lower altitude (around 700 m) and at 1-25°C at moderate altitude (around 1750 m). The annual precipitation is about 1610 mm. The temperature and precipitation data is taken from the automatic weather station of Indian Space Research Organisation (ISRO) and Rural Management and Development Department (RM&DD), Government of Sikkim located at 27.20 ºN Latitude and 88.54ºE Longitude. The maximum temperature is observed during the month of July and minimum during the month of January. The weather of Sikkim can be divided into four seasons, namely Winter (November- February); Spring (March-April); Monsoon (May – mid September); and Autumn (Mid September- October).

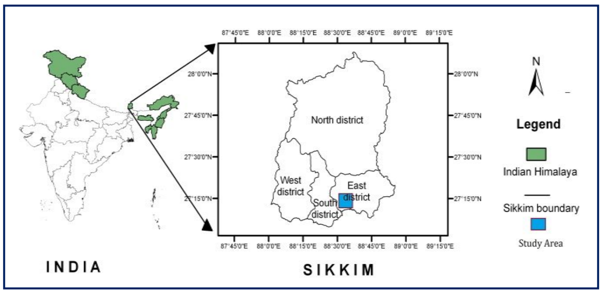

Figure I- Map of India showing Sikkim and the study area

Though the Eastern Himalayas receive abundant rainfall, but a large proportion of it is restricted to the monsoon season. Natural groundwater recharge is hampered by the high surface runoff thereby decreasing infiltration and aquifer recharge and consequently drying up of water sources [11]. Further study on climate data available from Gangtok indicates that winters are becoming increasingly warmer and drier with October to February being the exceptionally dry period [12]

2.2. Geology:

Central Pendam watershed is characterised by a granite gnesis (mylonltic) lingtse gnesis in patches and interbanded chlorate- sericiteschist/ phyllate and quartzite and blotetit quartzite of Gorubathan formation of Dailing Group.

The formation consists of mappable, monotonous sequence of inter banded chlorite sericite schist / phyllite, quartzite, meta greywacke, pyritiferrous black slate/ carbon phylllite, basic meta volcanic. Chlorite phyllite is dark green to light green whereas the quartz chlorite phyllite is only light green in colour. The geology of the study area shows fine quartz veins in Rongpo, Vasme, Duga and Pachekhani area. Quartzites are occurring as thin partings to mappable bands within the chlorite schist and quartz chlorite schist. Intercalation of quartzite and chlorite schist is observed in Rongpo, Duga, Pandem, Singtam area. Quartzites are mainly white to light green in colour depending upon the percentage of chlorite in them. They are also observed as grey to buff at places. Mostly these are fine grains in size and massive in nature [13].

Almost the entire water supply for domestic and agricultural purpose is derived directly or indirectly from the aquifer of the study area. The average household dependency of the springs is about 30 households per spring.

2.3. Methodology:

Water samples were collected from 12 spring sites across Central Pendam watershed from March 2013 to August 2013 The other field parameters like the pH, electrical conductivity and discharge are also measured on a bimonthly basis. The pH and conductivity are measured using a Tracer (LaMotte pH/ conductivity/ TDS/ Salinity meter code 1766 Tracer; see Fig. II) and the discharge is measured using a 13L/5L bucket and a stop watch.

Figure II- Photograph of Tracer

The spring samples collected in March 2013 and May 2013 were analyzed for $\delta^{18}O$ and $\delta^{2}H$ isotopes using Isoprime Continuous Flow Mass Spectrometer at Isotope Application Division, Bhabha Atomic Research Centre, Mumbai. Samples for measurement of stable isotopic composition of oxygen and hydrogen are prepared using gas equilibration method[14]. For oxygen isotope composition 2ml of water sample is equilibrated with CO_2 at 50ºC for 8h and for Deuterium composition 2ml sample of water was equilibrated with H_2 gas at 50ºC for 2h and the equilibrated gas is introduced into the spectrometer. The stable isotope results of oxygen and hydrogen are reported using the conventional delta (δ) notation[15]. $\delta^{18}O$ and $\delta^{2}H$ is expressed in per mil (‰) relative to Vienna Standard Mean Ocean Water (VSMOW). The analytical precision was ±0·05 per mil for ^{18}O and ±1 per mil for ^{2}H.

$\delta‰ = 1000(R_{sample} - R_{VSMOW}) / R_{VSMOW}$

where R_{sample} and R_{VSMOW} are the isotopic ratio of the sample and of VSMOW respectively. The climate data of temperature and precipitation were taken from the automatic weather station at Duga Block Administrative Centre (BAC) installed by the Indian Space Research Organisation (ISRO) and Rural Management and Development Department (RM&DD), Government of Sikkim.

3. Results and Discussion:

Precipitation in the form of rainfall and spring discharge for the study period showed a strong dependence. (Figure III and Figure IV). The rainfall showed variation with July being the rainiest month and January being the driest [10]. Similar rainfall dependence of Himalayan springs and their discharge has also been established by earlier studies [16,17,18]. Further studies have revealed that mountain spring discharge is a function not only of rainfall pattern and recharge area characteristic but it also depends on the aquifer characteristic [19]. Also the same study has revealed that many of such Himalayan aquifers in Sikkim Himalayas have become seasonal over the last decade.

The correlation of $\delta^{18}O$ with temperature, latitude, altitude, distance from sea and amount of precipitation was recognised by Dansgaard [20]. The isotope signature at a place is continuously modified by temperature and continual loss of moisture during the travel of the air mass [21,22].

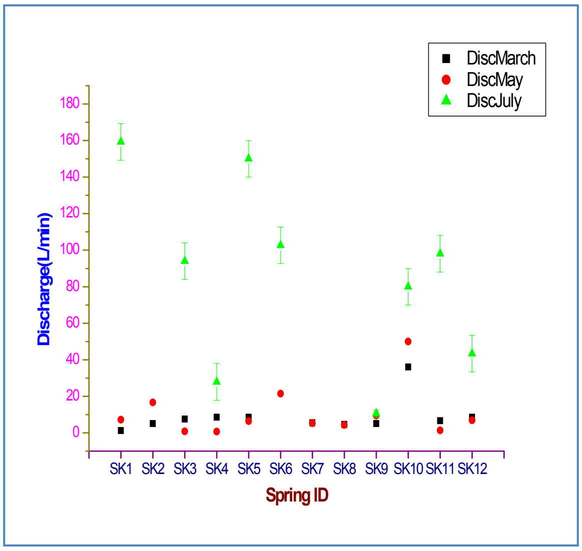

Figure III: Spring Discharge Curve for the period of March to July 2013

3.1. Spring Discharge and Rainfall

From figure III, it can be seen that the discharge for all the springs is minimum during March and maximum during July following an ascending trend. The discharge of springs is in the range of 1.2 to 36 L/min during lean period and 10.5L/min to 159L/min during peak season.

The analysis of rainfall data shows a similar characteristic and illustrates the spring discharge and rainfall interdependence.

From Figure III and IV, it is evident that the rainfall-discharge pattern of springs follows a definite co-related pattern with a time lag. The rainfall increases from March to July and then from August onwards the rainfall follows a decreasing trend. The rainfall in the study area has declined over the last three years even during the peak rainfall months of June and July.

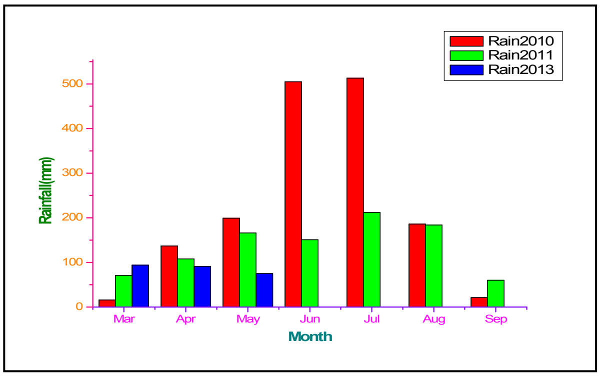

Figure IV: Month wise Rainfall for 2010, 2011 and 2013.

The discharge of the spring's peaks towards August, followed by a decrease and ultimately it reaches a minimum during the lean period from March to May as also indicated by previous studies [23]. The change in rainfall pattern has a marked influence on the spring discharge [24]. Over the last few years, the discharge from the spring as observed by the local community has shown a marked decline as well [19]. This decrease has resulted in an acute shortage of drinking water and a shift in landuse pattern is being observed which is further having an influence on the discharge and recharge of the springs.

3.2. Electrical Conductivity

The bimonthly record of the electrical conductivity of the springs is shown in Figure V. The pH of the spring samples varies from 5.9 to 7.2 (±0.2). Electrical conductivity (EC) of all spring samples is less than 100 µS/cm indicating all the spring samples are extremely fresh. From Figure V it is inferred that for most of the springs electrical conductivity show a higher value during the lean period and a lesser value during the high discharge period. The electrical conductivity increases during the lean season as a result of flow of relatively older water out of the storage. Whereas the decrease in the conductivity can be inferred due to an increase in the flow of the low conductivity recharging water (precipitation) into the springs [25].

This pattern of electrical conductivity indicates the spring flow is likely to be controlled by displacement water aquifer i.e. older water driven out of the aquifer rather than direct recharge through soil zone during rainy season.

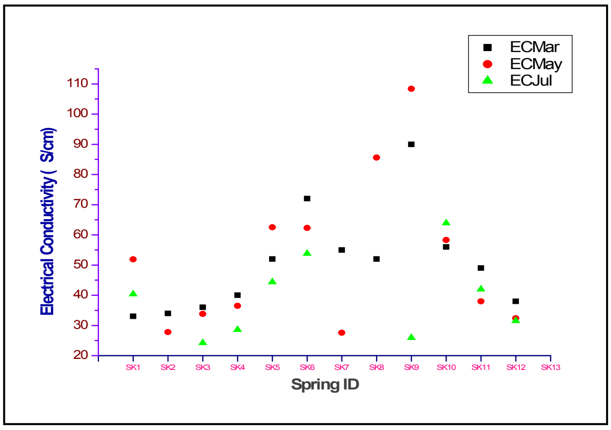

Figure V: Electrical conductivity of each spring bimonthly trend.

The discharge water with high electrical conductivity is water equilibrated within the soil zone and resides in pores and fractures nearer to the land surface. This water would be relatively warm and dissolve more salts thereby possessing a high electrical conductivity. During rainfall this water could be mobilized by the rainwater towards the spring resulting into a high electrical conductivity of the water after which the conductivity shows a decrease. This property could indicate multiple aquifers feeding a single spring. During the onset of rainy seasons the recharge of individual aquifer takes place thereby interlinking them and water flows through these towards the spring thereby increasing the electrical conductivity.

However in case of some springs the possibility of such interlinking of multiple aquifers may be ruled out. In addition we can also state that the fresh rainwater recharging the aquifer is mobilizing the older water which has spent a longer time in the aquifer. It may have interacted with the rocks and has a greater mineral content [27]. This mobilization process pushes the older water out towards the spring and gives greater electrical conductivity to the water. Now, as the recharge process is at peak during the rainy season; hence once the old water is flushed out the electrical conductivity of the water starts to show a constant value [25].

3.3. Stable Isotope Signatures:

In Figure VI, ^{18}O is plotted against ^{2}H. All spring samples fall above the Global Meteoric Water which is generally observed in the Himalayan region because rain water is depleted [15]. Linear regression line equation for samples collected in the month of March 2013 is $^{2}H = 5.5\ ^{18}O - 5.9$ (r =0.82, n=12) which indicates evaporative enrichment of stable isotopes during recharge process. The highest enrichment has been found in the spring named Lower Changey Source (SK-05).

Linear regression line equation for samples collected in the month of May 2013 is $^{2}H = 4.1\ ^{18}O - 16$ which indicates more enrichment than March samples with a linear regression line of $\delta^2H = 5.5\delta^{18}O - 5.9$

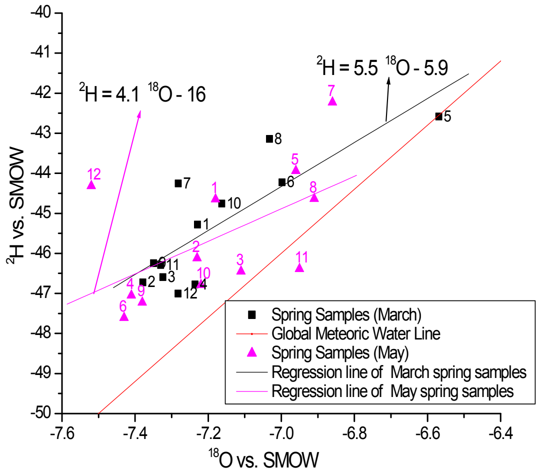

Figure VI: ^{18}O vs. ^{2}H plot of spring water samples collected in the month of March and May 2013

4 Conclusions:

The above study indicates that the Himalayan springs of Central Pandem catchment are of local origin and the possible recharge zone of the aquifers is within the local geographical area i.e. springshed. It also establishes the rainfall-spring interdependence thus making it clear that the source of recharge of the springs is rainwater. The electrical conductivity measurements further indicate that the recharge points of the springs are locally situated. The fluctuations shown by electrical conductivity values over the period suggests that the flushing process is dominant in most of the springs.

Our analysis indicates that the aquifers are recharged recently and hence the water does not transit long distance before it reaches the discharge point. It is concluded that the aquifers of each spring are a group of small interlinked aquifers. During monsoons, when the recharge is high, these individual aquifers get interlinked which increases the discharge of the spring. Post monsoon the interconnectivity of these aquifers is broken and thereby decreasing the spring discharge. This ultimately results in minimum discharge during lean period.

The isotope analysis illustrates that all spring samples lie above the global meteoric water line which is due to depletion in stable isotope concentration in Himalayan rainwater. The regression line indicates higher enrichment in May samples in stable isotopes than the samples of March. This could be due to evaporation enrichment of sample during the recharge process.

5 Recommendations:

Since most of the springs and their catchment area lie in private holdings or on agricultural land therefore geological analysis cannot help in identification of recharge areas to a high precision. Thus stable isotope analysis of the rainwater sample at various elevations (100 m apart) [28, 29] above the spring needs to be carried out and the isotopic signature at various altitudes will help in identification of the recharge area and the source of the spring. This will facilitate the identification of the various aquifers and their interconnectivity.

Hence, it will enable to target the artificial ground water recharge interventions to revive the springs to increase their lean period discharge and result in climate change adaptation for the local community.

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