# Isotope hydrogeological study on a few drying springs in Surla valley, Sirmaur District, Himachal Pradesh

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**In the Surla valley of the mountainous Sirmaur District of Himachal Pradesh, springs are the only available source of water for domestic and agricultural use. The drying of springs during summer causes a lot of hardship to the inhabitants of this region. Therefore, a study of environmental isotopes ($^2$H, $^{18}$O, $^3$H) along with hydrogeochemistry and geomorphology was undertaken to identify the recharge zones of the drying springs. From the stable isotope data of rainwater, altitude effect was estimated (–0.6‰ for $\delta^{18}$O per 100 m elevation) and recharge zones of the drying springs were identified (+700 to +1150 m amsl). Based on the recharge elevations identified from the isotopic study and from the interpretation of the geomorphological setting of the valley and taking into consideration the availability of space, it has been decided that contour-bunding, or building of check dams or levees structures with gabion are suitable methods of rainwater harvesting for augmenting recharge of the drying springs.**

**Keywords:** Artificial recharge, environmental isotopes, rainwater harvesting, springs.

SPRINGS are an important component of the hydrosphere where the groundwater flows onto the surface. Worldwide, springs are used as a source of water for domestic and agricultural purposes. Several places in the Himalaya dependent on spring waters are facing an acute shortage of drinking water, including the presently studied Surla valley in Sirmaur District, Himachal Pradesh. Drying of springs during summer causes a lot of hardship to the inhabitants of Surla valley.

Occurrence of springs mainly depends on recharge area characteristics such as the permeability of topsoil, geology of the area, slope of the ground surface and surface cover characteristics. Most of the springs located in the study area (Surla valley) are related to unconfined groundwater system and the hydrology of such springs is mainly influenced by rainfall and the surrounding catchments area[1]. Rainwater harvesting has been carried out in the mountainous regions of India with limited success[2,3]. Generally, the recharge structures were constructed based on geomorphology of the area without identifying the recharge areas[4]. Isotope techniques provide a unique tool for establishing the recharge areas and thereby improving the effectiveness of rainwater harvesting measures.

Therefore, isotope hydrogeological study has been carried out in Surla valley to identify the recharge zones of a few drying springs for augmenting recharge to the springs through rainwater harvesting.

Environmental isotope techniques have been used for more than five decades to study hydrological systems. The most frequently used environmental isotopes include deuterium ($^2$H), tritium ($^3$H), oxygen ($^{18}$O) and carbon ($^{13}$C, $^{14}$C) occurring in water as constituents of dissolved inorganic and organic compounds. $^3$H occurring in groundwater originates from cosmic rays reacting with the atmosphere[5]. Additionally, atmospheric nuclear weapon testing in the early 1960s injected large amounts of $^3$H into the atmosphere[6]. $^3$H is generally used to study the groundwater circulation and to estimate transit time[7].

Application of stable isotope ratios of hydrogen ($^2$H/$^1$H) and oxygen ($^{18}$O/$^{16}$O) in groundwater is primarily based upon isotopic variations in atmospheric precipitation[8]. Many researchers have applied these techniques for determining the recharge area of the groundwater[9,10], origin of springs[11], and to estimate the relative importance of recharge by precipitation and groundwater flow from higher slopes[12].

The study area lies in Sirmaur District, Himachal Pradesh (lat. 30°34′–31°38′N and long. 77°13′–77°16′E) in the lower Siwalik ranges of the Himalaya (Figure 1). Geomorphologically the area consists of high mountain ranges, hills and valleys with altitude ranging from 600 to 1300 m amsl. There is general increase in elevation from south to north. Low denuded hill ranges of the Siwalik represent the southwestern part of the area. The valleys are narrow and deep with steep slopes. The rock formations of the area are carbonaceous shales and slates of

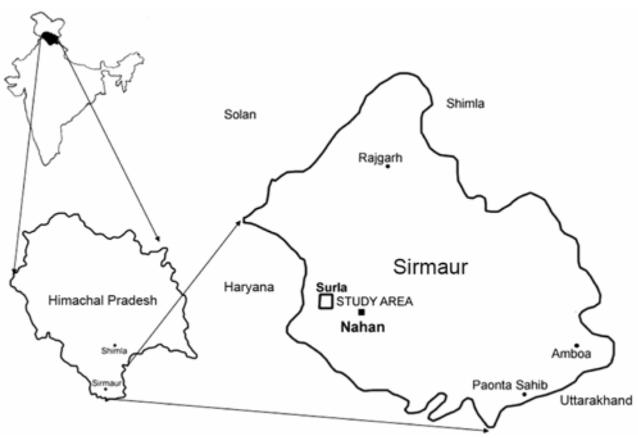


**Figure 1.** Location map of the study area in Sirmaur District, Himachal Pradesh.

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**Table 1.** Environmental isotope results of springs, dug wells and rainwater

| | February 2009 | | | May 2009 | | November 2009 | |
|---|---|---|---|---|---|---|---|
| Sample no. | $\delta^2$H (‰) | $\delta^{18}$O (‰) | $^3$H (TU) | $\delta^2$H (‰) | $\delta^{18}$O (‰) | $\delta^2$H (‰) | $\delta^{18}$O (‰) |
| Sp-1 | – | –7.8 | 7.1 | –43 | –7.2 | –45 | –6.8 |
| Sp-2 | – | –8.3 | 6.3 | –42 | –6.7 | –44 | –6.7 |
| Sp-4 | – | –7.2 | 6.1 | –38 | –7.2 | –39 | –6.0 |
| Sp-6 | – | –7.5 | 7.4 | –39 | –6.7 | –40 | –6.4 |
| Sp-7 | – | –8.4 | 7.1 | –47 | –7.5 | –44 | –6.6 |
| Sp-8 | – | –8.5 | 6.2 | –44 | –6.0 | –45 | –6.7 |
| Sp-9 | – | –7.8 | – | –44 | –6.2 | –43 | –6.7 |
| Sp-10 | – | –8.3 | 6.8 | –39 | –7.5 | –48 | –7.3 |
| Sp-11 | – | –8.3 | – | –46 | –7.3 | –47 | –7.2 |
| DW-1 | – | –8.2 | 6.8 | –45 | – | –43 | –5.6 |
| DW-2 | – | –7.0 | – | –32 | –5.2 | –44 | –6.4 |
| Rainwater | November 2009 | | | August 2010 | | | |
| RGS-1* | – | – | 8.1 | –44 | –7.3 | | |
| RGS-3 | –61 | –8.0 | – | –79 | –10.9 | | |
| RGS-5 | – | – | 7.8 | –87 | –12.3 | | |
| RGS-6 | – | – | – | –83 | – | | |
| RGS-8 | – | – | 7.7 | –93 | –12.8 | | |

*July 2010 ($\delta^2$H = –52‰; $\delta^{18}$O = –7.7‰). Sp, Spring; DW, Dug well.

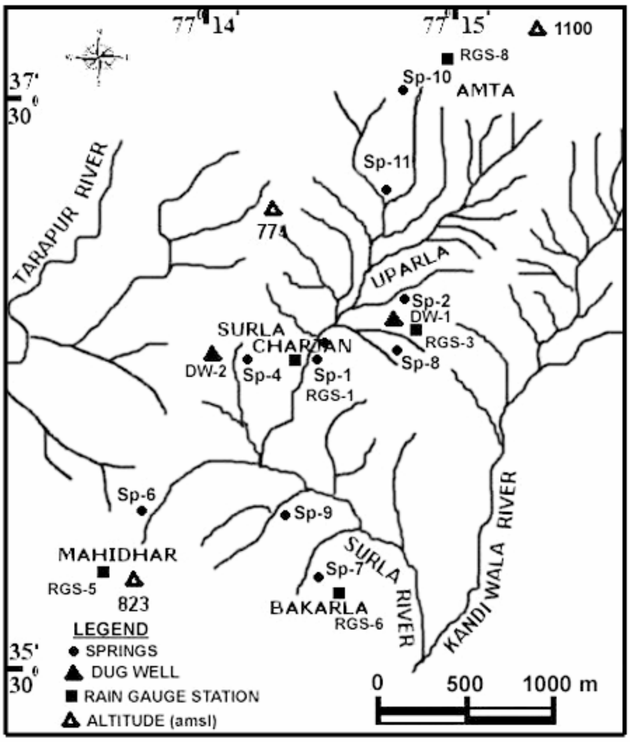


**Figure 2.** Drainage map of Surla valley along with the water sampling locations.

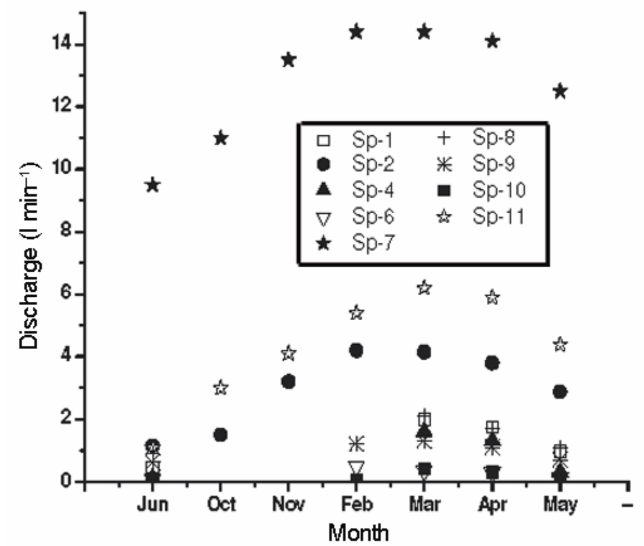


**Figure 3.** The hydrograph of springs (2009).

Mandhali Formation, Krol limestones, Subathu shales, Dharmshala shales and sandstones, Siwalik sandstones, shales and boulder conglomerate beds[13].

Hydrograph of the springs was prepared for the year 2009. Discharges of all the springs and physico-chemical parameters (pH, electrical conductivity, temperature) were measured in the field during the sampling programme (June 2009 to May 2010). Water samples were collected from nine springs and two dug wells in February, May and November and from rainwater. (The rainwater samples were collected at different elevations in November 2009 and August 2010.) The water samples were analysed for environmental isotopes ($\delta^2$H, $\delta^{18}$O) by the dual inlet isotope ratio mass spectrometer (GEO 20-20) using gas equilibration method[14] (precision: $\delta^2$H = ±1‰; $\delta^{18}$O = ± 0.1‰). The results of analysis are given in Table 1. Tritium content of the water sample was measured using a liquid scintillation counter (Perkin Elmer

Quantulus, model no. 1220) preceded by electrolytic enrichment[15] (precision: 0.5 TU ($\pm 1\sigma$)). Water samples were also analysed for dissolved major and minor ionic species using ion chromatograph (analytical error: ± 5%).

Locations of sampling of spring and rainwater are shown in Figure 2. Isotopic analyses of water are presented in Table 1. Hydrograph for the springs for 2009 is given in Figure 3.

From the results, it is found that the electrical conductivity of the spring waters falls in the range from ~ 200 μS/cm to ~ 800 μS/cm. It is dependent on the travel path of water and the associated rock–water interaction (dissolution of minerals). It was found that the spring waters show little seasonal variation in electrical conductivity.

From the hydrograph of the springs (Figure 3), it can be seen that the discharge of the springs decreases gradually around February, which is a characteristic of the springs having single recharge elevation. Also, the hydrograph of the springs along with the hydrogeological setting of the valley suggests, that probably these are either contact or fracture springs.

The results of the chemical analyses of the spring waters are presented in a tri-linear diagram (Figure 4). They indicate that the springs are Ca–Mg–$HCO_3$ and Ca–$HCO_3$ type of waters, and that the seasonal variations in the major and minor ions are not significant.

The isotopic ($\delta^2$H, $\delta^{18}$O) composition of spring samples collected in November 2009 (Figure 5) falls very close to the Global Meteoric Water Line (GMWL), indicating that the springs receive direct precipitational

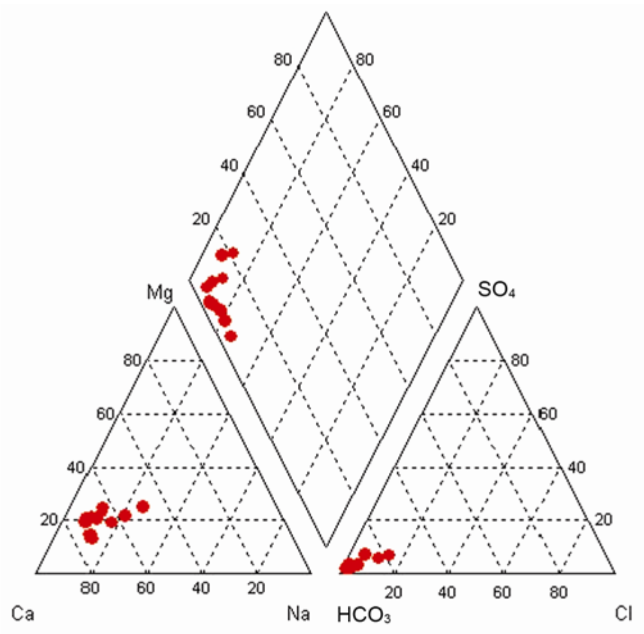


**Figure 4.** Piper plot for February 2009.

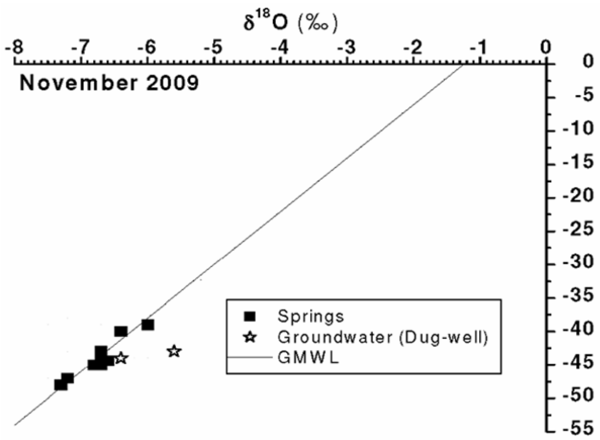


**Figure 5.** $\delta^2$H–$\delta^{18}$O plot of November 2009 samples.

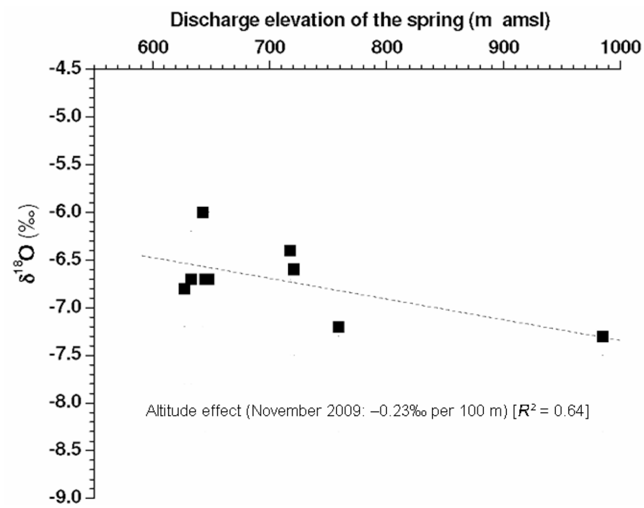


**Figure 6.** $\delta^{18}$O versus discharge elevation.

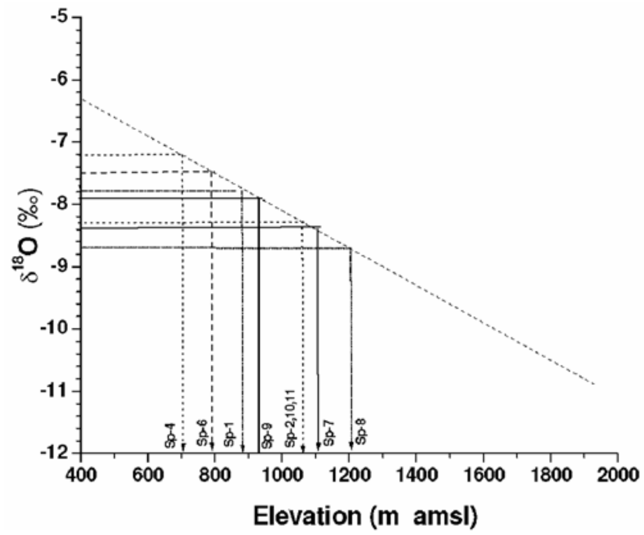


**Figure 7.** Estimated recharge elevation of the springs based on $\delta^{18}$O results of February 2009.

**Table 2.** Discharge elevation and estimated recharge elevation of the springs

| Sample no. | Location | Discharge elevation (m amsl) | Estimated recharge elevation (m amsl) |
|---|---|---|---|
| Sp-1 | Surla Amta | 627 | 850 |
| Sp-2 | Surla Upparla | 645 | 1050 |
| Sp-4 | Surla Charjan | 643 | 700 |
| Sp-6 | Mahidhar | 718 | 800 |
| Sp-7 | Bakarla | 721 | 1100 |
| Sp-8 | Kaharwali | 648 | 1150 |
| Sp-9 | Bakarla | 633 | 920 |
| Sp-10 | Amta | 985 | 1070 |
| Sp-11 | Surla Amta | 759 | 1050 |

recharge with negligible evaporation during recharge. The tritium content of the springs ranges from 5.8 U to 7.4 TU and that of rainwater is about 8 TU, which indicates that the residence time of spring water (i.e. time of travel from recharge area to discharge area) is very short. Hence, the springs can be used as proxies for rainwater to estimate the altitude effect in precipitation.

The $\delta^{18}$O versus discharge elevation of the springs at Surla (Figure 6) gave an altitude effect (rate of change of isotopic composition of precipitation with respect to altitude) of –0.23‰ per 100 m elevation for the November 2009 samples with a regression coefficient ($R^2$) of 0.64. Based on the obtained altitude effect and using $\delta^{18}$O of a rainwater sample collected in 2009, a relationship between $\delta^{18}$O of rainfall versus elevation was obtained: $\delta^{18}$O(‰) = –0.003(‰/m) ∗ elevation(m) –5.1(‰) (Figure 7). The estimated recharge elevation of the springs from this relation is given in Table 2. The recharge elevations in the valley range from +700 m amsl to +1150 m amsl.

Using the recharge altitudes deduced from the isotopic studies and based on a careful study of a geomorphological setting of the valley, locations for construction of rainwater harvesting structures were identified. Also, based on the geomorphological setting of the study area and taking into consideration the availability of space, it is suggested that construction of check dams or levee structure with gabion or contour bunding methods of rainwater harvesting are the best options for augmenting the recharge of the drying springs.


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