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USE OF ENVIRONMENTAL ISOTOPES TO STUDY THE EFFECT OF CLIMATE CHANGE ON PASSU GLACIER

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Abstract

Isotopic or nuclear techniques are used to find the effect of global warming on glaciers. Nuclear techniques are related to a branch of hydrology known as isotope hydrology in which environmental isotopes are used to solve major problems related to various aspects of water including its origin, age, recharge mechanism and interconnection between different aquifers. The main advantage of isotopic technique is the use of various isotopes as a tracer. Being natural tracer, environmental stable isotopes (oxygen-18, deuterium ^{2}H, etc.) need not be introduced or injected in the system under investigation but they are a part of the hydrological system. Environmental stable isotopes are measured as ratio of most abundant isotopes of a given element to that of less abundant against some reference material. These ratios are measured on gas source mass spectrometers. Tritium, ^{3}H is a short lived radioactive isotope of hydrogen with half-life of 12.43 years and is measured by counting beta decay events in a liquid scintillation counter.

Stable isotopes mass spectrometry alongwith tritium dating has been used to determine the source of moisture and the age of ice and melt-water at Passu Glacier. Samples were collected from the stream originating from Passu Glacial Lake which receives melt generated from the seasonal snow cover and glacier melt. Highly depleted values of stable isotopes of hydrogen and oxygen in the samples and highly positive value of deuterium suggests that moisture source of precipitation is from Mediterranean. Tritium values in Passu stream samples from March to August were around 20TU (tritium units) that correspond to the mixing of major part of melt generated from the seasonal snow cover and little from the glacier's melt. In Passu stream samples high tritium concentrations up to 75TU were observed from September to November, the period after the seasonal snow cover has been completely melted. It shows contribution of pure glacier melt in the Passu Glacial Lake during this period. High tritium concentrations in stream flow samples correspond to 1963-64 open weapons testing peak, causing tritium concentration rise. The presence of high tritium concentration in the Passu stream samples is the most visible sign of glacier melt in the area and the impact of climate change on these glaciers.

Keywords: Nuclear techniques, Environmental isotopes, Mass spectrometers, Tritium dating, Glacier melt.

Introduction

The effects of climate change are being felt with impacts across many economic sectors but water sector will be one of the most adversely affected areas. Rising global temperatures may lead to an intensification of hydrological cycle, resulting in dryer seasons and wetter rainy seasons and subsequently high risks of more extreme and frequent floods and droughts. Changing climate may also has significant impacts on the quality and quantity of available water. Pakistan has one of the world's largest glaciers reserves in the Karakorum-Hindukush-Himalaya ranges. More than 65% of the fresh

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water resources originate in these ranges during summer and supply water to the Indus River System (IRS) (Ahmed et al., 2009). Seasonal snow pack is the main part of the annual runoff that takes place in connection with the Spring melt. Flow of the Indus River is dominated by melt-waters from the Tibetan ice field, snow fall and snowmelt from higher elevation of the watershed and from episodic monsoonal rains (http://www.eoearth.org/article/Indus_River).

Ground water reservoirs recover during snow and ice melt (ICIMOD, 2010). Climate change being influenced by greenhouse gases emission and corresponding temperature rise is causing net shrinkage and retreat of glaciers in recent years. According to an report of IPCC (2007), about impact of climate change in Asia suggests huge mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water availability and hydropower potential by changing seasonality of flows in regions supplied by melt-water from major mountain ranges. Wide spread glacier recession due to climate change has been observed during the last fifty years but an accelerated trend came since 1990 (Kundzewicz et al., 2007). Decline in glacier mass will result in increased river discharge and increased danger of flood events (Aizen et al., 1997; Kundzewicz et al., 2007). Rise in temperature registered during the first decade of 21st century has been two times higher than anticipated. According to World Meteorological Organization's (WMO, 2011) statement on status of climate, the first decade (2001-2010) is the warmest decade recorded over the globe and 2010 ranked as the warmest year (+0.53°C) followed by 2005 (+0.52°C) and 1998 (0.52°C). Sixteen warmest years of the globe occurred during the last two decades.

It has been observed that the average air temperature measured at 49 stations of the Himalayan region rose by 1°C with high elevation sites warming the most since mid-1970s.

Global warming is defined as the rising of average temperature of earth's atmosphere and oceans. Warming of the climate system is unequal and scientists are more than 90% certain that most of it is caused by increasing concentrations of greenhouse gases produced by human activities such as deforestation and the burning of fossil fuels. These findings are recognised by the national science academies of all major industrialised nations (Barnett et al., 2005).

A study conducted by Chaudhry et al. (2009) indicated that Pakistan experienced 0.76°C rise in temperature during last 40 years. However, the increase in temperature in the mountain environment hosting thousands of glaciers was recorded as 1.5°C during the same time period. For Pakistan, 0.6°C rise in temperature was projected during 2001-2010 but it ended up with 0.93°C and northern mountain climate heated upto the level of 1.3°C which hosts the glaciers of Himalayas-Karakoram-Hindukush mountain ranges.

The use of stable isotopic techniques alongwith tritium dating can be used to determine whether glacier mass is increasing, decreasing or stays constant. In the past, stable isotope contents (δ^2H and $\delta^{18}O$) of water have successfully been used as naturally occurring hydrologic tracers to estimate the contributions of different water sources to stream flow, including snowmelt, glacier meltwater, and groundwater base-flow (Behrens et al., 1971, 1978; Dinçer et al., 1970; Martinec et al., 1974; Rodhe, 1981; Hooper and Shoemaker, 1986; Obradovic and Sklash, 1986; Maulé and Stein, 1990).

Hydrological Background

Isotopic composition of various elements in the global water cycle is in a kind of natural order. Water evaporates from the sea. The marine vapours for a large part precipitates over the oceans and the rest of vapor mass is transported to higher latitudes and altitudes, where the vapours cool down and condense. A part of the vapours is brought to the continents where it precipitates and forms different modes of surface and groundwater. Compared to the waters of the ocean, the meteoric waters (i.e., the atmospheric moisture, the precipitation, ground and surface water) are mostly depleted in heavy isotopic species ^{18}O and ^{2}H. Main reason for depleted values of meteoric water is the Rayleigh rainout effect, operating on limited water (vapours) reservoir in the atmosphere (Gat and Mook, 2001). The average ocean composition is accepted as a reference standard for isotopes of hydrogen and oxygen so that δ_{VSMOW} = 0‰ by

definition (Craig, 1965). All $\delta^{18}O$ and $\delta^{2}H$ values of water are given relative to the VSMOW standard where δ is referred as the part-per-thousand (or per mil) deviation of the isotope ratio (heavy/light) of a sample from a standard reference material.

Thus, stable hydrogen and oxygen isotope ratios are expressed in per mil with respect to VSMOW in equations 1 and 2, respectively.

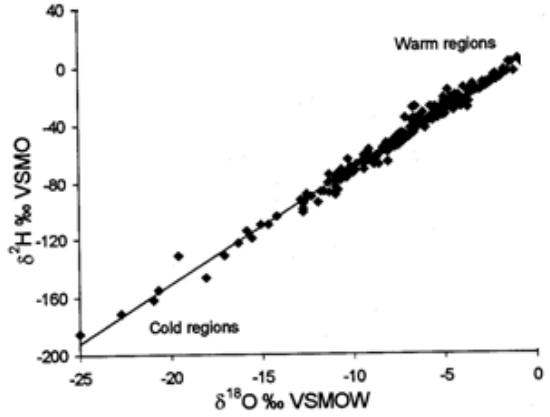
$$\delta^{2}H_{sample}‰ = \frac{^{2}H}{^{1}H}_{sample} \frac{^{2}H}{^{1}H}_{VSMOW} - 1\ 1000 \quad \ldots \quad 1$$

$$\delta^{18}O_{sample}‰ = \frac{^{18}O}{^{16}O}_{sample} \frac{^{18}O}{^{16}O}_{VSMOW} - 1\ 1000 \quad \ldots \quad 2$$

Global Meteoric Water Line (GMWL) and Deuterium Excess Parameter

The relation between $\delta^{2}H$ and $\delta^{18}O$ in precipitation is described by the Global Meteoric Water Line (GMWL) developed by Craig (1961) and expressed by the equation:

$\delta^{2}H = 8\ \delta^{18}O + 10$ permil.



This relation was developed as an average of many local water lines that differ from the GMWL as a result of climatic and geographic factors.

Differential fractionation of $\delta^{2}H$ and $\delta^{18}O$ occurs as a function of humidity during primary evaporation of water vapour from the ocean and also as a function of temperature during secondary evaporation as rain falls from a cloud. These two factors affect the slope and intercept (D-excess) of the Local Meteoric Water Line (LMWL) and produce a different LMWL at different locations.

The deuterium excess (D-excess) is mathematically defined by the equation 3, (Dansgaard, 1964):

$$d‰ = \delta^{2}H - 8 \cdot \delta^{18}O \quad \ldots \quad 3$$

where $\delta^{2}H$ and $\delta^{18}O$ are deuterium and oxygen-18 composition of water samples, respectively.

D-excess is a measure of the relative proportions of ^{18}O and ^{2}H contained in water and can be visually depicted as an index of deviation from the global meteoric water line (GMWL; d=10). While oxygen-18 ($\delta^{18}O$) and deuterium ($\delta^{2}H$) at moderate and high latitude continental areas are well correlated with the surface air temperature at precipitation site, the d-excess is correlated with the physical conditions (humidity, air temperature and sea surface temperature) of the oceanic source area of the precipitation (Merlivat and Jouzel, 1979). In addition, d-excess reflects the prevailing conditions during evolution and interaction or mixing of air masses *en route* to the precipitation site. Highly positive value of d-excess evolves due to differential fractionation of vapour mass shows that the source of moisture is from a faraway ocean. Similarly, small values of d-excess show that source of moisture is the ocean that is not far away from the precipitation place due to small differential fraction that occurs during moisture transportation. In Pakistan, normally there are two sources of moisture viz. Bay of Bengal and Mediterranean ocean, known as westerly winds. The isotopic index of both sources varies a lot from each other. Westerly winds travel a long distance during moisture transport. Therefore, moisture is more depleted from heavy isotopes which are being shed off from the vapour bank during journey. In comparison, moisture from Bay of Bengal travels smaller distance and moisture is less depleted from heavy isotopes. Thus, d-excess is an effective parameter for the determination of source of moisture.

Tritium ^{3}H is a short-lived isotope of hydrogen with half-life of 12.32 years. It decays in to ^{3}He by beta emission. It attracted

considerable interest during the era of thermo-nuclear bomb testing due to increased number of ^{3}T fallout from atmospheric weapons tests. It is used as a global tracer for studying dynamics of the hydrological cycle. Small amounts of tritium are produced naturally in the stratosphere by interaction of cosmic radiations on ^{14}N. Both natural and anthropogenic tritium enters the hydrological cycle via precipitation. Tritium concentrations are expressed as absolute concentrations, using tritium units (TU) so no reference standard is required. One TU corresponds to one ^{3}H atom per 10^{18} atoms of hydrogen.

Tritium dating is used to determine the age or residence time of water. The tritium data of snowmelt streams in the northern areas and long-term data of river Hunza at Danyore Bridge shows that average tritium value in fresh melt is around 20TU. Therefore, the residence time of water can be interpreted with this reference value. A value of tritium activity smaller than this reference value indicates mixing of fresh melt with old water. On the other hand, tritium activity more than the reference value of 20TU shows the presence of radioactivity in the water. The source of radioactivity in the past in this area might be high tritium content precipitation due to open atmospheric weapon testing during 1963-64. For close comparison, the precipitation data of Kabil from IAEA's GNIP (Global network of isotopes in precipitation) database is also used (http://www.iaea.org/water). There is good agreement of results between present and past tritium activity in this area.

Objective

This study explores the use of isotopic techniques to find the impact of global warming on the Himalayans glaciers and also explores the source of moisture causing precipitation in the region.

Study Area

Study area consisted of a part of Passu Glacier which lies in Hunza river basin some 15km from Gulmit, the Tehsil Headquarter of Gojal in the Gilgit-Baltistan region of Pakistan, about 150km upriver from Gilgit. Fig. 1 shows the map of Pakistan and location of Passu Glacier (enlarged part of the image) (Roohi, 2008). Fig. 2 shows the close view of Passu Glacier. Samples were collected from stream originating from Passu Lake. It is a glacial lake located at the terminus of 38km long east-west oriented Passu Glacier. Passu Lake receives water generated from the melting of seasonal snow cover and glacier melt. A stream is generated from the lake which later joins the River Hunza, a tributary of the River Indus.

Material and Method

Sample Collection & Analysis

Process of sample collection was performed with the help of Pakistan Meteorology Department (PMD). Samples were collected in leak-proof polyethylene bottles of one liter capacity and were analysed for stable isotopes of water molecule, i.e., oxygen-18, deuterium ($\delta^{18}O$, $\delta^{2}H$) and for radioactive isotope of water molecule, i.e., tritium.

$\delta^{18}O$ and $\delta^{2}H$ of water samples were determined relative to V-SMOW on mass spectrometers. The $\delta^{18}O$ of water was measured by the CO_2 equilibration method (Nehring et al., 1977). In this method, 5ml of sample water is introduced in a bottle and connected to manifold system. Vials were evacuated first and then equilibrated with carbon dioxide. The whole assembly was kept in a water bath in order to shake the bottles. After 24 hours of equilibration, isotopic signatures of water oxygen molecule swapped with oxygen molecule of carbon dioxide. This gas was analysed on mass spectrometer GD-150 with a precision of ±0.1‰.

Sample preparation for $\delta^{2}H$ is based on Zinc reduction method (Coleman et al., 1982). The process of reduction is carried out at 480°C. In this method, 8µl of water sample is reduced in the presence of 250mg of Analar Zn shots of mesh size 30 to 60 micron to produce hydrogen gas. This gas is analysed on mass spectrometer GD-150 with a measurement uncertainty of ±1.0‰ (Sajjad, 1989).

Tritium contents of the samples were determined by liquid scintillation counting after electrolytic enrichment (Florkowski, 1981). The standard error of measurement is of the order of ±1TU (Hussain and Asghar, 1982).

Samples collected from the Passu stream were in the form of meltwater. The lake water is frozen between December and March. Therefore,

melt samples during this period were unavailable. Weekly/fortnightly samples were collected from the stream from October 2010 till September 2011. The data of environmental isotopes alongwith d-excess in snowmelt stream samples are shown in Table 1.

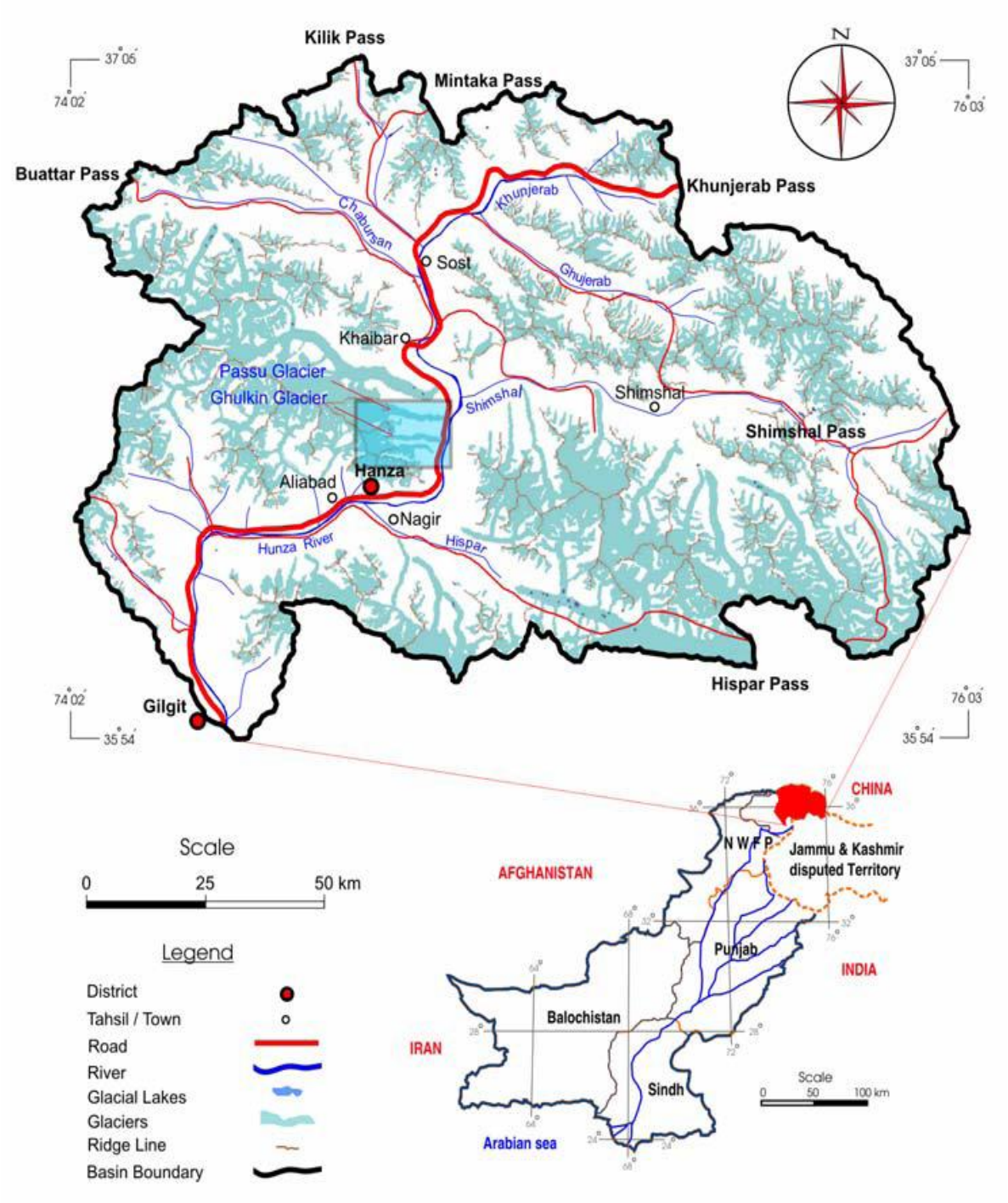


Fig.1. Location of Passu in the map of Pakistan

Fig. 2. Image of Passu Glacier from Google Earth

Table 1. Environmental isotopes data of samples from snowmelt stream

Sr. No	Date	$\delta^{18}O$ ‰	$\delta^{2}H$ ‰	d- excess	Tritium TU
1	29-10-2010	-15.14	-108.86	12.26	74.3± 3.6
2	06-11-2010	-15.04	-108.64	11.68	84.5± 4.2
3	13-11-2010	-15.37	-106.17	16.79	50± 2.3
4	20-11-2010	-15.32	-107.04	15.52	62.5± 3.2
5	27-11-2010	-15.4	-108.73	14.47	59.5± 3.2
6	04-12-2010	-15.37	-105.23	17.73	63.3±3.6
7	12-12-2010	-15.23	-104.99	16.85	94.1± 4.3
8	20-03-2011	-16.24	-109.15	20.77	93.5± 4.2
9	28-03-2011	-15.53	-108.35	15.89	18.0± 0.8
10	05-04-2011	-15.36	-105.46	17.42	23.5± 1.0
11	13-04-2011	-15.61	-108.11	16.77	73.8± 3.6
12	21-04-2011	-16.18	-108.56	20.88	10.2 ± 0.8
13	05-05-2011	-16.09	-105.2	23.52	21.2 ± 0.8
14	12-05-2011	-15.99	-106.24	21.68	17.4 ± 0.8
15	27-05-2011	-15.78	-106.92	19.32	16.3 ± 0.7
16	02-06-2011	-15.95	-105.75	21.85	16.4 ± 0.8
17	09-06-2011	-15.87	-107.62	19.34	17.9 ± 0.8
18	16-06-2011	-15.92	-107.49	19.87	17.4 ± 0.8
19	23-06-2011	-14.91	-100.76	18.52	15.0 ± 0.7
20	30-06-2011	-14.73	-98.75	19.09	NA
21	07-07-2011	-16.7	-110.75	22.85	NA
22	22-07-2011	-15.1	-100.73	20.07	17.6 ± 0.8
23	04-08-2011	-17.22	-119.71	18.05	NA
24	08-08-2011	-15.77	-104.33	21.83	19.2 ± 0.8
25	17-09-2011	-15.53	-109.57	14.67	18.3 ± 0.8
26	24-09-2011	-15.65	-106.27	18.93	17.4 ± 0.8

Results and Discussions

From long-term stable isotope data of water samples from River Hunza at Danyore Bridge (which is downstream at a distance of 40km from Passu glacier), the average value of $\delta^{18}O$ ‰ and $\delta^{2}H$ ‰ is -13.17 and -93.39, respectively. The average value of $\delta^{18}O$ ‰ and $\delta^{2}H$ ‰ of stream flow samples at Passu is -15.65 and -106.90, respectively. The snowmelt stream at Passu also joins the River Hunza but difference in their values is due to altitude effect. During the course of flow, the River Hunza is joined by many snowmelt streams at different altitudes making isotopic signatures of the River Hunza different at different locations. By comparing the elevation of these two locations, an altitude effect of -0.07‰ has been observed.

The d-excess values of snowmelt stream at Passu vary from 11.68‰ to 23.52‰ with an average value of 18.33‰. In those regions, where strong deuterium excesses are observed, the following Eastern Meteoric water line (EMWL) developed for the precipitation in the Eastern Mediterranean is used:

$\delta^{2}H = -8 \cdot \delta^{18}O+22$ ‰ (Gat and Carmi, 1970).

Highly positive value of d-excess in this study shows very high differential fractionation of $\delta^{2}H$ and $\delta^{18}O$ as a function of humidity during primary evaporation of water vapour from the ocean and as a function of displacement from the moisture source during transport. It shows that the source of moisture is from Mediterranean ocean and has been generated under 73% humidity. Due to differential fractionation over a long route of vapour transport d-excess has evolved as highly positive. Therefore, from highly positive value of d-excess and its close value to EMWL, it can be concluded that source of moisture for precipitation over Passu Glacier has originated from the Mediterranean Sea. The Passu Lake does not show any major contribution from Moon Soon rains which mainly originates from the Bay of Bengal or Arabian Sea, having enriched values of $\delta^{18}O$‰ and $\delta^{2}H$ with small value of d-excess. Fig. 3 shows the plot of stable isotope data of snow melt stream at Passu and displays the local meteoric water line (LMWL) and global meteoric water line (GMWL). Local meteoric line has y-intercept at 18 and global meteoric water line has y-intercept at 10. Most of the stable isotopic data lies on the LMWL well above the GMWL.

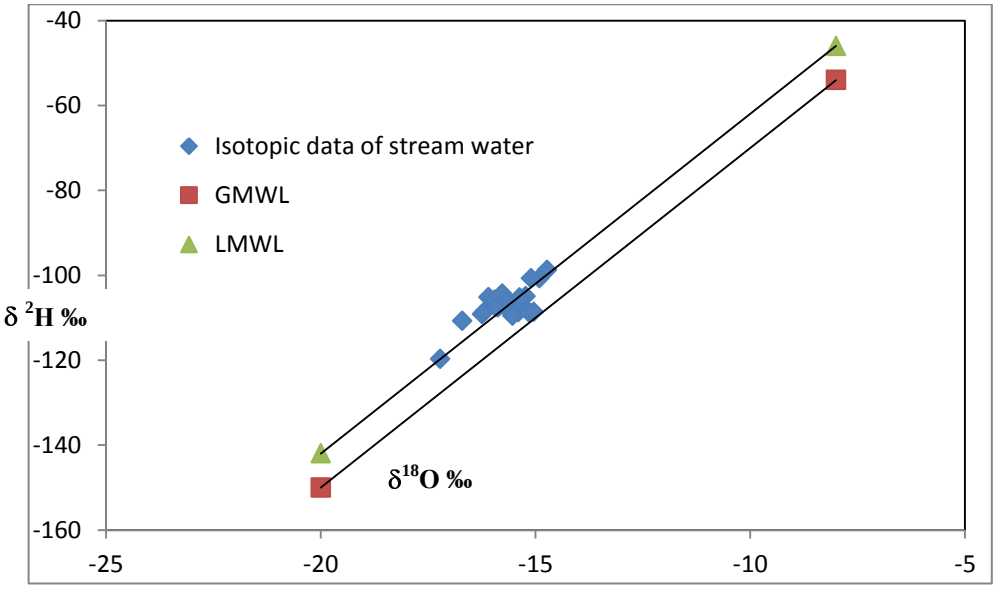


Fig. 3. Plot of stable isotope data of snowmelt stream at Passu

Tritium data of snowmelt stream is also shown in Table 1. Tritium values in snowmelt stream generated from Passu Glacial Lake from April to August were around 20TU which corresponds to the mixing of melt generated from the seasonal snow cover and glacier melt. In

stream samples, high tritium concentrations upto 94TU were observed from September to December, the period after the seasonal snow cover has been completely melted. The high tritium content during this period shows some contribution of 1963-64 tritium peaks due to testing of nuclear devices in open atmosphere and causing tritium concentration to rise manifold. For comparison, the tritium data of precipitation at Kabul during 1963-64 from GNIP database of International Atomic Energy Agency, which is the closest point to present location (Passu), is given in Table 2. Data plot of tritium in stream flow samples at Passu is shown in Fig. 3. Present results show the melting of snow cover generated during 1963-64 when tritium concentration in the precipitation was raised manifolds.

Table 2. Tritium Data of Kabul from GNIP (IAEA)

Date	Tritum (TU)
15-3-1963	**4073**
15-4-1963	**3420**
15-5-1963	**3330**
30-4-1964	**3405**
30-5-1964	**3345**

Considering the average tritium concentration in precipitation during 1963-64 around 3500TU and using the basic formula for radioactive decay $N_t = N_0 e^{-\lambda t}$, where N_0 is tritium counts at zero time and N_t is tritium counts at time *t*, lapsed between N_0 and N_t. One can expect tritium values as large as 200TU after four half-lives considering pure glacier melt. The maximum value of tritium observed in the stream flow is 94.1 ± 4.1TU, while the variation range over all is 15 to 94TU. The concentration of tritium is less than the expected value of 200TU (pure glacier melt), which confirms the mixing of glacier melt with fresh melt in varying proportions. From this data, it is concluded that the 1963-64 precipitation (rich in tritium) in the form of hard snow is still preserved at Passu Glacier. Tritium data also confirms the melting of glacier. The presence of high tritium concentration in the stream flow generated from Passu Glacial Lake and rising temperature situation in Karakorum-Hindukush area is the most visible sign of glacier melt due to global warming (see Table 4).

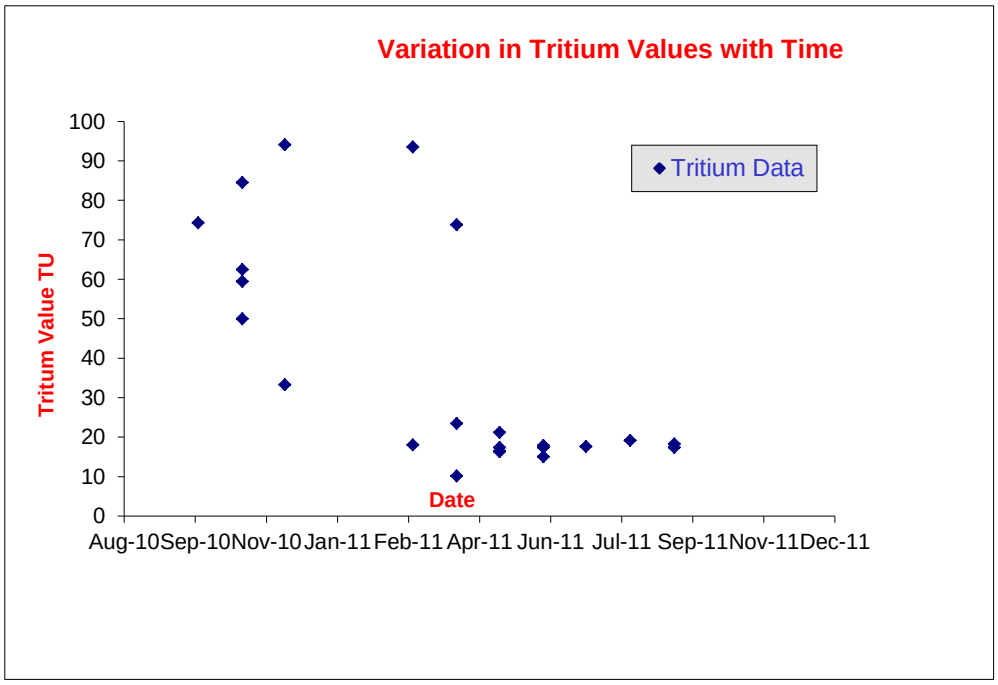


Fig.4. Data plot of tritium in samples of stream flow at Passu Glacier

Conclusion

- Source of moisture producing precipitation at Passu Glacier is from Mediterranean as confirmed by d-excess parameter.
- Presence of high tritium concentration in the stream flow after seasonal snow cover has been melted completely indicates the melting of glacier.

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