Comparison of Isotopic Composition of Atmospheric Moisture within and outside of Himalaya-An Implication in studying Monsoon Dynamics

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ABSTRACT
Air moisture samples were collected daily during May, 2012 to November, 2012 at Marhi-Mini Hydro-Electricity Project, Marhi, Manali, Himachal Pradesh and National Institute of Hydrology, Roorkee, Uttarakhand using condensation method for studying monsoon, pre-monsoon and post monsoon variations in isotopic composition. The isotopic composition (δD) was found to be more enriched in the samples collected from Himalayan region due to the contribution from local source i.e., moisture generated due to sublimation process in glaciated areas. However, it starts getting depleted in the monsoon season due to the arrival of oceanic vapours subjected to continental and altitude effects. The isotopic composition of water vapours shows a good correlation in time domain, inferring clearly monsoon signals, and opens up the possibility to use isotopic composition of air moisture for monsoon studies. The isotopic composition of vapours associated with monsoon is always depleted in comparison to non-monsoon vapours due to different sources of origin and various other factors therefore, isotopes can be used to track the movement of monsoon vapours and prediction of seasonal rainfall.

1. INTRODUCTION

The monsoon, one of the most dramatic climates on the planet, is characterized by a variety of physical mechanisms that produce strong seasonal winds, a wet summer and dry winter. The wet summer/summer monsoon rainfall over the Indian subcontinent shows a large inter-annual variability in three important aspects, namely, the onset date, quantum of monsoon rainfall and its activity within the monsoon (June-September) period.

The Indian summer monsoon, also known as the southwest monsoon, is an important component of the tropical climate system, known for its regular seasonality and abundance of rainfall accounting for 75% of the annual rainfall over most parts of the country. The droughts and floods in various parts of the country associated with the year-to-year variation of the average seasonal rainfall have devastating effect on people, agriculture and economy of the region. Therefore, there is a great need and demand for seasonal monsoon rainfall forecasts in different time scales.

The heavy stable isotopes of oxygen and hydrogen, (^{18}O and ^{2}H), are particularly useful tracers of climatological and hydrological processes because of the systematic mass-dependant partitioning of the three isotopomers $^{1}H^{1}H^{16}O$, $^{1}H^{2}H^{16}O$ and $^{1}H^{1}H^{18}O$ among solid, liquid and gaseous phases as water passes through the hydrological cycle. Variations in the relative abundances of these isotopomers, measured as $^{18}O/^{16}O$ and $^{2}H/^{1}H$ ratios and expressed conventionally as $\delta^{18}O$ and $\delta^{2}H$ values often provide characteristic labelling of a water molecule for studies ranging from tracing of the origin and distillation history of atmospheric moisture parcels to the analysis of runoff generation.

The isotopic composition of precipitation provides a conservative tracer for the origin, phase transitions, and transport paths of water. Variations in $^{18}O/^{16}O$ and $^{2}H/^{1}H$ ratios of meteoric precipitation are dominantly controlled by atmospheric parameters such as temperature, relative humidity, and evaporation and by geographic factors such as altitude, latitude, moisture source, and transport process.

The monsoon is a large scale wind circulation phenomenon that brings large amount of moisture on the Indian sub-continent during the period mid June to September. Earlier studies on monsoon dynamics mainly dealt with deviation of total precipitation from the normal, spatial variability in precipitation, extreme events and timing of onset of monsoon (Ajayamohan and Goswami, 2003; Gadgil and Sajani, 1998; Shukla, 1987). Most of these studies relied on conventional meteorological parameters such as temperature (Continental and sea surface), relative humidity, wind speed, wind direction, cloud pattern etc. However, sufficient accuracy in onset of monsoon, its dynamics on the continent and the timing of its withdrawal is not well understood. The complexity of the phenomenon is due to link between mixing of sub-regional moisture with continental scale moisture arising directly from Arabian Sea and/or Bay of Bengal and/or Indian Ocean.

Atmospheric water vapours play a key role in the precipitation events. Therefore, the isotopic composition of atmospheric water vapours has a direct effect upon that of precipitation. The isotopic composition of local precipitation is primarily controlled by regional scale processes like the trajectories of the water vapour transport over the continents and the average rainout history of the air masses giving precipitation at a particular place. Observation of stable isotope variation of atmospheric water vapour has an important significance to indicate the moisture origins and moisture transport. But the main factor controlling stable isotope variation of atmospheric water vapour might be different in different regions. Using the isotopic signatures of water molecules, it is possible to track the movement of air moisture. This is due to fact that with the onward movement of the air moisture heavy isotopes get systematically depleted (Krishan et al., 2012a) and the recycling of moisture due to condensation and subsequent evaporation cause a difference in relative enrichment in deuterium and oxygen isotopic composition. A few case studies on this philosophy were examined in coastal China (Xue-Fa et al, 2010; Liu et al, 2007).

In India, monsoon winds travels more than 2000 km from east coast to Northwest Himalayas before finally escaping into Pir Panjal. Indo-gangetic plain covers major part of this section and precipitation on this belt caters water requirement for about 40 million people. The movement of monsoon front on the isotope composition of precipitation was investigated by the Datta et al. (1991), Bhattacharya et al. (2003) and Peng et al. (2005). These studies although characterized isotopes in precipitation but, did not provide any details on isotopes in air moisture. Since, precipitation occurs only in few events and that too mainly during monsoon; the results of these works could not be used for modelling and prediction.

Using the isotopic signatures of atmospheric moisture, besides identifying the air moisture sources at Roorkee (Krishan et al., 2012b), the use of isotopic composition of air moisture for studying the climatological conditions (Krishan et al., 2012c) is also indicated. A very good correlation has been found between Roorkee and Hyderabad (Rao et al., 2012), Roorkee & Sagar (Krishan et al., 2012d) and Roorkee & Jammu (Krishan et al., 2012e).

In the present study, an effort has been made for the first time to examine change in isotopic composition of atmospheric moisture at two stations, one located in Himalayas (Manali) and other in the Indo-gangetic plain (Roorkee) in order to understand isotopic variability and its link with monsoon dynamics in the region.

2. STUDY AREA

The sampling station Roorkee is located in the foot hills of Siwaliks in the north western part of the Indo-Gangetic plains falling under the latitude $29^{0}52'$, longitude $77^{0}53'$ and altitude 268m whereas, Marhi, Manali is located in the mountains of the Indian state of Himachal Pradesh falling under the latitude $32^{0}19'$, longitude $77^{0}10'$ and altitude 3000m (Fig. 1). The normal rainfall of Roorkee and Manali is 1156.4 mm and 1363.8 mm per annum, respectively. Out of the total annual rainfall 86% at Roorkee and 52% at Manali is recorded during southwest monsoon period (June to September). Snowfall in the Manali region, which usually took place in the month of December, has been delayed over the last fifteen years to January or early February. Due to the heavy snow no sampling is possible from December to April at Manali. The monthly average maximum temperatures of Roorkee and Manali is recorded in the range of 20.4°C and 10.6°C (January)-39.2°C (May) and 27.2°C (July), respectively, while the monthly average minimum temperature in the range of 6.1°C and -1.7°C (January) to 24.9°C and 15.3°C (July) for Roorkee and Manali, respectively. There is a difference of approximately 10^{o}C in average temperature in Roorkee and Manali. The normal monsoon onset date for Roorkee and Manali is around 25th June, while the normal monsoon withdrawal date for Roorkee and Manali is around 26th September.

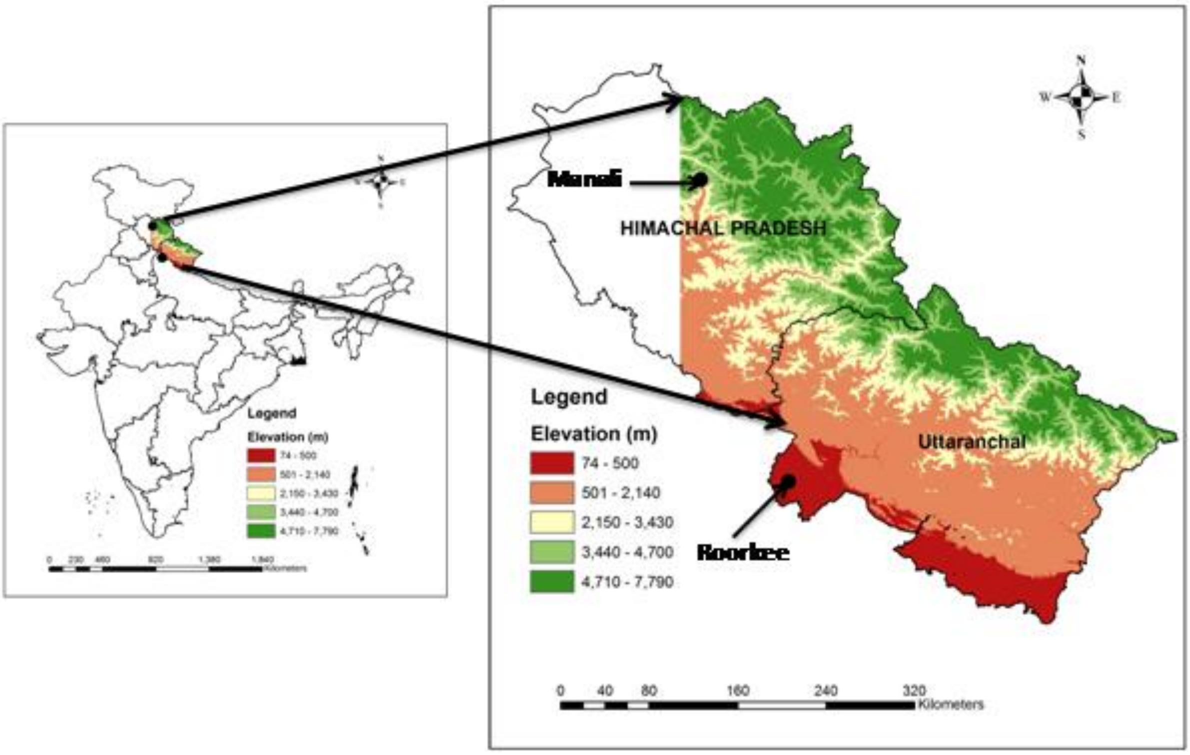

Fig. 1 Study area

2. METHODOLOGY

The air moisture samples, for isotopic analyses, are collected on daily basis by condensation method (Krishan *et al* 2011). Depending on prevalent relative humidity, it takes 30 minutes to 60 minutes for collecting 5 to 10 ml of liquid condensate. However, during the rainy season when relative humidity becomes very high, the sampling bottle (10 ml) is filled-up even within 30 minutes. After setting up the conical condensation device, the date, time, temperature and relative humidity are recorded using thermo-hygrometer (Krishan *et al* 2011).

Stable isotopes (^{2}H or D) in water were analysed using GV-Isoprime Dual Inlet Isotope Ratio Mass Spectrometer. 400 μl of the water sample is equilibrated with H_2 along with Pt catalyst at 40°C for 3 hrs. and the gas is introduced into the mass spectrometer. The measured values are reported as delta (δ) values (Coplan 1996). The precision of measurement for δ ^{2}H is ± 1‰.

3. RESULTS & DISCUSSION

The ambient temperatures during the sampling period at Roorkee and Manali ranged from 17.55^{o}C to 37.35^{o}C with an average of 28.76^{o}C and 1^{o}C to 25.80^{o}C with an average of 16.93^{o}C, respectively (Fig. 2), while the ambient relative humidity at Roorkee and Manali ranged from 20 % to 100% with an average of 60.8% and 20.5 % to 95.5% with an average of 48.72%, respectively (Fig. 2).

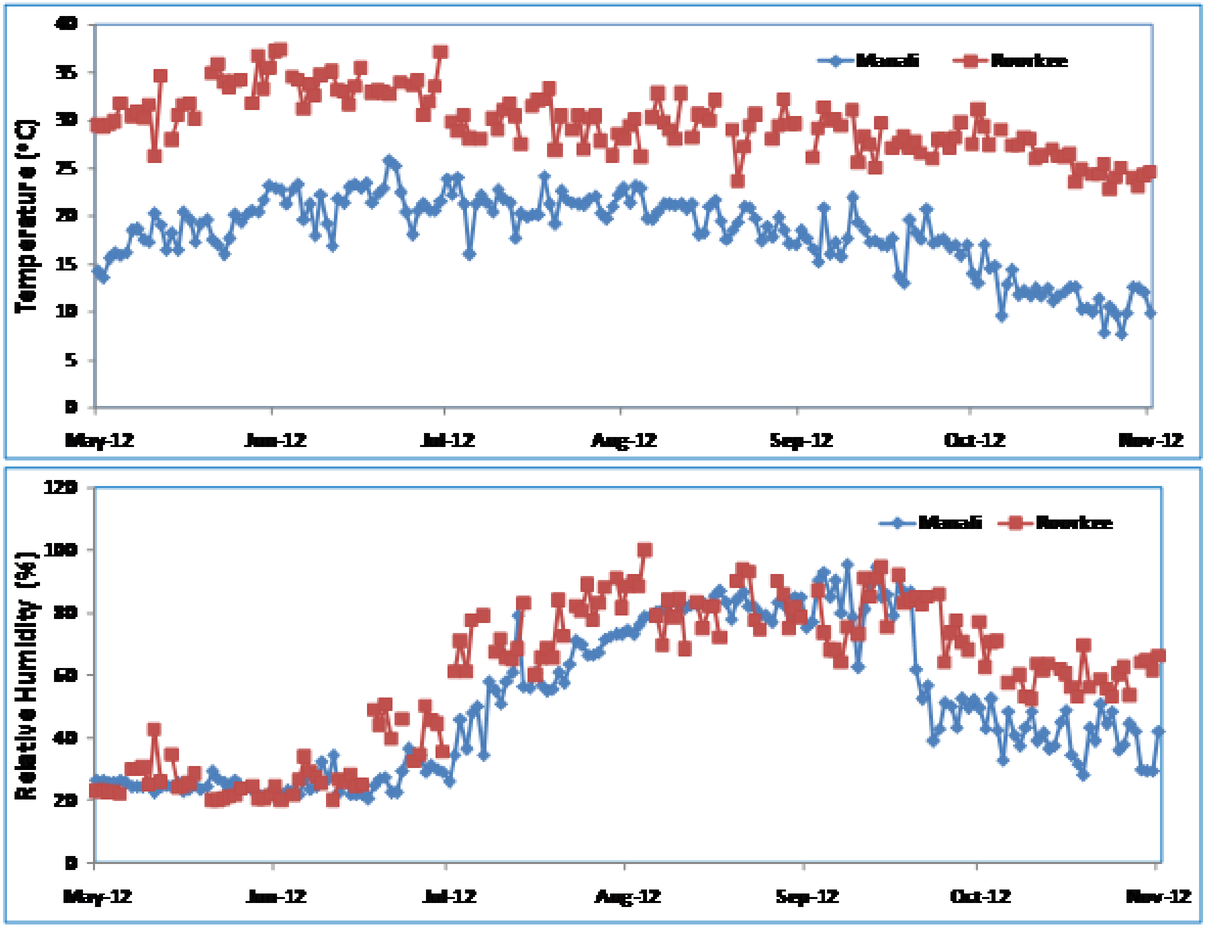

Fig. 2 Variation in temperature and relative humidity at Roorkee and Manali

Table 1: Seasonal variation on Meteorological parameters and isotopic at Roorkee and Manali (May, 2012 to November, 2012)

Season	Average Temperature (°C)		Average Relative humidity (%)		Average Vapour Pressure (Kpa)		Average Absolute Humidity (g/m³)		δD (‰)	
	Roorkee	Manali	Roorkee	Manali	Roorkee	Manali	Roorkee	Manali	Roorkee	Manali
Pre-monsoon (May-Jun)	32.79	19.89	28.97	25.57	1.44	0.60	10.17	4.41	-55.12	-4.87
Monsoon (Jul-Sep)	29.06	19.55	78.67	70.33	3.14	1.60	22.53	11.80	-107.03	-96.72
Post-monsoon (Oct-Nov)	23.95	9.93	63.00	38.39	1.89	0.48	13.76	3.69	-62.94	-68.84

As evident from the table 1, all the meteorological parameters (temperature, relative humidity, vapour pressure and absolute humidity) at Manali have lower values than that of Roorkee due to prevailing metrological conditions at higher altitude in Himalaya. In case of average ambient temperature, there is a 50% decline in pre-monsoon season as compared to post-monsoon season at Manali, while at Roorkee the decline is about 27%. But the average ambient relative humidity increases by 173% during monsoon season and 54% during post-monsoon season at Roorkee as compared to Pre-monsoon season, while at Manali there is an increase of 175% and 33% in monsoon season and post-monsoon season, respectively. The ambient temperature at both the stations shows a declining trend from pre-monsoon to post-monsoon season, while in case of ambient relative humidity, an increase is observed in monsoon season due to the increased moisture flux caused due to onset of southwest monsoon. With the withdrawal of monsoon the ambient relative humidity decreased at both the stations. This trend of the ambient average temperature and relative humidity putting an impact on the vapour pressure and absolute humidity as both these parameters showed an increase by 118% & 102%, respectively in monsoon season and 24% and 26%, respectively in the post-monsoon period compared to pre-monsoon period at Roorkee, while at Manali both these parameters show increase of 167% & 168%, respectively, in monsoon season however, a decrease of 25% & 20%, respectively is found in post-monsoon period compared to pre-monsoon period which is due to the decrease in ambient temperature.

In case of isotopic composition (δD) of atmospheric moisture, the values range from -6.30‰ to -166.03‰ with an average of -86.86‰ at Roorkee, while at Manali these range from 37.07‰ to -166.62‰ with an average of -74.57‰ (Fig. 3). At Roorkee, a depletion of 94% & 14%, respectively in isotopic composition of atmospheric moisture during monsoon season & post-monsoon seasons as compared to pret-monsoon were found. At Manali, a depletion of 1886% & 1314%, respectively in isotopic composition of atmospheric moisture during monsoon season & post-monsoon seasons as compared to pre-monsoon were found (Table 1). The enriched δD values of air moisture at Manali as compared to Roorkee during premonsoon season are mostly due to increased local contribution of δD into to atmosphere at Manali through evaporation/sublimation process taking place at low temperature which prevails at higher altitudes.

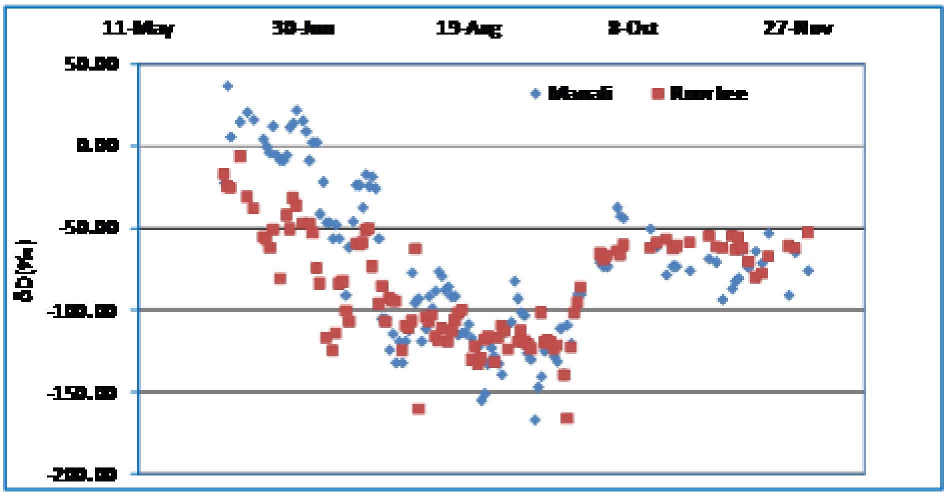

Fig. 2 Variation in isotopic composition (δD) of atmospheric moisture at Roorkee and Manali

The percent depletion in the isotopic composition (δD) of air moisture was found more at Manali than at Roorkee during the monsoon & post-monsoon period due to the contribution of oceanic monsoon vapours at Manali subjected more to continental and altitude effects than the oceanic monsoon vapours at Roorkee. This effect is also continued in the post-monsoon season also.

4. CONCLUSION

The isotopic composition (δD) was found to be more enriched in atmospheric moisture samples collected during pre-monsoon period from Himalayan region due to the contribution moisture from the local sources i.e., moisture generated due to evaporation/sublimation process in glaciated areas. However, it starts getting depleted in the monsoon season due to arrival of oceanic vapours subjected to continental and altitude effects. The isotopic composition of water vapours shows a good correlation in time domain, inferring clearly monsoon signals and opens up the possibility to use isotopic signature of atmospheric moisture for monsoon studies. The isotopic composition of vapours associated with monsoon is always depleted in comparison to non-monsoon vapours due to different sources of origins and various other factors; therefore, isotopes can be used to track the movement of monsoon vapours and prediction of seasonal rainfall.

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