Botanic Garden and Research Institute (JNTBGRI), Thiruvananthapuram, where research work has been undertaken on this species[16,17]. Therefore, the minimum number of germplasm under cultivation poses a great threat to the species. The farmers who are currently cultivating the species are aged and may give up the cultivation anytime. The younger generation of farmers are not interested in cultivating this species in the two regions. Realizing the economic and conservation significance of the species, the National Medicinal Plants Board (NMPB), Government of India, has identified and prioritized the species as one of the 32 medicinal plant species for its overall development and conservation under promotional and commercial scheme. The efforts of JNTBGRI in developing agrotechnology package for this species are noteworthy[16,17]. However, new techniques need to be developed to ease the cultivation and harvesting of the delicate, thin fibrous roots. The potentiality of the root of the species also needs to be scientifically evaluated for commercial utilization, which will encourage more farmers to take up the cultivation and thus, the species will be conserved. Despite the efforts of NMPB and other agencies, the species is still under peril. Therefore, further conservation efforts and promotion of its cultivation are urgently needed to save the species from extinction.

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Possibility of using isotopic composition of ground-level vapour for monitoring arrival and withdrawl of southwest monsoon

Stable isotopes of oxygen and hydrogen have long been used to trace the hydrological processes[1] on the principle that the lighter isotopes of water (e.g. H_2O) preferentially evaporate over its heavier isotopes (e.g. HDO or $H_2{}^{18}O$), and the heavier isotopes preferentially condense[2]. In this line, several studies[3–5] were carried out all over the world to characterize the local meteoric lines for generalizing the amalgamation of various hydrological processes taking place over multiple temporal and spatial scales. These studies may be able to provide us the precise analysis of a synoptic event due to the dependence on many physical and atmospheric processes[6]. Isotopic composition of moisture depends upon many processes like transportation, condensation, precipitation and re-evaporation of moisture. The composition of the vapour-plus-condensed water additionally depends on microphysical processes that determine the fraction of condensed water that is converted to precipitation. The isotopic composition of the precipitation at any vertical level depends on the composition of the water falling from above on the fraction of the precipitation that is re-evaporated in unsaturated air, and on isotopic exchanges that take place between the falling drops and the vapour surrounding them. The influence of convection on the water isotopic composition therefore depends on a combination of physical, microphysical and turbulent processes occurring within the clouds. Many modelling studies like general circulation model (GCM), Lagrangian trajectory models, and single-column model (SCM) have been used to analyse the processes that control the distribution of isotopes in a particular climatic condition. Therefore, the study of isotopic composition of water vapour may be useful for understanding such mechanisms and the southwest (SW) monsoon is one of them.

The SW monsoon brings large amount of moisture to the Indian sub-continent during the period mid-June to September. Earlier studies on monsoon dynamics[7–9] mainly relied on conventional meteorological parameters such as temperature, relative humidity, wind speed, wind direction, cloud pattern, etc. However, sufficient accuracy in the onset of monsoon, its dynamics on the continent and the timing of its withdrawal are not well understood. The complexity of the phenomenon is due to the link between mixing of sub-regional moisture and continental scale moisture arising directly from the Arabian Sea and/or Bay of Bengal and/or Indian Ocean. Due to systematic depletion of atmospheric moisture and its recycling because of condensation and evaporation, it is possible to track the movement of air moisture. Therefore, monitoring of isotopic composition of ground-level vapour (GLV) is an important research component[10] and the studies have been being carried out at limited stations from northern hemispheric mid-latitude regions[11–15].

The National Institute of Hydrology (NIH), Roorkee, has been monitoring the onset and withdrawal of the SW monsoon since 2007 using the isotopic composition (δD) of GLV at Roorkee. The samples were collected at Roorkee (lat. 29°52′, long. 77°53′ and altitude 268 m). The normal rainfall of Roorkee is 1156.4 mm, out of which 84% is recorded during June to September. The normal monsoon onset and withdrawal dates are 25 June and 26 September respectively. The monthly average maximum temperature of Roorkee is recorded in the range of 20.4°C (January)–39.2°C (May), while the monthly average minimum temperature is in the range 6.1°C (January)–24.9°C (July). The average relative humidity is 78%.

GLV was collected using condensation method[16] for the period 2007–2013 at Roorkee. The air moisture samples for isotopic analyses were collected on daily basis (one sample per day) from 9.30 to 10.00 am. The time-period is preferred because: (i) the relative humidity is usually higher compared to that in the afternoon. The higher the humidity, the greater will be the volume of liquid condensate collected at a given time; (ii) the temperature around this time is comparatively lower, and therefore, condensation is more and evaporation from the collected liquid is less and (iii) the melting of ice cubes in the aluminum cone is minimal and therefore, condensing efficiency of the cone does not change drastically over an hour or so of the sampling period. The location of the sampling was kept fixed for the entire study period. The condensation device was kept in a Stevenson screen at a height of 1 m from the ground level. Temperature and relative humidity were also recorded for this period.

The GLV samples were analysed for stable isotope (δD) in water using GV-isoprime dual Inlet isotope ratio mass spectrometer at the Nuclear Hydrology Laboratory of NIH. For δD analysis, 400 μl of the water sample was equilibrated with H_2 along with Pt catalyst at 40°C for 3 h and the equilibrated gas was introduced into the mass spectrometer. The measured values were reported as delta (δ) values[17]. The precision of measurement for δ^2H was within ± 1‰.

After isotopic analysis, it was found that GLV received during the SW monsoon period was always depleted compared to that received during non-monsoon period (Figure 1). The extent of depletion in isotopic composition of GLV and the period over this depletion

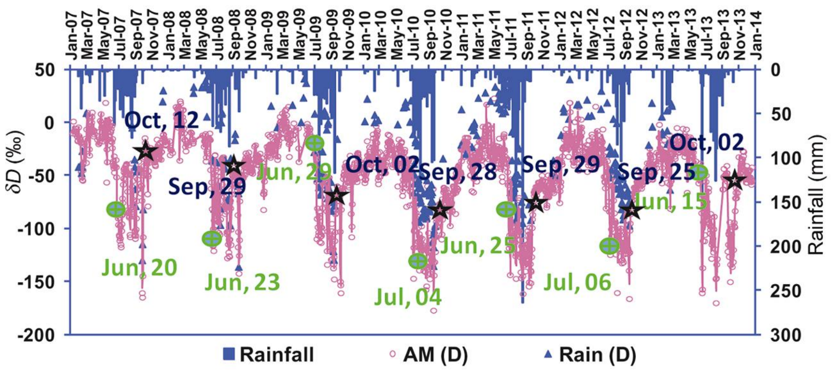

Figure 1. Variation in isotopic composition (δD) of ground-level vapour and rainfall during 2007–2013 at Roorkee.

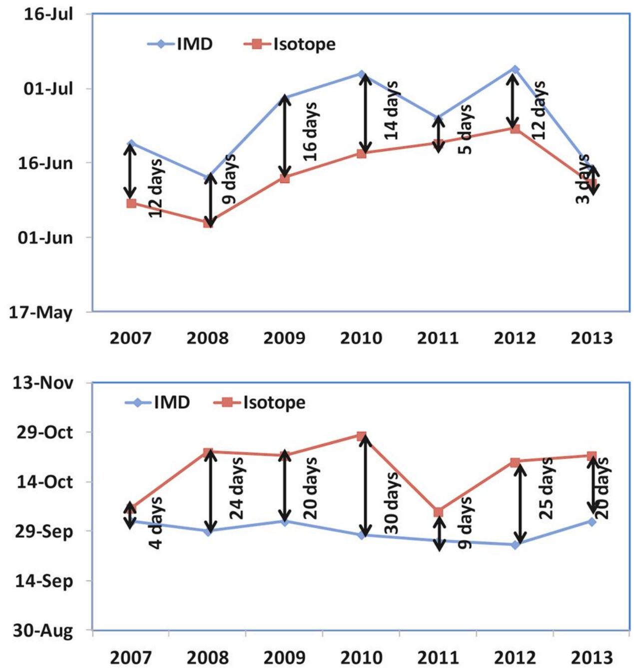

Figure 2. Dates of southwest monsoon arrival and withdrawal during 2007–2013 at Roorkee.

continues may be directly linked with monsoon strength (intensity, episodes and duration), showing a possibility of using isotopes to monitor movement of monsoon vapours.

During monsoon season (June–September), over the Indo-Gangetic Plains, moist winds blow in the SW direction. The change in wind pattern occurs from winter to the onset of monsoon during which the Himalayan winds blow over the Indo-Gangetic Plains in the northeast direction. The changing wind direction is expected to affect isotopic composition of moisture, temperature and absolute humidity.

The important observation from this study is that the isotopic composition (δD) of GLV depletes suddenly and persistently almost 3–16 days before the first monsoon rainfall (Figure 2) and there is uncertainty of half a month in monitoring the monsoon. This observation indicates that the new vapour sources arrive before the onset of monsoon and opens up the possibility of using isotopic composition of GLV as a tracer of these vapour sources that contribute to monsoon rainfall[10]. These vapours remain in the atmosphere even after the stopping of rainfall for 4–30 days (Figures 1 and 2), which is clearly visible in the difference in the dates of onset and withdrawal of the SW monsoon with the depletion and enrichment in the isotopic composition of GLV (Figure 1).

The applications of isotopic analysis of GLV in hydrology for identifying the source of air moisture, studying the monsoon dynamics and climatic conditions have already been established[18–24]. In this study the inter-annual variations with the isotopic composition of air moisture and change in the isotopic composition of air moisture are also seen during different months of the year.

It has been found that the δD values generally range from –10‰ to –20‰ before the arrival of the SW monsoon. The δD values start depleting with the onset of the monsoon and go down to –140‰ to –160‰ during August and September. The δD values start enriching from the end of September to November and reach up to –40‰ to –50‰ by the end of December and again enrich up to –10‰ to –20‰ in May and June. The same trend was observed during 2007–2013.

The present experiments are being conducted for analysing the spatio-temporal variation of isotope values in the ground-level atmospheric moisture and its relation to monsoon. The present study focuses on time-spectrum analysis making no specific assumptions to project the use of isotopic analysis of air moisture in atmospheric correlation. Although the isotopic composition is area-specific, but as the changes in the regional weather in one part of the country may affect moisture flow in other parts, the relative and dependent effects may be observable through micro investigations, as provided in the present study.

In future, adding this parameter to modelling studies may help improve weather prediction. The associated isotopic values with the moisture cannot be calculated or estimated directly from meteorological parameters, as they depend on both meteorological parameters and their source of origin. At this juncture, we do not claim here that isotopes are superior to other meteorological parameters, but only provide them as a new parameter in weather prediction, monsoon studies or climate change phenomenon.

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