STUDY OF CLIMATOLOGICAL CONDITIONS USING ISOTOPIC SIGNATURE OF AIR MOISTURE AT ROORKEE, UTTARAKHAND, INDIA

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ABSTRACT

In the present study, an attempt has been made to correlate the isotopic composition of the air moisture samples collected on daily basis by condensation method over a period of five years (2007-11) with the meteorological parameters. The trend of stable isotopic composition of air moisture for the past 5 years indicates a systematic depletion in isotopic average while the maximum depleted value of air moisture has been found almost same in all the five years which indicates the changing climatological conditions at Roorkee i.e. increased arrival .of oceanic vapours with time. This is a very important phenomenon and need to be understood fully. The isotopic composition of air moisture for the monsoons over a period from 2007 to 2011 shows a systematic depleting trend with an overall depletion by approximately 33‰ for $\delta^{18}O$ and 60‰ for $\delta^{2}H$ in 5 years. This systematic trend of change in stable isotopic composition indicates towards the change in climatological conditions at Roorkee in recent years which is also seen in other meteorological data. Further, investigations are in progress in this aspect which can contribute to improve the understanding of the isotope-hydrometeorology of India as well as to consider the stable isotopic signatures of air moisture and precipitation as one of the important meteorological parameters because other meteorological parameters only show the change in weather conditions while isotopic signatures also indicate the cause and source.

1.0 INTRODUCTION

Atmospheric water vapour is an important component of the Earth's hydrological cycle and its climate system because of its control on freshwater availability and heat & radiation budget. Water vapour is also an important greenhouse gas with a positive feedback to global warming. As global temperature rises, the amount of water vapour in the atmosphere may be expected to increase due to increased global evaporation. Therefore, atmospheric water vapour is being studied by hydrologists, meteorologists and climatologists with equal curiosity to more clearly understand how the changing water distribution across the Earth is affecting the climate.

Air moisture plays a crucial role in the water & heat budgets of the atmosphere and due to short residence time of water in atmosphere than to the mixing times in the atmosphere results in large variability in the amount of water in the lower atmosphere in both space and time. The actual amount of water vapour in the air depends on degree of heat (temperature) and dryness (relative humidity) of the area. Although, this water is usually invisible vapour but can be seen when air rises and cools, some of the water vapour turns into drops of liquids, forming the clouds, mist and haze that continually surround the Earth through the process of condensation. The moisture in the form of invisible vapour reaches in the atmosphere through evaporation from various water sources. For identifying the sources and their temporal evolution in response to changes in meteorological and geographical controls and their spatial distributions require tools that can trace water molecules through their annual hydrological cycle [1, 2] can be done through studies of stable isotopic composition of oxygen and hydrogen ($\delta^{18}O$ and $\delta^{2}H$) in the air moisture.

The heavy stable isotopes of oxygen and hydrogen, (^{18}O and ^{2}H), are particularly useful tracers of climatological and hydrological processes because of 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 hydrologic 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 labeling 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.

Application of oxygen and hydrogen isotope ratios for tracing the hydrological cycle is based on simple principle that lighter isotopologues of H_2O preferentially evaporate whereas heavier isotopologues preferentially condense, resulting in characteristic isotopic composition in terms of abundance ratio of heavy to light isotopes ($R = {}^{18}O/{}^{16}O$ or $D/{}^{1}H$) expressed as δ in per mil (‰) units with reference to international standard [$\delta^{18}O$ or δD = $(R_{sample}/R_{standard} - 1) \times 1000$]. Since vapours and rains have associated features, therefore a proportionate change is expected in their isotopic composition whenever source of their origin changes. The advantage of monitoring vapour over rain is due to its all-time availability in space. Considering this aspect, in the present study, isotopic analyses are carried out on the air moisture rather than on the conventional precipitation samples.

For isotopic analyses condensed air moisture samples are collected [3] and the isotopic composition of air moisture are related to weather parameters such as temperature, humidity, rainfall during the moisture sampling period. Stable Isotope Mass Ratio Spectrometers (IRMS) are normally used to measure the ratio of heavier to lighter atom of an element such as ${}^{18}O/{}^{16}O$ or ${}^{2}H/{}^{1}H$ which then represented as delta values of ${}^{18}O$ and ${}^{2}H$.

There are indeed very few case studies on isotopic ratios in air moisture [4] but these show that isotopic monitoring of air moisture over short and long term intervals may generate considerable new knowledge.

Globally, isotope data of surface vapour is available only from a limited number of stations [5-11]. A study in eastern Mediterranean region have observed a strong mean seasonal cycle of about 4 ‰ in $\delta^{18}O$ in surface vapour [6], peaking around July, which could not be adequately explained by changes in surface interactions or in air mass trajectories leaving a considerable gap in interpretation of the observed isotopic composition of atmospheric water vapour from this region.

In the present study, an attempt has been made to correlate the isotopic composition of the air moisture samples collected on daily basis by condensation method over a period of five years (2007-11) with the meteorological parameters.

2.0 STUDY AREA

The studies were conducted at National Institute of Hydrology, Roorkee (Uttarakhand), India falling under the latitude $29^0$52’, longitude $77^0$53’ and altitude 268m. The normal rainfall of Roorkee is 1156.4 mm per annum and out of which 1004.3 mm is recorded during the monsoon seasons (June to October). The monthly average maximum temperature of the study area is recorded in the range of 20.4 (January)-39.2^{o}C (May) and monthly average minimum temperature in the range of 6.1(January)-24.9 ^{o}C (July) and average relative humidity 78%.

3.0 AIR MOISTURE SAMPLE COLLECTION

The condensed air moisture samples for isotopic analyses are collected on daily basis at Roorkee, Uttarakhand, India by condensation method [3, 13]. In this method, the air moisture sample is collected using the conical condensation device. The conical condensation device comprises; (i) Aluminium cone; (ii) metallic stand for holding and vertically aligning the aluminium cone at desired height; (iii) a lid with knob for covering the aluminium cone; and (iv) a cylindrical wire-mesh cover for protecting the cone and the sample bottles.

The aluminium cone is aligned using the 8-screws provided for it, such that the tip of the cone is positioned just above the bottle and the droplets of the moisture condensed on the surface of the cone falls straight into the bottle. A 5-ml sampling bottle is placed into the groove at the base of the stand and ensured that the bottle is open (stub and cap removed), completely inserted into the groove and not shaking freely. The ice cubes are put into the cone up to the top, leaving little more space required for fixing the lid. The aluminium cone (filled with ice cubes and sealed by lid) in the stand is placed such that the axis of the aluminium cone is vertically aligned with the bottle placed in the groove. The position of the cone is adjusted such that the tip of the aluminium cone is centred at 0.5 cm above the mouth of the bottle. This will ensure that droplets of moisture condensing outside the aluminium cone can fall straight into the bottle and the falling droplets can be seen. 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 is very high, the sampling bottle is filled even within 30 minutes. After setting up the conical condensation device the date, time, temperature and relative humidity are recorded using thermo-hygrometer [3, 13].

The air moisture samples are collected for a period 2007 to 2011 by condensation method along with weather parameters like temperature and relative humidity. The air moisture samples are also being collected using the

Push & Trap method [3, 13] from April, 2009 but in this paper the isotopic data generated through condensation method have been used.

4.0 SAMPLE ANALYSIS

Stable isotopes (^{2}H or D and ^{18}O) in water were analysed using GV-Isoprime Dual Inlet Isotope Ratio Mass Spectrometer. For δ D analysis, 400 μl of the water sample is equilibrated with H_2 along with Pt catalyst at 40°C for 3 hrs. and then the equilibrated gas is introduced into the mass spectrometer. The δ^{18}O of the sample is measured by equilibrating 400 μl of water with CO_2 gas at 40°C for 7 h and then the equilibrated gas is introduced into the mass spectrometer. The measured values are reported as delta (δ) values [14]. The precision of measurement for δ^2H was within ± 1‰ and that for δ^{18}O with in ± 0.1‰.

D-excess is a parameter (intercept as represented by a symbol "d" in Global Meteoric Water Line) calculated using the relation D-excess‰ = $\delta d - 8 * \delta^{18}O$. This parameter acts as a measure of deviation of the given δ^{18}O and δD relation from the Global Meteoric Water Line (GMWL) value, which is now +11.27‰ [15]. Therefore, we have used this parameter to examine its deviation from the GMWL value.

5.0 RESULTS & DISCUSSION

The isotopic composition of the air moisture is correlated with the rainfall over a period of 5 years (2007-11) and is depicted if fig. 1. The depletion in the isotopic values of air moisture is observed during the monsoon period (July-October). The rainfall distribution has also shown some changes during the last 5 years. Prominent and well separated rainfall event can be identified as sharp isotopic peaks. The changing rainfall pattern from 2007 to 2011 can be seen in the width and depth of the isotopic troughs. The amount effect [16] is well known in the precipitation but its effect in the ambient vapour is less known. The present data pattern clearly demonstrates the amount effect and that can also be deciphered from air-moisture analysis.

The trend of isotopic variation (Fig. 1) indicates a systematic depletion in average isotopic composition shown by dotted line progressively in each consecutive year while the maximum depleted value of air moisture remains almost same every year during the span of 5 years study period. It indicates the changing climatological conditions at Roorkee (Fig. 1). The isotopic composition of air moisture for the monsoons over a period from 2007 to 2011 shows a systematic depleting trend with an overall depletion by approximately 33‰ for δ^{18}O and 60‰ for δ^2H in 5 years which can be attributed to the 70% increase in total rainfall amount during the monsoons (Fig. 3c) of this period also known as the amount effect. In fact, for major rain events, δ^{18}O values of vapours continue to decrease for 12 to 24 hours even after the cessation of rainfall [17] indicating that departure from isotope equilibrium involves advection and is therefore, more than a local phenomenon. It was observed that the amount effect is in some measures due to recycling of water vapour in storms [18]. Recently, It has been found that proportion and timing of monsoon vapours arriving at Roorkee from Arabian Sea and Bay of Bengal varies during the monsoon season resulting in the systematic depletion of isotopic values [4].

The D-excess value varied from 19 to 121‰, and the average value works out to be 71‰. Its deviation from the GMWL value of +11.27‰ shows that the atmospheric moisture being collected is a resultant of evaporated recycled water and also undergoes evaporation during condensation process. The increase in D-excess during the monsoon seasons from 2007 to 2011 by approximately 14‰ may indicate recycling of the local evaporated moisture (Fig. 2).

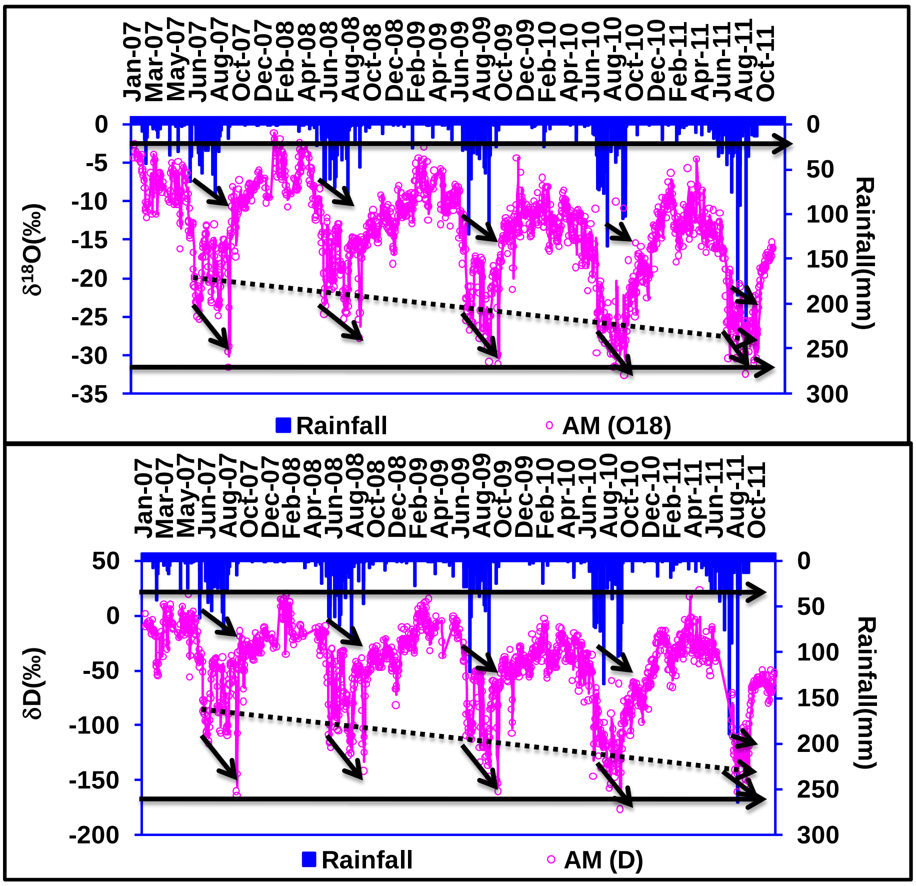

Fig. 1. Variation in isotopic composition of air moisture and rainfall at Roorkee for 2007-2011

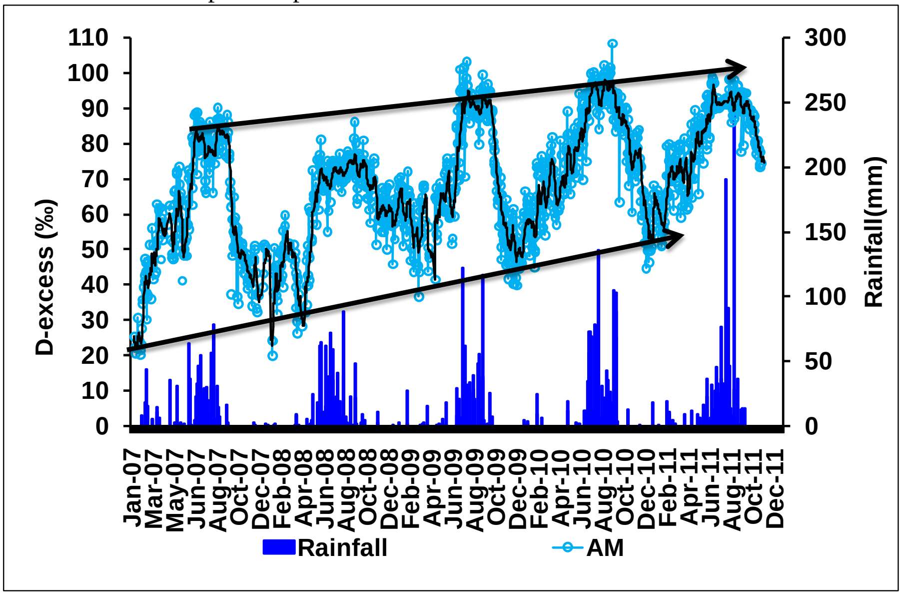

Fig. 2. Variation in D-excess in the air moisture samples at Roorkee for the period 2007-11

This systematic trend of change in stable isotopic composition indicates towards the change in climatological conditions at Roorkee in recent years which is also seen in other meteorological data. The total rainfall increased by 42% from 2007 to 2011(Fig. 3b) and out of which, in monsoon seasons (June to October) the rainfall amount increased by 70%. It has been found that at Roorkee the average rainfall in monsoon season is 73% (Fig. 3d) and it ranged from 63 to 91% of the total rainfall during 2007-11. However, a decline of approximately 4% (Fig. 3c) in average relative humidity and approximately 0.9^{o}C in average temperature was recorded during the 5 years. A systematic decrease in average minimum temperature is also recorded during 2007-11 (Fig. 3a).

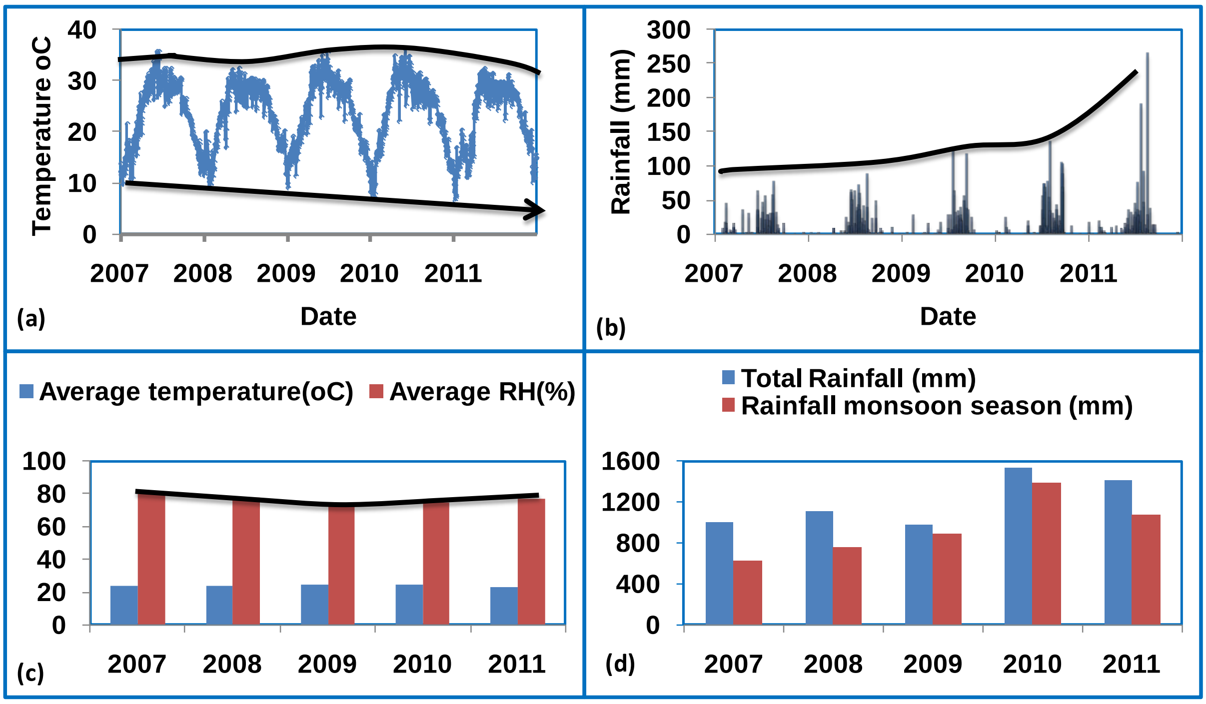

Fig. 3. Variation in Meteorological parameters during 2007-11 (a) temperature (b) rainfall (c) average temperature & average RH (d) total rainfall and rain in monsoon season

6.0 CONCLUSIONS

The present data pattern clearly demonstrates that the amount effect can also be deciphered from air-moisture analysis. The changing isotopic pattern of water vapour composition for the 5 year period also clearly demonstrates climate becoming more wet with intensification precipitation but, decrease in period of rainy days. Further, investigations are in progress in this aspect which can contribute to improve the understanding of the isotope-hydrometeorology of India as well as to consider the stable isotopic signatures of air moisture and precipitation as one of the important meteorological parameters because other meteorological parameters only show the change in weather conditions while isotopic signatures also indicate the cause and source.

7.0 ACKNOWLEDGEMENT

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REFERENCES

[1] www.prl.res.in/~iwinoffice

[2] S.K. Gupta and R.D. Deshpande, The Need and Potential Applications of a Network for Monitoring of Isotopes in Waters of India. *Current Science* 88, 107-118 (2005).

[3] Gopal Krishan**,** M.S. Rao, and Bhishm Kumar, Instrumentation for measurement of isotopic composition of air moisture. *Journal of Instrument Society of India* 41, 217-220 (2011).

[4] Gopal Krishan, M.S. Rao, and Bhishm Kumar, Identification of source of atmospheric vapour using isotopic signature of air moisture at Roorkee, Uttarakhand, India. In: Proceedings of a International conference on “Opportunities and Challenges in Monsoon Prediction in a Changing Climate" (OCHAMP-2012), Pune, India, 21-25 February 2012 at IITM, Pune. *www.tropmet.res.in/ochamp/extended_abstracts/.../OC-000101.pdf*

[5] Tian, L., L. Ma, W. Yu, Z. Liu, C. Yin, Z. Zhao, W. Tang, and Y. Wang, seasonal variations of stable isotope in precipitation and moisture transport at Yushu, eastern Tibetan Plateau, Sci. China, Ser. D, 51, 1121–1128, (2008).

[6] Angert, A., J. E. Lee, and D. Yakir, Seasonal variations in the isotopic composition of near-surface water vapor in the eastern Mediterranean, Tellus, Ser. B., 60, 674– 684, (2008).

[7] Gat, J. R., Klein, B., Kushnir, Y., Roether, W., Wernli, H... Isotope composition of air moisture over the Mediterranean Sea: an index of the air-sea interaction pattern. *Tellus* 55B, 953–965 (2003).

[8] Araguas-Araguas, L., K. Froehlich, and K. Rozanski, Deuterium and oxygen-18 isotope composition of precipitation and atmospheric moisture, Hydrol. Processes, 14, 1341 – 1355, doi:10.1002/1099-1085(20000615) 14:8<1341::AID-HYP983>3.0.CO;2-Z, (2000).

[9] Gat, J. R., Oxygen and hydrogen isotopes in the hydrologic cycles, Annu. Rev. Earth Planet. Sci., 24, 225 – 262, doi:10.1146/annu rev.earth.24.1.225, (1996).

[10] Jacob, H., and C. Sonntag, An 8-year record of the seasonal variation of 2H and 18O in atmospheric water vapor and precipitation at Heidelberg, Germany, Tellus, Ser. B., 43, 291– 300, (1991).

[11] White, J. W. C. and Gedzelman, S. D., The isotope composition of atmospheric water vapor and the concurrent meteorological conditions. *J. Geophys. Res.* **89**, 4937–4939, (1984).

[12] Yurtsever, Y. and Gat, J. R., Atmospheric waters. In *Stable Isotope Hydrology Deuterium and Oxygen-18 in the Water Cycle* (eds Gat, J. R. and Gonfiantini, R.), Technical Report Series No. 210, IAEA, Vienna, 1981, pp. 103–142.

[13] Gopal Krishan**,** M.S**.** Rao, and Bhishm Kumar, Instruments for measurement of isotopic composition of air moisture.Proceedings of NSI-36, Bareilly, India, 20 (2011).

[14] Coplen, T.B., New guidelines for reporting stable hydrogen, carbon, and oxygen isotope-ratio data. Geochim Cosmochim Acta 60:3359–3360, (1996).

[15] Rozanski, K., Araguas-Araguas, L. and Gonfiantini, R.. Isotopic Patterns in Modern Global Precipitation. *In: Continental isotope indicators of climate, American Geophysical Union Monograph* (1993).

[16] Clark, I. and Fritz, P., Environmental Isotopes in Hydrogeology, Lewis Publishers, Boca Raton, p. 328 (1997).

[17] Lawrence, J. R., Gedzelman, S. D. Dexheimer, D., Cho, H-K, Carrie, G. D., Gasparini, R., Anderson, C. R., Bowman, K. P.and Biggerstaff, M. I. (2004) *J. Geophys. Res.*, 109-D06115, Doi: 10.1029/2003JD004046.

[18] Lawrence, J. R. and White, J.W.C. The elusive climate signal in the isotopic composition of precipitation in *Stable Isotope Geochemistry: A tribute Samuel Epsteine, Geochem.* Spec. publ. Vol 3. (Eds: H.P Taylor, J. R. O'Neil and I. R. Kaplan). Pp. 169-185, Lancaster Press, San Antonio, Tex, (1991).

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Certificate

The author(s) certify that the paper titled "Study of climatological conditions using isotopic signature of air moisture at roorkee, uttarakhand, India" and submitted for consideration for Conference on "India Water Week" to be held in New Delhi from 10-14 April 2012 is in original and has not been published or presented at any other forum.

Signature of Author(s)

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