POTENTIAL APPLICATION OF NUCLEAR TECHNIQUES IN WATER RESOURCE SECTOR- A STATUS AND FUTURE PROSPECTS

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Abstract:

The global demands for freshwater have been increasing much faster than the ability of many nations to meet these demands. In this context, isotope techniques help to provide relaiable hydrological information for large areas for water resource assessment and management. The field of isotope hydrology started nearly 50 years ago and has entered into the mainstream hydrology through a closer interaction between isotope hydrologists and the hydrological community at large. The advantages of the isotopic tracers mainly reside from the fact that they can be specifically detected in very low amounts and concentrations which do not disturb the hydrologic system under investigation. In developed countries, it is routinely practiced in almost all hydrological investigations. In India, this is, although well tested in diverse geo-climatic regimes but due to the fact that the facility is available only at few laboratories in the country and it has not reached at routine use. The present paper through numerous case studies provides potential of the technique in hydrological investigations with an intention to get the reader familiarize with the state of the art knowledge of this technique.

INTRODUCTION

Isotope methods were introduced into water resources research in the 1960s as complementary tools to conventional hydrologic methods for addressing questions of where water goes when it rains, what pathways it takes to the stream and how long water resides in the catchment. In the international arena isotope hydrology as an institutional activity started with the formation of IAEA in 1957, with the objective mainly towards measurement of radioactive fallout from atmospheric thermonuclear testing, particularly tritium, and its impact on human health and on environment. Over its 50 years, through its global spread programmes it has generated more than 120,000 monthly records of stable oxygen and hydrogen isotopes and tritium from more than 900 meteorological stations worldwide (Global Network of Isotopes in Precipitation-GNIP) and more than 25,000 isotope records from river waters (Global Network of Isotopes in Rivers -(GNIR). Analysis of these data provided key relationship between precipitation isotopes and climate and opened up windows for various applications. These researches also led to development and refinement of water and sediment dating techniques; ^{14}C, ^{3}H, ^{3}He-^{3}H, ^{210}Pb, ^{36}Cl, ^{137}Cs, ^{129}I, ^{85}Kr etc. The growth in global research in isotope hydrology can be seen from the fact that between 1965 and 1970, less than 100 papers in hydrology published in major scientific journals included the use of isotopes. This number rose to more than 7000 between 1995 and 2000.

In India, around 1960's, Tata Institute of Fundamental Research, Bombay (now Mumbai) started its research on application of radioisotopes in the field of hydrology with its first study taken up in Gujarat and Rajasthan to determine the age of groundwater and recharge to groundwater bodies. The first National Symposium in the field of isotope hydrology was held on the topic "Application of Isotope Techniques in Hydrology and Hydraulics" on 26-27 November, 1974 at the Central Water & Power Research Station, Pune (Bhabha Atomic Research Centre, 1974). The first Ph.D. thesis with the title, "Application of Radioisotope to the Civil Engineering Problems" was submitted in 1968 at Pune University, Pune (Bahadur, J. 1968). Over the last 50 years, the knowledge of isotope hydrology has spread across the country mainly through conferences and collaborative programmes. Some of the organizations/institutions in India which are actively engaged in various types of hydrological studies using isotopes include, BARC, Mumbai; NGRI, Hyderabad; PRL, Ahmedabad; NIH, Roorkee, NRL, New Delhi; NIO, Goa, NCAOR, Goa; IITM, Pune, BSIP, Lucknow; IISc, Bangalore; CWRDM Kozhikode; WHIG, Dehradun; IIT, Kharagpur etc. Various state & central agencies and academic institutions are also involved in investigating various hydrological problems using isotopic technique. These include; CGWB, CWC, UPGWD, NEERI, Anna University; Delhi Univ.; IIT, Roorkee; JNU, New Delhi, Tezpur University etc. These studies provided immense information on paleowater and dynamic groundwater zones of water scarce regions of Rajasthan, recharge zones of springs in mountainous region, seawater groundwater interaction in coastal plains, groundwater conditions in hills and foot hills, lake dynamics, forest hydrology,1 leakage and seepage from dams and reservoirs, aquifer vulnerability, soil moisture movement, etc. To impart training on isotope hydrology, DST under its SERC programme also conducted several training programmes. The present paper provides basic theory of isotope techniques, illustrates through various case studies different types of investigations conducted using isotopic techniques in India.

STABLE AND RADIOACTIVE ISOTOPES

Isotopes are the atoms of an element having same atomic number (Z) but different atomic weight (A). The water contains about 1700 stable and unstable (radioactive) isotopes, commonly referred to as environmental isotopes. In water resource applications most widely used isotopes are that of oxygen (16O, 17O, 18O), hydrogen (2H, 1H) and carbon (12C, 13C and 14C). While nuclear configuration of stable isotope do not change with time the unstable isotopes decay with time and gets transformed to another type of atom (daughter element) with emission of radiations alpha (α), beta (β) particles and/or gamma (□) radiation etc. The decay of parent isotope activity (related to radiation emission rate) takes place at a systematic rate governed by equation:

$$A = A_0 e^{-\lambda t} \text{ --------------------------------(1)}$$

Where, Ao and A are the initial and final activity and λ is the decay constant which is characteristic of an isotope and is defined in terms of its *half life* (denoted by $t_{½}$ and is defined as the time in which the radioactive element decays to one half (1/2) of its initial strength) as;

$$\lambda = 0.693/ t_{½}$$

In the equation (1), A is determined experimentally through measurement of sample activity, A_0, the initial activity is estimated from combination of measured data and field data. On solving the equation (1) the time 't'(age) can be calculated which is nothing but the time elapsed to decay the parent activity from A_0 to A. For the case of ^{14}C and ^{3}H the equation (1) reduces to age equations as:

$$^{14}C \text{ age (years)} = 8270 \ln Ao/A$$
$$^{3}H \text{ age (years)} = \ln Ao/A$$

In the hydrological studies, the main environmental isotopes of interest are the stable isotopes deuterium (hydrogen-2), carbon-13, oxygen-18, and the radioactive isotopes tritium (hydrogen-3) and carbon-14. Isotopes of hydrogen and oxygen are ideal geochemical tracers of water because their concentrations are usually not subject to change by interaction with the aquifer material. Unlike radioactive isotopes, the stable isotopes do not decay with time. The variations of the isotopic ratios D/H and $^{18}O/^{16}O$ in water samples are expressed in terms of per mille deviation (δ‰) from the isotope ratios of mean ocean water, which constitutes the reference standard SMOW and is defined as;

$$\delta(\text{in ‰}) = \left[\frac{R_{Sample}}{R_{Standard}} - 1\right] \times 1000 \quad \text{----------------------------------(2)}$$

Where, R = D/H or $^{18}O/^{16}O$ etc.

If the δ value is positive, it refers to the enrichment of the sample in the heavy-isotope species with respect to the reference and negative value corresponds to the sample depleted in the heavy-isotope species.
During isotopic fractionation processes (e.g., condensation of water) heavier isotopes tend to prefer condensed phase (liquid phase in the case of condensation). As a result, along the trajectory of the air masses, each rainout preferentially removes the heavy isotopes from the vapour. The remaining vapour then becomes progressively depleted both in ^{18}O and D. Isotope fractionation, can be (i) equilibrium type (e.g., condensation of vapour in cloud water during rain) or (ii) non equilibrium type or kinetic type (e.g., evaporation in open space). The kinetic fractionation of ^{18}O is more than D (as compared to equilibrium fractionation). Hence, relative enrichment of ^{18}O (in liquid phase of water) during evaporation process is more than D. As the evaporation proceeds, the residual water enriches in heaver isotopes and the resulting shows the opposite effect. Due to the involvement of evaporation (kinetic fractionation) during infiltration, most groundwater enriched isotopic composition. Due to large reservoir size of groundwater, recharge component due to each rain event is a small fraction of the total reservoir. Therefore, rather than isotopic composition of individual rains, isotopic composition of groundwater shows weighted annual composition of precipitation. In general, isotopic composition of precipitation depletes with increasing latitude (*latitude effect*), altitude (*altitude effect*), distance

away from coast (*continental effect*) and rainfall intensity (*amount effect*). Therefore, the isotopic signature of different types of water like precipitation, rivers, lakes, reservoirs, groundwater, ocean etc. varies because of the processes explained above, operating kinetic/equilibrium isotopic processes, depending on the nature of source of water and its location. Hence, the isotopic signature of different water sources becomes very important to understand various hydrological processes.

Importance of water isotope applications in hydrological investigations have been discussed at length in vast literature based on studies in different parts of the world (Araguas-Araguas et al., 1998; Clark and Fritz, 1997; Dincer et al., 1974; Gat and Matsui, 1991; Gonfiantini, 1986; Kendall and McDonnell, 1998; Rozanski et al., 1993; Salati et al., 1979). Several Indian case studies have also been reported over the last few decades (Bhattacharya et al., (1985, 2003); Chandrasekharan et al., 1992; Dalai et al., 2002; Das et al., 1988; Datta et al., (1991, 1994., 1996a, 1996b, 1991); Deshpande et al.,(2003, 2010, 2011); Gupta and Deshpande, (2003, 2005a, b); Gupta et al., 2005; Krishnamurthy and Bhattacharya, 1991; Kumar et al., (1982, 2010); Maurya et al., 2011; Navada et al., 1993; Navada and Rao, 1991; Nijampurkar et al., 2002; Pande et al., 2000; Rai et al., 2009; Ramesh and Sarin, 1992; Sarin et al., 1992; Sengupta and Sarkar, 2006;Shivanna et al., (2004, 2008; Sukhija et al., 1998; Warrier et al., 2010; Yadav, 1997). Results of some of these studies is discussed in the following section.

SOME INDIAN CASE STUDIES

Sedimentation Rates and Pattern of Lakes using Radiometric Dating Techniques

Lake Nainital

The sedimentation rates were estimated at different locations in the lake Nainital located in Nainital district of Kumaun Himalayas, now in Uttaranchal (earlier in U. P. State), employing Cesium-137 (Cs-137) and Lead-210 (Pb-210) radiometric dating techniques of sediments. In order to estimate the sedimentation rate and life of Lake Nainital using radiometric sediment dating techniques, sediment cores were collected from different parts of the lake with a gravity corer. The length of collected cores ranged from 42 to 57 cm. The sedimentation rate obtained by ^{210}Pb in different parts of the lake varies from 0.48 cm/y to 1.24 cm/y. In case of ^{137}Cs, it varies between 0.60 cm/y and 1.35 cm/y. The sedimentation rate is higher (1.15 cm/y and 1.24 cm/y) in the intermediate portions located just adjacent to the bank zones while comparatively moderate (0.64 cm/y) in steeper bank zones. The deeper portions, away from the bank of the lake, receive sediment at a lower rate (0.48 cm/y). The average sediment accumulation rate as determined by radiometric dating method is 0.75cm/y. The sedimentation rates of a few other Kumaun lakes have been estimated using radiometric dating by other investigators and from the estimate it was found that in the case of Lake Bhimtal the sedimentation rates obtained by various investigators were same, i.e., 1.15 cm/y. It is interesting to note that the mean sedimentation rate in lake Nainital (0.75 cm/y) is comparatively higher than in other lakes (lake Bhimtal: 0.47 cm/y & 0.68 cm/y; lake Naukuchiatal: 0.37 cm/y; lake Sattal: 0.39 cm/y) of this region.

Identifying Leakages from Dams and Reservoirs

Leakage in Tehri Dam

The technique is successfully used in identification of seepage in the galleries of Tehri Dam (NIH 2009). Using the discharge and isotopic composition two separate fracture zones were identified. The reservoir water was the major component in leakage water occurring through seepage galleries

Seepages in the basement in some parts of Jodhpur city, India

Seepage water accumulation in the basement of a number of buildings was reported in some parts of Jodhpur city in the state of Rajasthan. Possible reasons for the seepages could be contributions from Kailana lake which is located few km away from Jodhpur or from water supply/ sewer lines. Water samples from basement seepages, lake, ponds, and local wells were collected for ^{2}H, ^{18}O and tritium. The lake water is isotopically depleted as they are fed by the Indira Gandhi canal which receives water from river Sutlej. The isotopic content of the basement samples fell on a mixing line between lake water and groundwater which suggested contribution of lake water to the basement seepages. This was also confirmed from the tritium values of the lake, basement samples and local groundwater

Seepage during Tunneling for Salal Hydropower Project

During construction of Tail Race Tunnel for the Salal Hydropower Project in Jammu, seepage was detected. The tunnelling was carried out through a dolomite rock which is highly jointed and often crumbly and sheared. Samples for the analysis were collected from nearby springs, nallahs, river Chenab and the seeping water. The isotopic results clearly indicate that the seepage water that has isotopic composition ($\delta^{18}O$ -7.7‰) all along the tunnel is different from isotopic composition of Chenab River (~-12‰). ^{3}H and EC profile of seepage waters showed a good correlation along the length of the tunnel and was different from the Chenab river water. Using Piston Flow model, the age of seepage water is estimated to be 10-15 years. It was concluded that the seepage water is old precipitation water stored or percolating in the fractured dolomite.

Hydrograph Separation of Bhagirathi River

At Dabrani

In order to separate out the three major components, (i.e., snow/glacier melt, surface runoff and subsurface/groundwater) in the total flow isotopic indices, Ec and discharge data were used in three component model estimation of contribution. The glacier/snow component was negligible in December/January and a maximum contribution of 64% in May with an annual average of 35%. The subsurface contribution ranged from 24% in May to 100% in December. On an average, it comes to 49% of the total annual discharge. The hydrograph separation clearly indicates that the snow melt started from January and reached a maximum in May. Therefore, if one compares it with the total melt discharge in the ablation period of 2005, it is only about 40% of the total discharge.

At Devprayag

The maximum contribution has been found 31% to 51% of the total discharge for the rainfall events that occurred during the month of July or September in the year 2005. Variation in runoff percentage is due to the amount and intensity variation of rainfall. On the monthly basis, contribution of surface runoff varies from 14% to 43% of the total discharge. On average, runoff contribution is 19% of the total discharge during the 2005. The snow and glacier contribution becomes negligible during winter month and maximum snow melt is 60% of the total dischage in April month. The contribution of snow and glacier discharge is estimated 25% of the total discharge during the year 2005. The groundwater contribution is ranging from 32% to 100%. The maximum contribution of groundwater is in December month and minimum in rainy period. If one compares with total discharge in year 2005, it comes about only 56% of the total discharge.

Surface Water and Groundwater Interaction

Case Study of the Yamuna River

The approach is based on the fact that the river Yamuna originates at higher and normally has a different stable isotopic composition than that of groundwater being recharged by infiltration of local precipitation. The studies carried out by NIH, Roorkee and few others have revealed that the river Yamuna has stable isotopic signatures ($\delta^{18}O$) in the range of -8‰ to -9‰ while the groundwater in Delhi region varies between -6‰ to -7‰ where recharge due to precipitation dominates. Therefore, stable isotopes of hydrogen and oxygen have been used to determine the contribution of groundwater to river or vice versa at the selected locations in the study area. In case of river Yamuna contributing to the groundwater regime, there are two possible sources of recharge to groundwater, viz. infiltration of local precipitation and infiltration of river water. Based on the $\delta^{18}O$ variation in groundwater, the river water and the ranney well, the component of river water in the pumped water has been computed. The percentage of water contribute by the floodplain region to groundwater varies from 41% in the month of August to 9% in February.

Estimation of Natural Groundwater Recharge

Groundwater Recharge in Bundelkhand Region of U. P., India

Bundelkhand region in India faces acute water deficiency due to high surface run-offs. The groundwater reserves have been found very limited and groundwater level is also deep at number of places. Keeping in view the prevailing conditions in Bundelkhand region, it is necessary to estimate the correct value of recharge to groundwater due to monsoon rains, which is the main source. It is clear from the results obtained that there is a wide variation in the values of recharge to groundwater. This variation may be due to different type of soil, topography, hydrogeology, groundwater level conditions, cropping pattern, rainfall pattern, evapotranspiration and several other local factors which are very difficult to account for.

Identification of recharge zones and recharge sources in District Haridwar & Saharanpur

The groundwater from different aquifers: Shallow, Intermediate and Deep aquifers were studied to identify the groundwater recharge source in the districts of Haridwar and Saharanpur. The major findings of the study are:

- The tritium and oxygen isotope data suggest the major recharge zone located in Bhabhar-Siwalik extended over an altitude range of 500m-1000m above mean sea level and a local recharge zone in the south of Roorkee towards Purkazi
- The Shallow aquifers in the Solani-Yamuna interfluve are recharged locally and those in Solani-Ganga interfluve are recharged mainly in Bhabhar-Siwalik region.
- The Main Ganga Canal is effective in recharging the shallow aquifer over a width of few kilometers all along its stretch.
- The deeper aquifers are semi-confined to confined type.
- The mean transportation rate of groundwater in the Solani – Ganga interfluve is about 1.1 m/d. As seen from the environmental tritium data, the interconnection between shallow, intermediate and deeper aquifers in the plains region between Behat and Solani faults and also in the Solani –Ganga interfluve is poor

Mugali Chetla Tanda Watershed in Anantapur district of Andhra Pradesh, India

An experimental study was taken up on a pilot basin in two tanks within the Mugali Chetal Tanda Watershed in Anantapur district of Andhra Pradesh. The infiltration test using double ring infiltrometer with a constant head was performed on undisturbed tank soil. Tritium (isotope of hydrogen) was used to understand and to follow the downward movement of infiltrated water. The study indicated that in the case of irrigation tank, a steady state infiltration rate of 67 mm/h has increased to 350 mm/h with the removal of 65 cm silt showing a six-fold increase in infiltration rate. Infiltration rate was found to be reducing by removal of 25 cm and 50 cm silt and the analysis of soil fraction indicated presence of clay at these depths. The study at percolation tank indicated that the infiltration rate of 10-20 mm/h has increased to a maximum of 310 mm/h with removal of 40 cm silt.

Groundwater recharge in the Semi-arid region of Karnataka, India

Environmental isotope and injected tracer techniques were used to estimate the contribution of storms as well as annual precipitation to groundwater recharge and its circulation, in the semi-arid region of Bagepalli, Kolar district, Karnataka. Some of the groundwater samples collected during the post-storm periods was found to be highly depleted in stable isotope and with higher d-excess relative to that of the pre-storm period groundwater samples. An injected tracer experiment was carried out to estimate the direct recharge of the groundwater and was estimated to be ~33 mm of the 550 mm annual rainfall in 1992. There was no significant variation in the env. ^{3}H content of the post- and pre-storm groundwaters indicating fast circulation of groundwater.

Groundwater recharge in the Arid areas of Rajasthan, India

An integrated study on groundwater recharge and behaviour of contaminants in the unsaturated zones in Saraf ki Dani, Sihania and Lakrasar site in Barmer district of western Rajasthan have been carried out. Unsaturated zone core samples were collected in the above sites and the soil water was extracted by vacuum distillation and analysed for ^{2}H, ^{18}O while for chemistry elutriation method of extraction was used. The groundwater recharge in the above sites ranged from ~10 to 18 mm per annum.

Groundwater Management in Coastal Aquifers Using Isotopes

Groundwater Recharge in the Coastal Aquifers of Tiruvadanai, Tamilnadu, India

Environmental isotopes (^{2}H, ^{18}O, ^{3}H, ^{13}C, ^{14}C, ^{34}S), in conjunction with hydro-geology, hydro-chemistry (major ions) and in situ physico-chemical parameters (EC, T, pH, DO), were employed to understand the groundwater recharge (natural, artificial) processes and hydrodynamics of a deep coastal sedimentary multi-aquifers at Tiruvadanai (namely Tiruvadanai Aquifers) in the Ramanathapuram District of Tamilnadu State, Southern India. Based on the hydrogeological, hydrochemical and environmental isotopic evidences, three types of groundwater recharge processes to the Tiruvadanai aquifer system are discerned. The suitable river for planning large-scale artificial recharge measures could be the north-bounded ephemeral river, mostly using recharge borewells, rather than the south-bounded ephemeral river.

Krishna Delta, Andhra Pradesh

In order to analyze seawater intrusion in southern parts of Krishna Delta, Kumar et al., (2011) analyzed groundwater samples from multiple aquifers for stable oxygen, hydrogen isotopes & ^{14}C and tritium dating; and hydrochemical details. On the basis of chloride concentration and Na/Cl ratio, water is categorized into fresh (Cl- <250 mg/l), freshening (Cl->250 mg/l and Na/Cl>1) and saline zone (Cl->250 mg/l and Na/Cl $\leq$ 1). Based on this criterion it was observed that the salinity front is extended up to 25, 30 and 50 km distance in shallow, intermediate and deeper aquifers respectively from the coast. Measurable tritium in groundwater was observed in area near Prakasam Barrage, area close to canal network particularly in the area eastern delta and at few locations in southern parts indicating fresh water recharge of recent origin. In the intermediate and deeper aquifer although the pattern was similar but the spread of modern water beyond Prakasam Barrage reduced with the depth of aquifer. The measured un-calibrated ^{14}C ages ranged from 2500 yrs to 30,000 years. Older ages observed mostly towards the coast. The dilution of age is interpreted as due to modern recharge. The stable isotope data indicates that the groundwater is mainly of precipitation origin which is affected by varying degree of evaporation enrichment of its isotopic composition. It is concluded that the increased canal water irrigation has led to freshening of the groundwater and this should be intensified to the southernmost part of the study area characterized by isolated aquifers and high salinity.

Submarine Groundwater Discharge

At Vihinjam, Kerala

A team from BARC, Mumbai (Jacob et al., 2007) collected groundwater samples from the shallow aquifer of coastal Vizhinjam to investigate submarine groundwater discharge (SGD) in Kerala coast, southern India. These groundwater samples exhibited ^{222}Rn activities 2 orders of magnitude higher than in coastal waters. The average ^{222}Rn activity in the Vizhinjam coastal water was about 14.1 ± 1.7 Bq/m3 whereas in groundwater it is about 4640 ± 3830 Bq/m^3. The large difference in activities among these end members helped in using ^{222}Rn as an indicator of groundwater discharge into the sea. By mass balance method SGD 10.9 cm/d was estimated.

Recharge Zones of Springs

Identification of Recharge Zones of Springs at Gaucher, Uttarakhand

In an another study conducted jointly by Isotope Applications Division, Bhabha Atomic Research Centre, Mumbai and Himalayan Environmental Studies and Conservation Organization, Dehradun on the identification of recharge areas at Gauchar area of Chamoli (Shivanna et al., 2008). Stable isotope data of precipitation collected from three different heights of the valleys, viz. 1180, 990 and 800 m amsl, during September 2004 show that $\delta\ ^{18}O$ varied from –10.0 to –8.2‰ and δD varied from –69.2 to –56.3‰. The isotopic composition of spring water varied from –7.7 to –7.0‰ for δ 18O and from –57.9 to –50.3‰ for δ D. The recharge area of the low-altitude springs was determined and it was found to be 1250 m amsl. The topography and geology of the area suggests that the presence of thin, weathered, top soil cover underlain by hard and compact quartzite, phyllite and granite with a steep gradient does not allow the rainwater to percolate down, and hence the spring waters were mostly derived from seepage waters.

Effectiveness of Artificial Recharge Measures

Ozar Watershed study in District Nasik, Maharastra

Groundwater, precipitation and Hantur Canal samples from the Ozar watershed were analyzed for $\delta^{18}O$ and ^3H. It is inferred that the groundwater is more dominated by recharge from canal waters through earthen channels and rainfall recharge component is comparatively very less. Moreover, the data reflect that the groundwater is young with negligible aquifer storage.

Source Attribution and Pollution Assessment of Water using Isotopes

Datta et al. (1996, 1996a, 1999) found that high nitrate, fluoride and heavy metals groundwaters are associated with high ^{18}O waters, indicating that significant quantities of evaporated (isotope enriched) surface run-off water and rain water infiltrate along with anthropogenic nitrate and fluoride salts in the soil and wastes. Datta et al. (1996, 1996a) reported that variable mixing of contemporary recharge with old groundwater, degrees of recharge/evaporation, adsorption/dispersion processes in the soil zone, slow infiltration of agricultural and urban surface run-off, and over-exploitation induced lateral intermixing of contaminated groundwater with fresh water along specific flow-pathways results in variation in pollutants contents, increasing lateral extension of contaminated groundwater and decrease in the fresh water potential. Datta and Tyagi (1995, 1996); Datta et al. (1996) showed that the spatial distribution and relationships of isotope ^{18}O and chemical contaminant species clearly indicate the direction of pollution plume movement and mixing of multiple sources of highly saline/contaminated groundwater with relatively fresh groundwater or river water along specific flow-pathways.

Stable Isotopes of Atmospheric Water Vapour

Atmospheric water vapour plays an important role in hydrological cycle and climate in earth system. It also plays an important role in precipitation event of a region. The water vapour enters the continental region as bulk air moisture that acts as a source for precipitation. Evaporation from local water bodies and evapotranspiration also contributes to precipitation in a region. Hence, monitoring of isotopic signatures of atmospheric air moisture is important to understand source, processes undergoing during the rainout process. To Study the isotopic behaviour of atmospheric water vapour at ground level was one of the main objective of the Programme Isotopic Fingerprinting of Waters of India (IWIN) in which NIH, Roorkee is an active component. NIH Study group have established various sampling locations across the country (including its regional centres) to actively monitor the behaviour of atmospheric water vapour in India. The initial study has shown that stable isotopes can be effectively used to monitor the trajectory of monsoonal winds across the country. A special emphasis have been given in understanding and prediction of monsoon onset and withdrawal using stable isotope, which is in progress. Future trends and new applications in isotope hydrology are largely possible due to steady advances occurring in analytical methods and instrumentation as well as in the availability of global isotope data.

FUTURE DIRECTIONS FOR RESEARCH

It is important to note that isotope studies, even used on their own, have proved to be useful reconnaissance tools in areas where mainstream hydrogeological data are sparse. Isotope studies are now embedded in the training of most hydrogeologists and can be considered alongside other tools available. Considering vast areal distribution of the sub-continent, a large number of isotope professionals are needed. This needs introducing isotope hydrology course in universities and technical institutions, technology transfer from isotope hydrology institutions to other water sector organizations and training the executives of water sectors. Access to specialist laboratories remains a problem and every effort needs to be made to support in establishing atleast a few state of art laboratory in the country. In long term view, efforts are needed to set-up distributed permanent stations to record long term isotopic hydro-meteorological data for precipitation, groundwater, rivers, snow and glacier. However, it should be emphasized that the use of these methods requires close collaboration with hydrologists in order to ensure a proper use and maximum interpretation of isotope data.

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