ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

Isotope hydrology - present status and future prospects in India

BHISHM KUMAR and S. M. SETH
National Institute of Hydrology, Roorkee-247667, India, Email: bk@cc.nih.ernet.in

Abstract

The application of isotopes to hydrology is comparatively new but the vast potential of isotope techniques to understand the various complicated hydrological processes has increased the interest among the scientific community. Several research institutions/ organisations in India are presently using different isotopic techniques for obtaining useful information on the different components of the hydrological cycle. Many hydrological studies have been carried out in parts of Andhra Pradesh, Gujarat, Haryana, Karnataka, Kerala, Maharashtra, Pondicherry, Punjab, Rajasthan, Sikkim, Tamilnadu, Uttar Pradesh and West Bengal states of India using isotopes.

There are number of organisations/institutions in India which are engaged in various types of hydrological studies using isotopes. The detection of isotopes in different facets of hydrological cycle is now possible in ultra low concentration with very high precision and reliability. It has encouraged the scientific community to increasingly use these techniques.

Although extensive work has been carried in past few decades in India using isotope techniques but still there is a need to exploit the potential of these techniques. The useful hydrological information like, the contribution of different recharge sources and location of recharge zones for deeper aquifers, possibility to recharge the groundwater bodies artificially and sources and extent of groundwater contamination etc. can be obtained using isotope techniques. This may be helpful in finding possible solutions for a number of hydrological problems particularly in case of large and densely populated urbanised cities where the water related problems are becoming crucial. In addition, there are number of other potential areas like, artesian wells in Tarai and Bhabhar Belt, water balance and sedimentation in water bodies, surface water and groundwater interaction in case of perennial rivers, stream flow measurement in mountainous areas, seepage and leakage from water bodies, snow and glacier studies, flow of soil moisture through unsaturated zone and recharge to aquifers, sea water intrusion and salinization mechanism of groundwaters, soil erosion and watershed management studies and evaluation of effectiveness of artificial recharge measures etc. which can be taken up on priority basis for the studies using isotope techniques in our country.

This paper provides a review of the isotope hydrological studies carried out in India in past four decades, environmental isotope measurement facilities available and the list of the organisations which actively involved in hydrological studies using isotopes in India. An effort has also been made to focus various important studies that can be carried out in India in order to understand the various hydrological problems that are presently being faced and many those that will be faced in next couple of decades.

INTRODUCTION

Although the use of isotope techniques in the field of hydrology was initiated more than 5 decades back but, the systematic and unending efforts were started by the International

Atomic Energy Agency (IAEA) Vienna which came into existence in the year 1957. The first discussion on the hydrological application of isotope was conducted by a panel of experts on 6-9 November 1961 in Vienna at the IAEA Headquarters (IAEA, Vienna, 1962). Two years later in Tokyo, the IAEA sponsored an international symposium on the application of isotope techniques in hydrology which recorded 27 important papers reporting progress on various research projects employing isotope techniques. Since then the IAEA had been organising the international symposium at a regular interval.

The application of radioisotopes in the field of hydrology was initiated in India in early 1960's by Tata Institute of Fundamental Research (TIFR), Mumbai and the first study was taken-up in Gujarat and Rajasthan to determine the age of groundwater and recharge to groundwater bodies. An All India Symposium on "Radioactivity and Meteorology of Radionuclides" was organised by Bhabha Atomic Research Centre (BARC), Mumbai in the year 1966 in which few research papers related to the application of radioisotopes in hydrological investigations were presented. But in true sense, 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 (CWPRS), Pune by BARC. The second national symposium on Isotope Application in Industry was organised by BARC on 2-5 Feb. 1977 in Mumbai (BARC, 1977) and a workshop on 'Nuclear Techniques in Hydrology' was organised by the Committee on Isotopes in Industry, Department of Atomic Energy on March 19-21 1980 at National Geophysical Research Institute (NGRI), Hyderabad (NGRI,1980). After that, a number of seminars/symposia/ workshops have been organised in the field of isotope hydrology by BARC, Mumbai, NGRI, Hyderabad and National Institute of Hydrology, Roorkee and now it is a regular feature to organise such seminars/symposia/ workshops and training courses in this field almost every year in the country.

The first Ph.D. thesis with the title, 'Application of Radioisotope to the Civil Engineering Problems' was submitted in 1968 at Poona University, Pune (Bahadur, J, 1958) and since then many Ph.D. programs have been completed in the country on various topics related to isotope application. School of Hydrology (now Department of Hydrology), University of Roorkee, Roorkee took up the teaching program as an elective course (one unit course) for master's degree in Hydrology, and experts from IAEA, Vienna, under UNDP project, prepared a standard model course for master's program in the year 1974-75. The contents of the course covered almost the entire research and development component as reported in IAEA publication (IAEA, TRC-91, 1983). The teaching of isotope hydrology in some form or the other, is being done at different universities/institutions (IIT Kharagpur, Madras and Kanpur, University of Roorkee and University of Pune etc.) in India.

There are number of organisations/institutions in India which are engaged in various types of hydrological studies using isotopes. The list of such major organisations is given at the end of this paper. The use of environmental stable and unstable isotopes, artificial radioisotopes and sealed radioactive sources have been mainly directed towards the studies of characterising water masses and origin of water, sea water intrusion, interconnection of water bodies, soil moisture movement and groundwater recharge, seepage/leakage from reservoirs/canals, water balance and dynamics of lakes, groundwater salinization,

characterisation of geothermal waters, stream flow measurements, sediment transport, sedimentation in water bodies, dating of groundwaters and many others . These studies have been mainly carried out in parts of Andhra Pradesh, Gujarat, Haryana, Karnataka, Kerala, Maharashtra, Pondicherry, Punjab, Rajasthan, Sikkim, Tamil Nadu, Uttaar Pradesh and West Bengal states of India using isotopes.

The recent advances in nuclear instrumentation have made it possible to detect the isotopes in ultra low level concentrations with high precision and greater reliability. This has encouraged the scientific community to increasingly use these techniques. However, extensive work has been carried out in India in past few decades but still, there is a need to extend the use of isotope techniques in various fields of hydrology. The various isotope hydrological studies and research carried out in India during the last four decades are described below in brief.

PRESENT STATUS OF USE OF ISOTOPES IN INDIA

Studies Using Environmental Isotopes

The isotopes, which find their way into the atmosphere due to various natural and anthropological activities, are called environmental isotopes. These isotopes become the part of hydrological cycle and play an important role in identifying various hydrological processes and parameters. The environmental isotopes may be stable and radioactive in nature.

The stable isotopes of hydrogen and oxygen i.e., ^{1}H, ^{2}H, ^{16}O, ^{17}O and ^{18}O do not decay with time and various species of water molecule are formed like, $^{1}H_2{}^{16}O$, $^{2}H_2{}^{16}O$, $^{1}H_2{}^{16}O$, $^{1}HD^{18}O$, and $^{1}H_2{}^{18}O$ etc. These species of water are introduced in hydrological cycle by natural process. The ratio of D/H and $^{18}O/^{16}O$ are measured by using stable isotope ratio mass spectrometer/s and compared with seawater as standard SMOW or VMSOW. The SMOW and VSMOW stand for standard mean oceanic water and Vienna standard mean oceanic water respectively.

The facility for measuring stable isotopes mass ratio for oxygen and hydrogen for hydrological studies are available with five organisations in India namely, NGRI, Hyderabad, BARC, Mumbai, Physical Research Laboratory (PRL), Ahmedabad, Defence Laboratory, Jodhpur and Nuclear Research Laboratory (NRL), IARI, New Delhi. Mass spectrometers available with Atomic Minerals Division, Hyderabad and ONGC, Dehradun are also used for the measurement of stable isotopes mass ratio, mostly for other than hydrological studies.

Tritium (^{3}H), Carbon-14 (^{14}C), Chlorine-36 (^{36}Cl) are radioisotopes produced naturally by cosmic ray interaction and also introduced by thermonuclear explosions in the atmosphere. These are injected in the hydrological cycle by natural processes. Measurements of these radioactive isotopes in very small quantity are tedious. The tritium (half-life 12.23 years) is used to determine the age of ground water ranging upto 40 years. The carbon-14 (half-life 5730 years) is used to determine the age of ground water ranging upto 25,000-40,000 years while Chlorine-36 can be used to determine the age of groundwater in the range of 10^4 to 10^5 years. These radioisotopes can be used for the

study of recharge to groundwater, dating of groundwaters and identification of modern or paleowater, water rock-interaction, identification of aquifers in fractured rocks, location of recharge sources and turn over period of water bodies.

Cs-137 and Pb-210 are other useful environmental radioisotopes. Cs-137 is reached into the atmosphere due to the testing of atomic devices while Pb-210, basically of geogenic origin, reaches into the atmosphere when geogenic Ra-226 decay into Rn-222 and being a gas, it escapes into atmosphere and finally decays as pb-210.

At present, four institutes, namely BARC Mumbai, NGRI Hyderabad, NIH Roorkee and PRL Ahmedabad have facilities to date groundwaters using ^{3}H and ^{14}C in India. Birbal Shahni Institute of Paleobotany, Lucknow also has the facility to measure C-14 activity in groundwaters but it does not have environmental tritium measurement facility. Centre for Water Resources Development and Management (CWRDM), Kozhikode, Kerala also has tritium dating facility but it does not have C-14 dating facility. Dating of waters using ^{36}Cl could not be initiated in India due to non-availability of the required facility in our country. Recently the Advance Institute of Physics, at Bhubneshwar, Orissa, has procured an acceleratory mass spectrometer . It is therefore, assumed that this technique will also be used in India in near future for dating very old groundwaters. The facilities for measuring Cs-137 and Pb-210 are available with many organisations in India including BARC, Mumbai and NIH, Roorkee.

The various hydrological studies carried out by different organisations and individuals in India using environmental isotopes have been categorised into few major studies and summarised below.

Isotopic characteristics of waters: This is one of the isotopic studies of prime importance that lead to initiate many other isotope hydrological studies. Gupta and Sharma (1987), have carried out studies related to measure D and ^{18}O isotopes ratio in groundwater as well as waters of rivers, lake, hot springs etc. collected from a variety of locations. Stable isotopic characteristics of the Ganga and Brahamputra rivers have been carried out by Ramesh et al (1982) and Bhattacharya et al. (1985). The results indicated a large continental effect in groundwaters (isotopic variations with respect to distance from sea cost). Studies showed the most depleted ^{18}O values in the sub continent in the high altitude lakes in Bhutan followed by upper reaches of the Ganga at Devprayag and Rishikesh, obviously due to melt waters of Himalayan glaciers. Studies related to geochemistry, oxygen and hydrogen (D) isotopes ratio of thermal springs in western continental margin of India has also been studied by Chandrasekharan et al. (1989). Krishnamurthy and Bhattacharya (1991) have studied the role of evapotranspiration in Indian monsoon. The temporal variation in oxygen-18 and deuterium composition of New Delhi rainfall (1961-1983) has been analysed by Datta et.al (1991). Bartarya et al. (1995) and Pande et al. (1999) have studied the systematics of surface water bodies in Himalayan region using oxygen-18 and D isotopes. Geochemical and isotopic characteristics of geothermal areas of Central and Northern India have been studied by Navada et al (1995). Nachiappan (2000) has studied the altitude effect for Himalayas region, which is of prime importance in order to initiate isotope hydrological studies in the region, for outer Himalayas.

It seems that efforts have not been made to carry out long term and systematic studies for the development of a database for isotopic characteristics of waters in India, neither by any organisation nor by any individual.

Groundwater Pollution: The salinity problem in groundwaters is increasing in coastal areas including some parts of Haryana, Rajasthan, U.P. and Punjab states. The information about the causes of salinity and its remedial measures is necessary to check its further spread. Isotopes can play a major role in identifying the sources of salinity and its mechanism. Navada et.al. (1986) have carried out studies of groundwater salinity and recharge in Midnapore, West Bengal using environmental tritium, O-18 and deuterium isotopes. Datta (1990) and Datta et al. (1996 and 1997) have carried out detailed isotopic and geochemical studies in parts of Delhi City. Causes of salinity increase in groundwaters and intermixing of saline and fresh groundwaters have also been studied by Tyagi et al. (1997) and Datta et.al (1999) in parts of Delhi City using environmental isotopes. Shivanna et al (1998) have studied the salinity in deep groundwaters of charnockite terrain at Kokkilimedu in Tamil Nadu. Kulkarni et .al (1997) and Shivanna et.al (1998) using environmental isotopes have investigated the salinity problem in drinking water in coastal Orissa. Studies related to salinity ingress in coastal area and arsenic pollution in groundwater in West Bengal have been studied using geochemical and environmental isotopes by Shivanna et.al (1998).

Seepage and Leakage: The seepage/leakage from water bodies poses different types of problems like, water logging, increase of salinity and development of usar land and threat to the structures of Dams etc. Environmental isotopes can be used to estimate the seepage/leakage from water bodies with less efforts and comparatively less expenditure. BARC has carried out several studies regarding leakage from dams and reservoirs using environmental isotopes. The leakage in Jhamarkotra phosphorite mines in Rajasthan has also been studied by Kulkarni et al. (1998) using hydrochemistry of groundwater and environmental isotopes. It was found that the recycled water reaches mines through the high permeable geologic formation in the vicinity of the mines.

Lakes and Rivers studies: Lakes and rivers are the most neglected water bodies in India and very few integrated hydrological studies have been carried out using isotopes. Environmental isotopes can play a major role in the study of surface water and groundwater interaction and the two most crucial components i.e., sub-surface inflow and sub-surface outflow to/from a lake can be estimated using oxygen-18 and deuterium isotopes. The hydrodynamics of water bodies and interconnections of springs and lakes etc. can also be established using isotopes.

The study of river Ganga and groundwater interaction was carried out by Navada et al. (1982) on a reach of 210km long between Hardwar and Narora using oxygen-18 and deuterium isotopes. Sarvanakumar et.al (1994) have carried out isotopic investigations in Pookot lake in Kerala while a first ever integrated hydrological study of lake Nainital has been carried out by Kumar et al. (1998, 1999), Nachiappan et .al (1998, 1999) and Sarvanakumar et.al (1999). This includes the study of water balance, hydrodynamics, interconnection of springs with lake, pollution aspects, and rates and pattern of sedimentation including estimation of useful life of the lake. Studies related to the origin of salt lakes in Thar Desert (Ramesh et.al, 1993), isotopic studies of evaporation from Sambhar lake in

Rajasthan (Yadav, 1997) have also been carried out in the recent past using stable isotopes. The oxygen and deuterium isotopic analyses of Antarctic lake's water have also been carried out by Sinha et.al (2000). NIH has recently carried the studies of rates and pattern of sedimentation in Dal-Nagin lake (Kumar and Nachiappan, 2000) and Mansar lake (Rai et al., 2000) in J&K.

Dating of groundwaters, Identification of recharge sources and location of recharge zones: This is one of the most important area of studies that needs immediate attention of the scientific community to save the zones of recharge of deeper aquifers from the anthropological activities and contamination. It has been observed that in most of the cases, the details about the recharge sources and location of recharge zones for deeper aquifers are not available in India. The information about interconnection is also very useful to understand the availability of groundwater in different aquifers and to take necessary measures for saving the aquifers from contamination. But, it seems that no sincere efforts have been made in this direction to study these aspects of different aquifer systems in the country.

The scientists of PRL and TIFR (Somayajulu, 1969, Lal et.al 1970, Nijampurkar, 1974) have conducted chronological studies in Gujarat and Maharashtra and introduced Silicon-32 for dating of groundwaters. Silicon-32 (half-life only 500 years) can be used to determine the age of groundwater ranging upto 1000 to 2000 years. In fact, it was a long felt need to find out an environmental isotope for determining the age of groundwaters between the range of 40 years (Tritium) and 25000 years (Carbon-14). Therefore, Silicon-32 fill-up this gap. However, due to large requirement of water to extract Si-32, this technique could not be popularised. Borole et al. (1979) and Bhandari et al. (1986) have carried out radiocarbon dating of groundwaters to estimate regional aquifer transmissivity in Watrak Shedi sub-basin of Sabarmati basin, for a group of aquifers that are found between 30-80 m depth. The value of transmitivity (7640 m^2/day) estimated by this method was found to be in fair agreement with the values obtained by pumping test.

Sukhija (1978) has studied the recharge to groundwater through soil profiles in granitic and sedimentary terrain using integrated environmental tritium method and radiocarbon dating of groundwaters in various parts of Gujarat and Maharashtra. Sukhija et al (1996, 1997) have also studied the hydrodynamics of over exploited aquifers in Tamil Nadu including evaluation of artificial recharge measures using environmental isotopes and hydrochemical approach.

Environmental tritium and radiocarbon studies have been carried out in Vedavati river basin in Karnataka and Andhra Pradesh to determine the general recharge conditions of aquifers and interconnections of groundwater bodies including ages of groundwaters (Kumar et al 1980). About 40 samples of groundwaters were analysed and it was found that the water bodies are not interconnected. The groundwater was found in most of the water bodies of recent origin i.e. ages within 25 years except at few places. The recharge measurements were also carried out at three sites in Lower Maner basin falling in Karim Nagar district of Andhra Pradesh using environmental tritium.

Studies related to interconnection between the aquifer system of Cauvery Delta in Tamil Nadu and recharge to deeper groundwater bodies in Rajasthan has been carried by

Navada et al (1984). Datta et al (1994, 1995, and 1999) have studied the groundwater flow and recharge conditions including hydrodynamic zones in phreatic aquifers of Delhi area using oxygen-18. Nachiappan et al (1995, 2000) have studied the surface water and groundwater interaction along river Ganga using environmental isotopes.

The origin and age of groundwater along paleochannels in Rajasthan and groundwater problem in Thar Desert have been studied by Nair et.al (1999). NIH has also carried out study of identification of recharge sources to groundwater bodies and their areas of recharge using oxygen-18 and environmental tritium in District Hardwar and Saharanpur (Rao et.al., 2000). Similar study is also in progress in Krishna Delta in order to understand the salinity ingress near the coastal area. The Institute is also involved in the study of effectiveness of artificial recharge measures being taken in few watersheds near Pune, Nasik and Jalgaon in Maharashtra using environmental isotopes. The NGRI Hyderabad is also carrying out investigations related to high yielding wells in hard rock region using ^{222}Rn in Andhra Pradesh.

Studies Using Artificial Radioisotopes

Radioactive isotopes can be produced artificially under controlled conditions in the reactor or laboratory. The artificial radioisotopes like ^{3}H, ^{40}K, ^{24}Na, ^{32}P, ^{60}Co, ^{82}Br, ^{86}Rb, ^{89}Sr, ^{90}Sr, ^{131}I, are frequently used in different chemical and physical forms for carrying out various types of hydrological investigations. The hydrological studies carried out in India using artificial radioisotopes can be divided in two broad categories, using injected tracers and using sealed sources. The details of these studies are summarized below.

a) Using Injected Radiotracers: Tracers like ^{3}H, ^{46}Sc, ^{51}Cr, ^{82}Br, ^{131}I, ^{60}Co, ^{198}Au have been extensively used for various studies related to soil moisture movement and groundwater recharge, seepage/leakage from canal/reservoir, stream flow measurement in mountainous region, interconnections of water bodies, sediment transport, dynamics of lakes etc in India by different organisations. Some of the important studies carried out in India using injected tracers are summarized below.

Groundwater recharge using Tritium Tagging Technique: The tritium tagging technique for the estimation of recharge is based on the assumption that the downward movement of soil moisture follow the piston model flow (Munnich, 1983) i.e., any fresh water added to the surface due to precipitation or irrigation would move downward as a layer by pushing an equivalent amount of water beneath it further down and so on, such that the moisture of the last layer in the unsaturated zone is added to groundwater.

Rama, Goel and Datta carried out pioneering work in India using tritium tagging technique. Datta et al (1973), Datta (1975), and Datta and Goel (1975) have first taken up this study in western UP, Haryana and Punjab. The average recharge values reported by them in Western UP, Punjab and Haryana are 25%, 18% and 15% of the average rainfall 989 cm, 46cm and 47cm respectively. Datta et al. (1977, 1980) and Bhandari et al (1986) have also measured the rate of downward movement of soil water along with groundwater recharge some parts of Gujarat State covering an area of 22000 sq.km. About forty representative stations were established in different parts of the Sabarmati basin, Mahi Right bank canal command area and coastal Saurashtra to find out the values of ground-

water recharge from infiltration of rainwater. The soil moisture movement was monitored for a period of three years (1976-79). The results obtained for the percentage of recharge indicated a moderate to low values i.e., 18%, 14% and 6%. About 14% of the total average rainfall (80 cm) was estimated to be stored in the Sabarmati basin. In Mahi right bank canal command area, the percentage of recharge to groundwater was estimated little higher (23%). Datta et al. (1979, 1980) have also developed a conceptual model for the study of transport of soil water or recharge through unsaturated soil zone. Datta has also carried out a few experiments to study the recharge at different places having similar soil conditions but different crops and irrigation practices. These studies showed that more recharge takes place in fields with irrigation watering and fractional recharge i.e., less through fields with vegetation. Bahadur et al. (1974) and Arora et al. (1974) have also studies the requirement of water by plants using radioisotopes. Mukherjee (1986) has also carried out study of recharge to groundwater in rainfed alluvial area and in IARI farm using tritium tagging technique.

Athavale et al. (1978, 1980) have estimated recharge to the phreatic aquifer of lower Maner basin, covering 1600 sq.km. area and having seven different geological formation using tritium tagging technique and found the recharge values ranging from 4.7cm to 24 cm with an average for the entire basin at about 9.5cm for annual average rainfall, 125 cm. Studies related to recharge measurements in few basins namely, Godavari-Purna basin, the Kukadi basin in Deccan traps and Banganga basin between Jaipur and Agra have also been carried out by this group of scientists.

Nigam and Kumar (1980) have covered the Bundelkhand districts of U.P. by doing yearly study of recharge to ground water due to rain and irrigation using tritium tagging technique. The results of the recharge to groundwater due to rains in rainy seasons varies from 9% to 29% depending upon the type of soil and other geomorphologic features. These studies are still continued by UP Ground Water Department out in many other parts of U.P. Raja et al. (1983) have also carried out extensive studies for the study of recharge to ground water using the same techniques mostly in eastern districts of U.P.

NIH Roorkee has also carried out studies of recharge to groundwater in parts of Narmada catchment in M.P. Studies are also being carried out by NIH in Maharastra and western districts of Uttar Pradesh. A mathematical formulation has been developed for the estimation of recharge to groundwater with respect to rainfall, on the basis of studies carried out by PRL and U.P. GWD in Gujrat and U.P. respectively (Kumar and Nachiappan, 1995). The mathematical formulation can be used to estimate recharge to groundwater for the area with respect to rainfall in subsequent years.

Seepage/leakage and discharge using Tracer Dilution Techniques: The artificial radioisotopes like Iodine-131, Bromine -82 and Tritium are generally used as tracers. Various hydrological studies related to the estimation of groundwater flow velocity and direction, seepage loss from water bodies; aquifer characteristics, and measurement of discharge of mountainous rivers/streams have been carried out in India by many organisations and individuals. The basic principle of the tracer dilution method is based on the change in tracer concentration with the inflow water. By knowing the rate of change in injected tracer concentration many important characteristics of water bodies can be estimated.

The tracing of movement of injected tracers help in tracing the leakage points in water bodies, contaminants migration and information of sediment transport direction and quantity.

Ansari et al. (1970) have carried out a few experiments at Supagora Dam site of Kalinadi Hydroelectric Project in Karnataka and at Sean Harabagh tunnel in Himachal Pradesh. The estimated filtration velocities using tritium dilution technique varied from 1.4×10^{-4} to 2.12×10^{-5} cm/sec. and 6.5×10^{-7} cm/sec near Supagora dam and Harabagh tunnel respectively. Punjab IPRI Amritsar has also carried out extensive field experiments along various canals in Punjab and determined seepage loss using tritium dilution techniques. An empirical relation has also been established by IPRI which is known as Punjab formula, $P = 5xQ^{0.0\text{-}625}$, where Q is the discharge of canal and P is seepage loss. U.P. IRI, Roorkee (1971, 1987) has carried out experiments along various canals in Bundelkhand, Vindhyan region and also in alluvial plains in U.P. and found wide ranges of seepage loss from different canals. Krishnamurthy et al (1976) identified the source of seepage from tail race tunnel at the Salai hydroelectric project and Chilla Hydle Channel using radiotracers. The scientists of U.P. GWD, Lucknow (Kumar and Saxena, 1987) have also carried out several experiments along the various canals in Sharda Sahayak Canal Command area and also along Upper Ganga canal. Singh et al (1992) have reported various radiotracer dilution techniques for the study of canal seepage including a case study of seepage loss estimation from Upper Ganga canal. An empirical relation has been established to calculate the actual filtration velocity for the correct estimation of seepage loss from canals by Kumar and Nachiappan (1999).

Discharge measurement of mountainous stream/rivers has been carried out in India using radioactive tracers by many investigators. Singhal et al. (1978) have carried out several experiments for the measurement of discharge of hilly rivers like Alaknanda, Baspa (a tributary of river Sutlej), Sangla and Kolo (tributary of river Rai in H.P.), Ganga, Yamuna, Song and Lakhwar Vyasi Dam using tritium as tracer. BARC has also carried out the measurements of discharge in many rivers and stream including Tapti and Beas using Bromine -82 and Tritium as radioactive tracers. NIH has also carried out discharge measurement study on river Teesta in Sikkim using ^{82}Br and ^{3}H in collaboration with BARC, Mumbay (Kumar et al.,1992)

Sediment transport studies have been carried out in India mainly by BARC, Mumbai. Over 40 large scale sediment transport studies using either ^{46}Sc (glass) or ^{198}Au labeled silt in all major and medium ports along the Indian coastline have been carried out by BARC (Yelgaonkar et al., 1968) to examine the suitability of dumping sites for dredged silt as well as the alignment of proposed navigational channels.

b) Sealed Sources: Neutron and gamma ray radioactive isotopes are mostly used as sealed sources. The soil moisture and density probes employing Ra/Be or Ra/Am neutron source and Cs-137 gamma ray source are very popular for carrying out various studies in unsaturated zone. Similarly, exclusive gamma ray probes employing Cs-137 and Co-60 etc. are also used for soil moisture measurement and movement studies in unsaturated zone using Gamma Ray Transmission Technique. There are few other types of sealed sources that are used for various other hydrological investigations like water equivalent of snow, suspended sediment concentration etc.

Soil-moisture and density probes: Soil moisture probes like Gamma Ray Transmission Probe, Gamma Ray Scattering Probe, Neutron Scattering Probe, have been used for the study of soil moisture movement, recharge to ground water, density of soil strata and soil compaction at different places in the country.

Neutron moisture probe has been used for the study of Civil Engineering problems and significantly a Ph.D. thesis was submitted on the topic "Radioisotope applications in Civil Engineering Problems" in 1968 at Pune University, Pune (Bahadur, J., 1968). Kiran Shankar et al (1979) has developed and used this method by carrying out laboratory controlled experiments. CWPRS, Pune (Ansari et al, 1977) has also used Neutron soil moisture and density probes extensively for the study of in situ surface soil density and moisture on various dam sites. NIH has used the Neutron Moisture and Density Probe in the study of movement of soil moisture through unsaturated zone and in the estimation of recharge to groundwater in Tarai and Bhabar belt in Western Uttar Pradesh. A comparative study of recharge to groundwater using tritium tagging method and neutron probe reveals considerable difference in the estimated recharge values (Kumar et al., 1996).

Gamma Ray transmission probe/technique although not used extensively in our country, is a very unique, easy and accurate technique for the study of soil moisture movement and estimation of groundwater recharge. This technique has been used at the University of Roorkee and a Ph.D. thesis was submitted on the topic "Development and use of gamma ray transmission technique for the study of soil moisture profile in situ" in 1982 (Kumar, 1982). This method has been developed and used for the study of soil moisture measurement, movement and estimation of recharge to groundwater and drainage characteristics (Saksena et al., 1974; Singh et al, 1977; Kumar et al 1979; 1982, 1993 and Singh et al ,1988).

Gamma ray transmission/scattering probes and neutron scattering probes have also been used for the study of thickness of snow cover and water equivalent studies in India by few scientists. The neutron probe method have also been developed and used for the study of soil moisture movement and recharge to groundwater at UOR, Roorkee and NIH, Roorkee (Shankar et al., 1979; Nigam et al., 1980; Kumar et al., 1995).

FUTURE PROSPECTS FOR THE USE OF ISOTOPES IN INDIA

The Tarai and Bhabhar belt has unaccounted flowing wells but due to lack of knowledge about the extent of water availability from these sources, the judicious planning for the use of flowing water has not been possible so far. Isotope techniques employing environmental isotopes like ^{18}O and D can be used for the identification of recharge zone and evaluation of water availability in order to plan the schemes to utilise water from artesian wells.

It seems that very few efforts have been made for the study of water balance and sedimentation rates in natural lakes in India using isotopes. Information is also required on the recharge zones and sources of water input to lakes. Isotope technique using environmental stable and radioactive isotopes can be used with advantage for obtaining above information in order to carry out water balance and taking necessary measures for maintaining environmentally sound echo system including ecological balance of the region.

Rivers are important source of water supply for various uses and the management of river water has to be planned judiciously. Since surface water and groundwater are two elements of the same system, the understanding of interaction between surface water & ground water form an important element of estimation of water availability and planning for its proper use. The information on surface water and groundwater interaction can be obtained by using stable isotopes and artificial radioisotopes.

The estimation of flow in mountainous rivers is not possible with reasonable accuracy using conventional methods due to the condition of riverbed and turbulent nature of river flow. Tracer dilution techniques using artificial radioisotope can be a very effective measure to estimate the stream flow with reasonable amount of accuracy.

The construction of dams in mountainous region with basaltic foundation poses a problem of seepage and leakage through the foundation of dam and bed of reservoir. The use of environmental stable isotopes and artificial radioisotopes along with the dyes can provide a very useful tool for handling such problems.

Glacier and seasonal snow covers are important source of water in high altitude region especially in Northern India. The evaluation of water equivalent of snow and snow and glacier melt contribution forms an important element of water resources estimation. Isotopic snow gauges have been used for estimating point water equivalent of snow. Environmental gamma ray has also been used with advantage for this purpose abroad. Possibility of that in Indian terrain use is to be explored. Stable isotopes (oxygen-18 and deuterium) can be used to get the information on snowmelt contribution in Indian rivers that originate in Himalayas. This information will be very useful from planning and management point of view of Indian water resources.

Study of soil moisture movement through unsaturated zone of porous media and evaluation of recharge to groundwater including availability of soil moisture at different times in the top soils are very important from agro-hydrological point of view. These studies can be carried out with more reliability using gamma ray transmission and neutron scattering probes. Gamma ray transmission technique has been found suitable for these studies through laboratory and pilot studies carried out in India outside there is a need to improve this technique so that field level trials can be made and usefulness of this technique for evaluation/ monitoring can be established and applied.

In Northern part of the country, there are large areas where problem of salinity is being experienced, especially in areas where old waters of the saline nature are available. This situation has been experienced in Uttar Pradesh, Punjab, Haryana and Northern Rajasthan. The deltaic regions in south have increasing problem of salinity ingress, which may have several causes including salinity ingress through seabed. The dating of deeper saline water and tracing out the saline zone using environmental isotopes can help in the identification of sources of salinity and necessary measures can be taken accordingly to save the deeper aquifers from further spread of salinization.

The deeper aquifers are the most neglected water bodies in our country while these cater the maximum need of groundwater. The unplanned urbanisation has led to the scarcity of

groundwater and ground water contamination in many mega cities. More over if the present scenario continued, the shallow aquifers will either be dried up or contaminated in most of the densely urbanised areas in next few decades. Therefore, this is the time when studies should be directed to understand the recharge sources and location of recharge zones of the deeper aquifers so that the increasing urbanisation may not affect the recharge and water quality of these aquifers. Environmental isotopes can be used to identify the sources of contamination and sources of recharge and location of recharge zones. This study is required to be carried out for all the mega- cities and other densely populated urbanised areas.

Vast parts of the country fall under arid and semi-arid zone where availability of surface water as well as ground water is a major problem. The isotopes can play a crucial role in identifying the sources of ground water that can be used for longer periods and places suitable for artificial recharge.

The scarcity of ground water has forced to take artificial recharge measures in many parts of the country. However, scientific studies are needed to understand the effectiveness of the artificial measures being taken in the country in an unplanned manner and other evil effects on groundwater quality. This can be done with less efforts by using environmental isotopes.

There are other important studies like sediment transport near harbour, and investigations related to thermal waters. The use of environmental stable and artificial radioisotopes can provide the valuable information in these fields also.

The most important aspect for the use of isotope techniques in India is to develop a database of environmental isotopes so that the various hydrological studies could be planned as or when these are required. Presently, the environmental isotopic composition is being monitored in precipitation only at 1-2 stations, which are also not operating on regular basis. Therefore, keeping in view the large size of the country surrounded by long chain of Himalayan ranges and coastal line, at least 5-6 stations should be established in the country for monitoring environmental isotopic composition in precipitation and groundwaters.

National Co-ordination Committee for Isotope Hydrology in India (NCCIH)

In order to make full use of the facilities and expertise available in the country and to provide effective communication between practising hydrologists and isotope scientists, Director, BARC, Mumbai has constituted a National Co-ordination Committee for Isotope Hydrology. NIH, Roorkee and IAEA, Vienna, Austria were instrumental in the costitution in this committee.

Organisations Using Isotopes for Hydrological Studies in India

There are mainly nine major organisations which are directly associated with the use of isotopes for hydrological studies in the country. The list of such major organisations is given below.

1. Bhabha Atomic Research Centre, Mumbai, Maharashtra
2. National Geophysical Research Institute (NGRI), Hyderabad, Andhra Pradesh

3. Physical Research Laboratory (PRL), Ahmedabad, Gujarat
4. Nuclear Research Laboratory, (Indian Agricultural Research Institute) New Delhi
5. Defence Laboratory, Jodhpur, Rajasthan
6. Centre For Water Resource Development & Management, Kozhikode, Kerala
7. National Institute Of Hydrology, Roorkee, Uttar Pradesh
8. U.P. Irrigation Research Institute, Roorkee
9. U.P. Groundwater Department, Lucknow

References

Ansari, Azher and R.A. Dhawale (1970), Radiotracer investigations for location of source of seepage at Harabagh tunnel, Beas Sutlej link project, Himachal Pradesh, Seminar on Engineering Geology Problems in River Valley Projects in Northern India, Roorkee.

Ansari, Azhar, N. Ghosh and Mahajan, N.M. (1977), Application of nuclear gauges for foundation studies in some river valley projects. Seminar on Nuclear Instruments and Systems, ECIL, Hyderabad.

Arora, R.P., Mukherjee, P., Bhakta, R.N. and Bahadur, J. (1974), Radiation technique for monitoring the deep drainage in irrigated wheat fields , Proc. symp. Application of isotope techniques in Hydrology and Hydraulics. Poona Nov. 26-27 p.342.

Athavale, R.N. (1977), Tracer techniques in groundwater hydrology, Proc. of a workshop on 'Exploration Techniques for groundwater organised by Committee on Science and Technology in Developing Countries (COSTED), Bangalore, India, pp. 316-358.

Athavale, R.N.,Murti, C.S. and Chand, R., (1980), Estimation of recharge to the phreatic aqifers of the lowr maner basin , India by using the tritium injection method, J. of Hydrology, Vol.45, No.3/4, pp.185-202.

Bahadur, J. (1968), Application of radioisotopes to the Civil Engineering problems, Ph.D. thesis submitted to the Univ. of Poona.

Bahadur, J., Arora, R.P., Mukherjee, P., Bhakta, R.N. (1974), Tritium tracer technique for study of water movement in alluvial soils, Proc. symp. use of radiations and radioisotopes in studies of Plant productivity, Pantnagar, Feb.

BARC (1974), Application of isotope techniques in hydrology and hydraulics', Proceedings of the First National Symposium held at CWPRS, Pune, November 26-27, 1974.

BARC (1977), Isotopes Application in Industry', Proceedings of the Second National Symposium held on Feb. 2-5, 1977 at Bhabha Atomic Research Centre, Trombay, Bombay.

Bartarya, S., S.K. Bhattacharya, R. Ramesh & B.L.K. Somayajulu (1995), 0-18 and D Systematics in the surficial waters of the Gaula river catchment area, Kumaun Himalaya, J. Hydrol. 167, 369-379.

Bhandari, N. et al. (1986), Hydrological investigations in Sabarmati and Mahi basins and coastal Saurashtra using radio isotopic and chemical tracers. N.Bhandari, HILTECH (Min. of Water Resources, Govt. of India, NIH, Roorkee).

Bhattacharya, S. K., S.K. Gupta & R.V. Krishnamurthy (1985), Oxygen and hydrogen isotopic ratios in groundwaters and river waters from India, Proc. Indian Acad. Sci (Earth Planet, Sci.), Vol.94, No. 3, Nov.1985.pp.283-295.

Borole, D.V. et al. (1979), Uranium isotope investigations and radiocarbon measurement of river groundwater systems. Sabarmati basin Gujarat, India, Isotope Hydrology, 1978, Vol.1, IAEA, Vienna, pp. 181-201.

Chandrasekharan, D., R. Ramesh & J. Balasubramaniam (1989), Geochemistry, Oxygen and hydrogen isotope ratios of thermal springs, Western continental margin of India Field and experimental results, Water Rock Interaction. (ed. D.L. Miles), 149-154.

Datta, P.S., Goel, P.S. Rama and Sangal, S.P. (1973), Groundwater recharge in Western Uttar Pradesh. proc. Ind. Acad. Sci., Vol. LXXV, No.1, pp.1-12.

Datta, P.S. (1975), Ground water recharge studies in the Indo-gangetic alluvial plains using tritium tracer. Ph.D. thesis, Unpublished, Department of Chemistry, IIT, Kanpur. 385-389.

Datta, P.S. , Desai, B.I.. and Gupta, S.K., (1977), Hydrological investigation in Sabarmati basin. 2, Comparison of ground water recharge rates in parts of Indo-gangetic Sabarmati alluvial, PRL, Ahmedabad, Report No.HYD-77-06.

Datta, P.S. and Goel. P.S. (1977), Ground Water recharge in Panjab State (India) using trititum tracer, Nordic Hydrology, 8., 225-236.

Datta, P.S., B.P. Desai and S K Gupta (1979), Simulation of water movement through vadose zone in current Trends in Arid Zone Hydrology (ed. S K Gupta and P Sharma) Today * Tomorrow's Printers and Publishers, New Delhi, pp. 93-102.

Datta, P.S., S K Gupta and S C Sharma (1980), A conceptual model of water transport through unsaturated soil zone. Mausam, Vol.31, No.1, pp. 9-18.
Datta, P.S. (1990), Deuterium and oxygen-18 studies in groundwater of Delhi area, India-comment. J.Hydrology, 113-
Datta P.S., Tyagi S.K. and Chandrasekharan, H. (1991), Factors controlling stable isotopic composition and rainfall in New Delhi, India J. Hydrology, 128: 223-236.
Datta, P.S., Bhattacharya, S.K. and Tyagi S.K. (1994), Assessment of groundwater flow conditions and hydrodynamics zones in phreatic aquifer of Delhi area using oxygen -18, Proc Intl. Workshop on "Groundwater Monitoring and Recharge in Semi-Arid Areas", Hyderabad, IAH/UNESCO Publication, S IV:12:24.
Datta P.S. and Tyagi, S.K. (1995), Isotopic investigation on groundwater recharge conditions and flow regime in Delhi region - A review. Proc. International Conf. Water & Energy 2001, Oxford & IBH Publn. Vol.II:629-642.
Datta, P.S., Deb, D.L. and Tyagi, S.K. (1996), Stable isotope (O-18) investigations on the processes controlling fluoride contamination of groundwater. J. Contaminant Hydrology, 24(1):85-96.
Datta, P.S., Deb, D.L. and Tyagi, S.K. (1997), Assessment of groundwater contamination from fertilizers in Delhi area based on O-18, NO3 and K composition. J. Contaminant Hydrology, 27(3-4): 249-262.
Datta, P.S. (1999), Groundwater situation in Delhi: Red Alert- An internal report, Nuclear Research Laboratory, Indian Agri. Research Institute, New Delhi.
Gupta, S.K. and P. Sharma (1987), Application of nuclear techniques to groundwater hydrology in India-some case studies. Bhujal News, Vol.2, No.3, pp. 5-10.
IAEA, Vienna, (1962), Application of isotope techniques in Hydrology, STI/DOC/10/11, proceedings of a symposium.
IAEA, TR-91 (1983), Guidebook on Nuclear Techniques in Hydrology, IAEA, Vienna, Tech. Rep. Series No. 91, IAEA, Vienna, Austria.
Kiran Shankar, Bhishm Kumar and B.P. Singh (1979), Determination and analysis of the variation of soil moisture at various depths by Ra-Be Neutron Scattering Probe, proceedings of the Indian Science Academy 45(Part-A):476-484.
Krishnamurthy, K. and Rao, S.M. (1976), Experience with radiotracer methods for hydroelectric projects., Proc. National Symp. on Hydrological problems related to the Development of Power and Industries, IIT, Kanpur, sept. pp. B61-10.
Krishnamurthy, R.V. and Bhattacharya, S.K. (1991), Stable Oxygen and hydrogen isotope ratios in shallow ground waters from India and a case study of the role of evapotranspiration in the Indian monsoon. In stable isotope Geochemistry: A Tribute to Samuel Epstein (Eds. H.P. Taylor, Jr., O'Neil, J.R. and Kaplan, I.R.). The Geochemical Society, Special Publication No.3, 187-193.
Kulkarni, K.M., S.V. Navada, A.R. Nair, S.M.Rao, K.Shivanna, U.K. Sinha, Suman Sharma (1997), Drinking water salinity problem in coastal Orissa-Identification of past trasngression of sea by isotope investigation. Intl. Symp. on isotope techniques in the study of past and current environmental changes in the Hydrosphere and Atmosphere, IAEA, Vienna.
Kulkarni, K.M., Shivanna, K., Nair, A.R. and Navada, S.V. (1998), Isotope-hydrogeochemistry of groundwater around Jhamarkotra Phosphate Mines, Rajasthan, Bhujal News, Vol.13, No. 3&4, Dec. 1998, pp. 13-16.
Kumar, B. and B.P. Singh (1979), A quick and accurate calibration of the Gamma-Ray Transmission Method for the study of a soil water system, Applied Radiation and Isotopes 30:493-495.
Kumar, B., Athawale, R. N., and Sahay, K. S. N.(1980), Use of stable isotope method in hydrological investigations with special reference to studies in lower Maner Basin, Andhra Pradesh, Proc. of the Workshop on 'Nuclear Techniques in Hydrology, held on March 19-21, at NGRI, Hydrabad.
Kumar, B. (1982), Development and use of Gamma ray transmission method for the study of moisture profile insitu, Ph.D. Thesis, University of Roorkee, Roorkee.
Kumar, B. and B.P. Singh (1982). Evaporation studies of soil water system using gamma ray transmission method. Proc. of the International Symp. on Hydrological aspects of Mountainous Watersheds, School of Hydrology, Univ. of Roorkee, Roorkee Nov. 4-6. Vol.1.
Kumar, B., and R.C. Saxena (1987), A remedial use of Radio-Isotope Techniques for the study of water logging in Sharda Sahayak Canal Command Area in U.P.,Published in the Proceedings of National Seminar on Impact of Environmental protection on Future Development of India, held on 6-8, April 1987 at Nainital, U.P.
Kumar, B., S.Chandra and B.P. Singh (1993), Movement of Water pulse in soil column by gamma ray transmission method. Jr. of the Inst of Engrs, Civil Engineering Div., Vol. 73, March, pp. 173-179.
Kumar, B., S. V. Navada & Rajan Vatsa (1992), Discharge measurement of river Teesta in Sikkim using tracer dilution method, Intl. Conf. Hyd. of Mountainous areas, 28-30 May, 1992, Shimla, India.

Kumar, B. & Rm.P. Nachiappan (1995), Correction of length of water column in the measurement of seepage loss from water bodies by single well dilution techniques using radio-tracer, IAHS/IAMAS Symposium and Workshop H4 "Comparison of Tracer Technologies for Hydrological Systems, IUGG Assembly, July 3-14, Boulder, USA.

Kumar, B. and Rm.P. Nachiappan (1995), A mathematical approach based on tritium tagging technique to evaluate recharge to groundwater due to monsoon rains, Tracer Technologies for Hydrological Systems (Proc. of a Boulder Symposium, July, 1995) IAHS Publn. No. 229:237-248.

Kumar, B, S.K. Verma and U.K. Singh (1996), Comparative study of soil moisture movement and recharge to groundwater using neutron moisture gauge and tritium tagging technique. Proceedings.

Kumar, B., Rm.P. Nachiappan and S.P. Rai (1998), Hydrological study of lake Nainital, Kumaun Himalayas, U.P.- a project report submitted to Deptt. of Environment, Govt. of U.P., Lucknow.

Kumar, B. and Rm P Nachiappan (1999) 'On the sensitivity of Craig and Gordon model for the estimation of the isotopic composition of lake evaporates'. Water Resour. Res. 35(5):1689-1691.

Kumar, B., Rm. P. Nachiappan and S. P. Rai (1999), Impact of sedimentation on the hydrology of lake Nainital, Kumaun Himalaya, India, Proc. International Conference on Water, Environment, Ecology, Socio-Economics, and Health Engineering (WEESHE), Seoul National University, 18-21 OCtober, 1999, Seoul, Korea.

Kumar, B., Rm. P. Nachiappan, S. P. Rai, Saravana Kumar and S. V. Navada (1999), Improved prediction of life expectancy for a Himalayan lake: Nainital, U.P., India, Mountain Res. and Development 19(2):113-121.

Kumar, B. and Nachiappan, Rm.P., (2000), Estimation of rates/pattern of sedimentation and useful life of Dal-Nagin lake using radiometric dating techniques of sediments, a project report submitted to AHEC, Univ. of Roorkee, U.P., India.

Lal. D. (1970), Silicon-32 hydrology, Proc. of a Symp. on Isotope Hydrology 1970, 9-13 March, IAEA, Vienna.

Mukherjee P. (1986), Isotope technique to monitor seasonal groundwater recharge in a raianfed alluvial sandy loam agricultural field Proc. of a seminar on Water Management in arid and semi-arid zone, H.A.U. Hissar 27-29 Nov.

Munnich, K. O.(1983), 'Moisture movement in unsaturated zone, Guide book on Nuclear techniques in Hydrology, Tec. Rep.Series no. 91, IAEA, Vienna, pp. 203-218.

Nachiappan, Rm. P., Bhishm Kumar, S. V. Navada & S. Balakrishanan (1995), Identification of groundwater isotopic index for surface water - groundwater interaction studies, Extended Abstract, IAEA-SM-336, Intl. Symp. on Isotopes in Water Resour. Mgmt., 20-24 March, IAEA, Vienna.

Nachiappan, Rm. P., Bhishm Kumar (1998), Hydogeochemistry of a mountainous lake in Kumaun Lesser Himalayas'. Presented in the International Seminar on Applied Hydrogeochemistry, Annamalai University, 18-20 November, 1998, Annamalainagar, India.

Nachiappan, Rm. P., Bhishm Kumar (1999), Study of interconnection between a lake and surrounding springs using environmental tracers in Kumaun Lesser Himalayas. Proc. International Symposium #S4 on Integrated methods of catchment hydrology - Tracers and Remote Sensing, IAHS, IUGG Assembly, 22-23 July, 1999, Birmingham, U.K.

Nachiappan, Rm. P. (2000), Surface water-groundwater interaction studies using isotope techniques. Ph.D. Thesis submitted in the Deptt. of Earth Sciences, Univ. of Roorkee, Roorkee.

Nair, A.R., S.V. Navada, S.M. Rao (1999), Isotope study to investigate the origin and age of groundwater along paleochannels inJaisalmer and Ganganagar district of Rajasthan Vedic Saraswati Memoir 42, Geol. Soc. of India. pp 315-320.

Navada, S.V. and Rao, S. M. (1991), Study of Ganga river- groundwater interaction using environmental oxygen-18, Isopenpraxis, 27(8); 380-384.

Navada, S.V. et al. (1984), Potentialities of isotope technique in groundwater recharge studies in Rajasthan - Some field experience. Proc. Symp. on challenging problems of desert environment.

Navada, S.V. et.al. (1986), Application of environmental isotopes in groundwater hydrology. Ind. Journal of Earth Sciences, Vol.13, No. 2-3. pp. 223-234.

Navada, S.V., A.R. Nair, Suman Sharma, and U.P. Kulkarni (1995), Geochemical and isotope studies of geothermal areas of central and northern India. IAEA-TECDOC-799: 63-92.

NGRI (1980), Nuclear Techniques in Hydrology, Proceedings of the Workshop held on March 19-21, 1980 at National Geophysical Research Institute, Hyderabad.

Nigam, D.D. and Bhishm Kumar (1980), A method of calculating recharge to ground water and flow of ground water from/to rivers using tritium, Workshop on Nuclear Techniques in Hydrology, N.G.R.I., Hyderabad, March 19-21, pp. 92-102.

Nijampurkar, V.N., (1974), Application of cosmic ray produces isotope Silicon-32 to hydrology with special reference to dating of groundwaters. Ph.D. Thesis, Unpublished. Bombay University.

Pande, K., J.T. Padia, R. Ramesh & K.K. Sharma (1999), Stable isotope systematics of surface water bodies in the Himalayan and Trans-Himalayan (Kashmir) region Proc. Ind. Acad. Sci. (Earth. Planet.Sci.).

Rai, S.P.et al (2000), Estimation of rates/pattern of sedimentation and useful life of Dal-Nagin lake using radiometric dating techniques of sediments, submitted to Deptt. of Pollution Control, J&K, India.

Raja, R.K., Anil Kumar, Chhabra, S.S. (1983), Estimation of groundwater recharge by isotopic method. T.M. No.54-RR(G-8) and 54-RR(G-9).

Ramesh, R. and M.M. Sarin (1982), Stable isotope study of Ganga-Brahmaputra river system, J.Hydrology, 139,49-62.

Ramesh, R., R.A. Jani & R. Bhushan (1993), Stable isotopic evidence for the origin of water in the salt lakes of Rajasthan and Gujarat. J. Arid. Environments 25, 117-123.

Rao, M.S., Bhishm Kumar and Nachiappan, Rm.P. (2000), Identification of aquifer recharge sources and zones in part of Ganga-Yamuna Doab using environmental isotopes. Accepted for presentation in ICIWRM to be held on 19-21 Dec., 2000 in New Delhi.

Saksena, R. S., Satish Chandra and B.P. Singh (1974), A Gamma ray transmission method for the determination of moisture contents in soils J. of Hydrology 23 (1974), 341-352.

Saravanakumar, S. V. Navada, S. M. Rao, Rm. P. Nachiappan, Bhishm Kumar, T. M. Krishnamoorthy, S. K. Jha and V. K. Shukla (1999), 'Determination of recent sedimentation rates and pattern in Lake Naini, India by ^{210}Pb and ^{137}Cs dating techniques'. Applied Radiation and Isotopes 51:97-105.

Saravanakumar, U., V.P.Kulkarni, S.V.Navada and K.Vasu (1994), Isotopic investigation of lake pookot, Wynad District, Kerala. Presented at Water Congress held at CWRDM, Kozhikode.

Shivanna, K., S.V. Navada, A.R. Nair, K.M. Kulkarni, S.M. Rao (1998), Isotope Geochemical evidences of groundwater salinity and climatic change in east coast of India. Proc. Symp. Late Quatemary Geology and Sea level changes, Cochin.

Shivanna,K., S.V. Navada, K.M. Kulkarni, U.K. Sinha, S. Sharma (1998), Application of isotope techniques to investigate groundwater pollution in India, IAEA-TECDOC-1046.

Singh, B. P. and Bhishm Kumar (1988), Gamma-ray transmission method for the study of soil-water characteristics, Indian Journal of Pure and Applied Physics,Vol.26, May 1988, PP. 376-379.

Singh, B. P. and Satish Chandra (1977), Evaluation of the optimum thickness of soil between source and detector in gamma ray transmission method. J. of Hydrology, Vol.32. 189-191.

Singhal, M.K. et.al (1978), Flow rate measurement of mountainous river by isotopic tracer. Proc. of a Symp. on study and management of water resources in arid and semiarid regions, PRL, Ahmedabad.

Sinha, R. et.al. (2000), Hydrogen and oxygen isotopic analysis of Antarctic lake waters. Current Science, Vol. 78, No.8, April 25.

Somayajulu, B. L. K., D.N. Yadav and M M Sarin (1994), Recent sedimentary records from the Arabian Sea. Proc. Indian Acad. Sci. Vol.103. No.2. June. pp.315-327.

Somayajulu, B.L.K. (1969), Cosmic ray produced ^{32}Si in near coastal waters, Proc. Ind. Acad. Science LXIX , 338.

Sukhija, B.S. (1978), Ground water recharge rates in semi-arid region of India using environmental tritium. Proc. of a Symp. on Study and management of Water Resources in Arid and Semi-arid region, held at PRL, Ahmedabad, 1978.

Sukhija, B.S. et.al. (1996), The use of environmental isotopes and chloride as natural tracers to investigate the effects of depressurisation of a coastal aquifer for lignite mining, India Hydrogeology J., 4, 70-88.

Sukhija, B.S. et.al. (1997), Environmental tracers and hydrodynamics of over-exploited aquifers. Gambling with Groundwater-Physical, Chemical and Biological Aspects of Aquifer-Stream Relations Brahama et.al., (eds.) pp. 521-526.

Tyagi, S.K. Datta, P.S. Mookerjee, P. and Bhattacharya, S.K. (1997), Delineation of groundwater zones and contamination characteristics based on ^{18}O isotopic and SO_4 data. proc. 2nd Intn. R&G Conference on Water and Energy, CBIP Publication, 21-24 Oct.,. Vadodara.

UP IRI, Roorkee (1971), Measurement of seepage losses by tracer technique and seepage meter method. Working paper, 29th Zonal meeting of CBIP Krishna Raja Sagar.

UP IRI, Roorkee (1984), Final report on estimation of seepage loss from canals by radio isotopes, T.M. No.54 - RR (G-15), 1984.

Yadav, D. N. (1997), Oxygen isotope study of evaporating brines in Sambhar Lake, Rajasthan (India). Chem. Geol. (Isotope geoscience):

Yelgoankar,V.N., A.S.Pendharkar, S.M.Agashe, U.S.Kumar, S.V.Navada, U.P.Kulkarni, G.N. Mendhekar (1968), Radiotracer study to investigate the dilution and dispersion of sewage off Worli coast. Proc. Int.Conf. on Application of radioisotopes and radiation in Industrial Development Mumbai. pp 350-354.