ISOTOPE HYDROLOGY IN INDIA

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INTRODUCTION

The primary function of hydrology is to provide scientific facts about water in hydrological cycle. This is being done using sophisticated scientific instrumentation and methods for managing water resources under very difficult conditions. It is always planned to get the maximum benefit of water resources with minimum harm to the environment.

The first discussion on the hydrological application of isotopes was conducted by a panel of experts on 6-9 November 1961 in Vienna at the IAEA headquarters[1]. Two years later, in Tokyo, the IAEA sponsored the first International Symposium on the Application of Isotope Techniques in Hydrology[2] which recorded 27 important papers reporting progress on various research projects. IAEA Vienna had been organizing international symposium at regular interval in the years 1967, 1970, 1974, 1978, 1983, 1987, 1991[3-7].

The application of radioisotopes had been initiated in India in early 1960's by the Tata Institute of Fundamental Research to determine the age of ground Water and recharge to ground water bodies in Gujarat and Rajasthan. An All India Symposium on Radioactivity and Meteorology of Radionuclides was also organized by Atomic Energy Establishment, Trombay, Bombay in 1966 in which a few research papers related to application of radioisotopes in hydrological investigations were presented.The national symposium on the 'Application of Isotope Techniques in Hydrology and Hydraulics' was held on 26-27 November 1974 at Central Water and Power Research Station, Poona[8], organized by DAE.The national symposium on 'Isotope Application in Industry' was organized by BARC on 2-5 February 1977 in Bombay[9] and a workshop on 'Nuclear Techniques in Hydrology' was organized by Department of Atomic Energy in March 19-21 1980 at National Geophysical Research Institute (NGRI), Hyderabad[10]. A workshop on 'Isotope Hydrology' was organized by DAE at BARC in 1983 and a seminar on 'applications of Isotopes' in 1987. In 1990, a symposium on 'Tritium measurements and applications' was also organized by DAE at BARC, Bombay. Now, it has been a practice to include one or two sessions on 'Application of Nuclear Techniques in Hydrology' in almost all national/international seminars/ symposiums organized in India.

School of Hydrology (now Department of Hydrology), University of Roorkee, Roorkee took up the teaching programme (one unit course) as elective course for master's

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degree in Hydrology, and experts from IAEA, Vienna, under UNDP project, prepared a standard model course for master's programme in the year 1974-75. The contents of the course covered almost the entire research component and development as reported in IAEA publication[11]. The teaching of nuclear hydrology in some form or other, in various courses is also being done at different universities/institutions in India.

ISOTOPES AND HYDROLOGICAL INVESTIGATIONS

A. ENVIRONMENTAL ISOTOPES (STABLE)

The atoms of an element having different atomic numbers but the same atomic weight are known as its isotopes. Isotopes are of two types i.e., stable and radioactive. The stable isotopes of water molecule i.e., ^{1}H, ^{2}H, ^{16}O, ^{17}O and ^{18}O which do not decay with time, but it is significant that various species are formed like ^{1}H ^{16}O, ^{1}H ^{2}H ^{16}O, $^{1}H_2$ ^{18}O etc. and these species vary due to various physical processes in hydrological cycle. The ratio of D/H and $^{18}O/^{16}O$ are measured by using mass spectrometers and compared with ocean water as standard (SMOW). Mass spectrometeric facilities are available at NGRI, Hyderabad; Hydrology and Tracer Section,Isotope Division, BARC, Bombay and Physical Research Laboratory, Ahmedabad as national facilities which are exclusively used for nuclear hydrological studies. Mass spectrometeric facilities are also available with Defence Laboratory, Jodhpur, Nuclear Research Laboratory, IARI, New Delhi, Atomic Minerals Division, Hyderabad and ONGC, Dehradun for the measurement of stable isotopes mass ratios.

NGRI has carried out integrated geohydrological investigations in the lower Maner basin in Andhra Pradesh by analyzing the water samples for D/H and ^{18}O and ^{16}O ratios. D and ^{18}O values of 1977 precipitation samples showed a linear correlation while the results obtained from lakes, Maner river, its tributaries and dug wells provide very interesting information regarding evaporation effect and interrelationship of precipitation, surface and sub surface water. Isotope balance studies showed that the Masueancha stream, the only perennial tributary to the Maner, in the basin, is sustained during summer season mainly through the contribution from lake water. Groundwater isotopic data revealed that the recharge to phreatic aquifers in different geological units of the basin is mainly due to direct percolation of the precipitation (B.Kumar et al)[12].

The NGRI, Hyderabad in collaboration with Central ground Water Board have carried out various studies like delineation and interconnections between aquifers and identification of recharge zones etc. in the Vedavati river basin in Tamil Nadu and Kerala, Union Territory of Pondichery, Pambar Manimuttar river basins in Ramanathanpuram district and Neyveli area in South Arcot district in Tamil Nadu.

Isotope Division of BARC has used stable isotopes extensively in the study of (i) seepage from Chilla Hydel Channel UP, (ii) source of recharge to the groundwater in Jalore area of Barmer Distt.,Rajasthan, (iii) salinization of groundwater in coastal Minjur aquifer near Madras, in Midnapore district of West Bengal, and (iv) salinization of groundwater in some parts of Haryana[13], (v) interconnection between aquifers in Cauvery delta, (vi) surface water and groundwater interaction along river Ganga, (vii) origin of isothermal water, (viii) mixing of deep hot waters with shallow cold waters in Jatapai (MP) and (ix) hot springs in some parts of Bihar, W. Bengal and Orissa.

Physical Research Laboratory group have carried out the studies of D and ^{18}O isotopic ratios in groundwater as well as waters of rivers, lakes and hot springs etc. taken from a variety of locations in India. The groundwaters showed a large continental effect (isotopic variation with distance from coast) both in western and eastern sectors. Studies showed the most depleted ^{18}O values in the subcontinent in the high altitude lakes in Bhutan followed by Upper reaches of Ganga at Devprayag and Rishikesh, obviously due to meltwaters of Himalayan glaciers[14].

Defence Laboratory, Jodhpur and Nuclear Research Laboratory, IARI, New Delhi have also carried out studies like recharge to groundwater and period of recharge of deep groundwater bodies in Rajasthan and studies of evaporation from root zone in the areas near Delhi respectively.

B. ENVIRONMENTAL ISOTOPES (RADIOACTIVE)

Tritium (^3H) and Carbon-14 (^{14}C) are produced by cosmic radiations and introduced by thermonuclear explosion in the atmosphere. These are injected in the hydrological cycle by natural process. Measurement of very small quantity of these two radioactive isotopes is very tedius. At present, three institutes, namely BARC, Bombay; NGRI, Hyderabad, and PRL Ahmedabad have such facilities in India.

The tritium (half life 12.23 years) used to determine the age of ground water ranging up to 100 years. The carbon-14 (half life 5700 years) is used to determine the age of ground water ranging up to 50,000 years. The Tata Institute of Fundamental Research (TIFR) group[15] and PRL[16] group of scientists had carried out the chronological studies in Gujarat and Maharashtra using tritium and carbon-14. The TIFR group[17-19] had introduced the use of silicon-32, for the age detection of ground water. Silicon-32 (half life only 500 years) is used to determine the age of ground water ranging up to 1000 to 2000 years. In fact, it was a long felt need to find out an environmental isotope for the determination of the age of water between the range of 100 years (T) and 50,000 (^{14}C) and therefore, ^{32}Si had filled this gap. However, ^{32}Si age dating is very complex and also the half-life is uncertain. Its recent estimate is about 100 years.

The PRL and TIFR group of scientist have also determined the regional flow velocities and residence times using environmental tritium, carbon-14 and silicon -32 in different aquifers at various places in the country.

Environmental tritium and radio-carbon studies were also carried out in Vedavati River basin, situated partly in Karnataka and partly in Andhra Pradesh, to determine the general recharge conditions of the aquifers and interconnections of groundwater bodies and age of groundwater. About 40 samples of groundwater were analyzed and found that the water bodies are not interconnected and groundwater belongs to an age of 25 years except at few places.

The NGRI has also carried out recharge measurement studies using environmental tritium technique at three sites in Lower Maner basin falling in Karimnagar district of Andhra Pradesh. The recharge to ground water through soil profiles in granitic and sedimentary terrains were calculated using the 1963 peak in tritium introduced by atomic bomb testing in atmosphere and also by using the integrated tritium method

(Sukhija)[20] groundwater dating using radiocarbon and recharge studies using environmental tritium in various parts of Gujarat and Maharashtra.

BARC[21] has carried out studies of recharge to groundwater and dating of deep groundwaters in Rajasthan. Study of seepage from tail race tunnel at Salar hydroelectric project, interconnection of aquifers in the Cauvery delta in Tamil Nadu have also been carried out by Hydrology and Tracer Section of BARC, Bombay[22] using environmental isotopes. BARC has also carried out studies of groundwater salinity and recharge in Madinapore, West Bengal and in coastal Orissa using environmental tritium and Carbon-14.

PRL scientists[23-26] have carried out radiocarbon dating of groundwater to estimate regional aquifer transmissivity in Watrak Shedi sub basin (of Sabarmati Basin) for a group of aquifers between 30-80 m. depth. The value of transmissivity, 7640 m^2/day estimated by this method was found to be in fair agreement with the values obtained by pumping test.

C. ARTIFICIAL ISOTOPES (RADIOACTIVE)

Radioactive isotopes are produced artificially under controlled conditions in laboratory as wellas in nuclear reactors. The artificial radioisotopes are frequently used for various hydrological investigations as tracers. Some of the important isotopes are: Br-82 as pottassium bromide, I-131 as pottassium iodide, Cr-51 as Chromium EDTA, Co-60 as pottassium cobalt cyanide, Au-198 in hydrochloric acid. Co-60, Cs-137, Am-241 as by-products in fission fragments. These three later sources are used as sealed radioactive sources.

Radioactive isotopes have three unique properties which are particularly useful in hydrology, i.e. penetrability of radiations, radioactive decay with time and detectability in minute quantity. The artificial radioisotopes can be obtained from Bhabha-Atomic Research Centre, Trombay. Bombay while the required equipment can be procured from Electronics Corporation of India Ltd., Cherapalli, Hyderabad and few other private organisations.

The details of few techniques which are mostly used in hydrological investigations using various artificial radioisotopes with the research component done in India are given below.

i) Injected Tracer Techniques

One of the most important applications of isotopes in the field of hydrology is on the stress from the basic principle of tracing technique. There are two major requirements for a tracer i.e. (i) it must behave exactly like the traced material. (ii) it must have at least one property that distinguishes it from traced material so that it can be easily detected.

The availability of a variety of radioactive isotopes with half lives extending from a few seconds to thousands of years and their easy detection in situ even in very small quantity/concentration make them a very useful tool to be employed in hydrological investigations as tracers. The advantages of radioactive isotope in tracing experiments are as follows:

i. Emission of radiations is not affected by physical and chemical conditions of the environment.

ii. It is very easy to detect very low concentration of radioactive tracer.

iii. The place of injection can be well defined and remains known very accurately.

iv. Precise quantitative interpretations are often possible from radioactive tracing experiments by following the time evaluation and space distribution of injected tracer.

The information obtained from artificial tracer experiments for a given hydrologic system is confined to a particular selected region.

There are many uses of injected tracers in hydrology, some of them are described here.

(a) Tritium Tagging Technique for Recharge Studies.

The tritium tagging techniques for the estimation of recharge is based on the assumption that the downward movement of soil moisture follow the piston model flow[27-28] 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.

In tritium tagging technique, tritium of specific activity is injected at a certain depth, well below the root zone and also beyond the sun heating effect. The soil moisture so tagged by injecting tritium moves downwards along with the infiltrated water due to subsequent precipitation or irrigation. The soil samples from the premarked point of injection are collected from different depths after a chosen interval of time. The soil samples are treated for distillation and tritium activity is measured for the calculation of recharge to groundwater.

Pioneering work in India using tritium tagging technique was carried out by TIFR and Kanpur group[29]. They[30] 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, 46 cm and 47 cm respectively. Datta et al also measured the rate of downward movement of soil water along with groundwater recharge in Sabarmati basin in Gujarat covering an area of 22000 sq km . The downward movement rate varied from 5 cm /yr to 280 cm/yr. while recharge value was found to be 10% of the average rainfall, 80 cm. Datta et al[31-34] have also developed a conceptual model for the study of transport of soil water or recharge through unsaturated soil zone.

NGRI Hyderabad group[35] has estimated recharge to the phreatic aquifer of lower Maner basin, covering 1600 sq km area and having seven different geological formations using tritium tagging technique and found the recharge values ranging from 4.7 cm to 24 cm with an average for the entire basin, 9.5 cm for annual average rainfall.

125 cm. The NGRI group[36,37] has also carried out the recharge measurements in few basins namely, Godavari-Purna basin, the Kukadi basin in Deccan traps and Banganga basin between Jaipur and Agra.

PRL group[26,38] have completed two major projects i.e. Sabarmati Hydrology Project and Isotopic Study of Soil Moisture Movement in Thar Desert. The scientists of PRL used various radioisotopes like tritium, radiocarbon, Si-32 and uranium isotopes along with dissolved chemical constituents to find out the values of groundwater recharge from infiltration of rain water in Sabarmati basin, Mahi Right bank canal command area and coastal Saurashtra.

About forty representative stations were established in different parts of the Sabarmati basin and 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 was estimated to be stored in the Sabarmati basin[39-41]. In Mahi right bank canal command area, the percentage of recharge to groundwater was estimated little higher (23%) indicating a high return flow from irrigation[42]. A comparison drawn from the results of recharge obtained in sabarmati basin with those for the Ganga, the Ramganga and the Yamuna basins in northern India indicated a relatively higher groundwater recharge (18%).

Empirical formulae based on the experimental results have also been established by PRL scientists[43]. Studies of soil moisture movement and groundwater recharge carried out by PRL scientists in Thar desert using tritium tagging method indicated the factors which control groundwater recharge . The groundwater recharge was found to vary between 5-14% of the rainfall.

Simple conceptual models to visualize the flow mechanism as well as to predict tracer/pollutant movement during unsaturated and saturated flow have also been developed by PRL scientists. The process of dispersion and mixing during transport of water is mathematically simulated using the model[44-47].

NRL, IARI group[48,49] have also carried out study of recharge to groundwater in rain fed ailuvial area and in IARI farm using tritium tagging technique.

The BARC group of scientists[50] have used potassium cobalt-cyanide, $K_3{}^{60}Co(CN)_6$ as a tracer instead of tritium for recharge measurements and reported its advantage over the tritium for recharge measurements. Its movement can be monitored in situ by radiations logging of the ^{60}Co through an adjacent bore hole.

BARC group has also carried out study of recharge to groundwater using tritium tracer in Tapi alluvial region in Maharashtra and in some parts of Rajasthan. Some studies are also carried out in Karnataka.

IARI group 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. IARI group[51,52] has also studied the requirement of water by plants using radioisotopes.

University of Roorkee[53] has studied the recharge to ground water due to rains using tritium tagging technique in Sharda command area of Uttar Pradesh. UP IRI group[54] has also carried out extensive studies for the study of recharge to ground water using this technique in eastern districts of Uttar Pradesh.

The UP GWD Group, Lucknow[55] has also covered the Bundelkhand districts of UP by doing yearly study of recharge to groundwater due to rain and irrigation using tritium technique. The studies are also being carried out in Vindhyan region and other districts in U.P. The results of the recharge to groundwater due to rains in rainy seasons varied from 9% to 29% in Bundelkhand region.

(b) Bore hole Dilution Tracer Technique for Various Hydrological Studies

The artificial radioisotopes like Iodine-131, Bromine-82 and Tritium are generally used as a tracer to get the various hydrological informations like:

1. Velocity, direction and seepage loss of water from water bodies
2. Aquifer characteristics like porosity, transmissivity, hydraulic conductivity etc.
3. Interaction of water bodies and stratification of aquifers.
4. Location of barriers in ground water flow
5. Flow net analysis

The basic principle of these studies is based on the change in tracer concentration with the inflow of water. By knowing the rate of change of tracer concentration, the groundwater flow velocity is determined. Once the groundwater velocity is determined, the permeability/hydraulic conductivity of an aquifer can be determined by knowing hydraulic gradient which can be measured in situ by knowing the piezometric head at different distances from the bore hole.

In order to calculate the porosity, transmissivity etc., the tracer is introduced in one well and water is pumped from the other well situated at a distance. The water samples from the pumped water are collected and radioactivity is measured. Thus, by knowing the volume of pumped water, the effective porosity and transmissivity of the aquifer are determined.

Seepage from the canals or dams can also be determined by using the bore hole dilution technique. The scientists of BARC[56-58], CWPRS[59-69], .UPIRI, Roorkee[70,71], U.O.R.,Roorkee, UPGWD, IPRI, Amritsar and NRL (IARI) have carried out several experiments to measure the seepage loss from canals. A few experiments were carried out at Supagora Dam site of Kalinadi Hydroelectric Project in Karnataka and at Sean Harabagh tunnel in Himachal Pradesh and found filtration velocities 1.4 $\times 10^{-4}$ to 2.12 $\times 10^{-5}$ cm/sec. and 6.5 $\times$ 10^{-7} cm/sec using tritium dilution technique near Supagora dam and Harabagh tunnel respectively.

IPRI Amritsar Group of scientists have also carried out extensive field experiments along various canals in Punjab and determined seepage loss using tritium dilution technique. An empirical relation has also been established by IPRI which is known as Punjab formula, $P = 5 * Q^{0.0625}$, where Q is the discharge of canal and P is seepage loss.

UPIRI, Roorkee scientists have carried out experiments along various canals in Bundelkhand, Vindhyan region and also in alluvial plains in UP and found wide ranges of seepage loss from different canals. The scientists of UP GWD, Lucknow[73] have also carried out several experiments along the various canals in Sharda Sahayak Canal Command area and also along Upper Ganga Canal and suggested an empirical relation which can be used to calculate the actual value of filtration velocity for the correct estimation of seepage loss from canals.

Few experiments were carried out in Sikar basin in Rajasthan in 1974 for investigating hydraulic characteristics. The porosity was found to be 3.2%, 8.4% and 10.9% with an average of 7.5%. The average values of hydraulic conductivity and transmissivity were found to be 3 m/day and 222 m^2/day respectively.

Hydrology and Tracer Section of Isotope Division, BARC, Bombay has developed a point dilution probe for the measurement of groundwater velocity in situ.

ii) SOIL MOISTURE AND DENSITY PROBES:

Neutron-scattering probe for the determination of moisture content in soil strata is now commercially available. This probe is used to monitor the moisture content in situ at various depths. This equipment is available commercially. Many Neutron probes are now available with various Research and academic institutions in India. Neutron moisture probe has also been used for the study of Civil Engineering Problems.

Gamma ray scattering probes are used to find the soil density at different depths.The change in soil density due to the presence of water is recorded, thereby the profile of moisture is determined. Few Gamma ray scattering probes are available at various institutions in India.

These two probes, though commercially available, are not used by various institutes extensively. One can use these probes to determine the change in moisture content in unsaturated zone (Kiran Shankara et al[74]) due to rains and irrigation and subsequently, can be the data to determine the recharge values.

Neutron moisture probe has been also used at NIH Roorkee for the study of soil moisture profile and recharge to groundwater.

iii) Gamma Ray Transmission Technique

This is the method developed by a group of scientists[75-85] at University of Roorkee (Department of Physics and School of Hydrology). This techniques has been used by the scientists at UP Ground Water Department for various hydrological studies and now is being used at National Institute of Hydrology, Roorkee.

In Gamma ray transmission technique, radioactive source ^{60}Co or ^{137}Cs and detector [NaI (Tl), photomultiplier, spectrometer] are mounted at some distance in two tubes in such a manner that both can be lowered simultaneously without disturbing the geometry of source and detector. The attenuation of the intensity of the gamma radiations by soil moisture system can be used to measure the soil density. The mass absorption coefficient for various elements commonly found in the soil, is same while for hydrogen atom, it is quite large. This fact is exploited to determine the moisture content of the soil by Gamma ray transmission method. Details of this technique are available in the Ph.D thesis entitled, 'Development and use f Gamma Ray Transmission Technique for the Study of Soil Moisture Profile in situ'[(75)]. at U.O.R., Roorkee.

D. OTHER STUDIES USING RADIOISOTOPES

Discharge measurement of mountainous stream/rivers have also been carried out in India using radioisotope tracer technique by many organisations. UP IRI[(86)] has 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 model of Lakhwar Vyasi Dam using tritium as tracer.

BARC has also carried out the measurements of discharge in many rivers and streams including Tapti and Beas using Bromine -82 and Tritium as radioactive tracers.

Recently National Institute of Hydrology has also carried out discharge measurement study on river Teesta in Sikkim using ^{82}Br and ^{3}H in collaboration with BARC, Bombay.

Leakages/seepages from Dams/channels have also been studied extensively in India using radioactive isotopes. BARC has carried out leakage studies in Srisailem, Bhadra, Aliyar, Kadana, Poip and Dimbha, Supa and Lakya dams. CWPRS, Pune[(87-95)] has carried out many experiments for the study of leakage/seepage from various dams like Pench in Maharashtra, Koyna, Ukai and Navagam in Gujarat, Kota Barrage in Rajasthan using Gold -198, Bromine-82 and tritium.

Sediment transport studies have also been carried out in India mainly by Bhabha Atomic Research Centre, Bombay. Over 40 large scale sediment transport studies using ^{46}Sc as glass mainly in all major and medium ports along the Indian coastline to examine the suitability of dumping sites for dredged silt as well as the alignment of navigational channels.

PRL group has used seasonal variation of Uranium concentration (^{235}U, dpm/l) and its isotopic ratio (^{235}U/ ^{238}U) as tracers to estimate effluent discharge of groundwater into the Sabarmati river. The study indicated that about 7% of annual discharge through the river upstream of Ahmedabad, was derived from effluent groundwater discharge, the maximum contribution being 25% at some points of river.

Groundwater pollution and dynamics of geothermal waters have also been studied by BARC using artificial and environmental isotopes including stable isotopes.

CWPRS extends the facility to calibrate the various nucleonic gauges. Board of Radiation and Technology (BRIT) Bombay in association with Isotope Division, with the consent of Division of Radiological Protection (DRP) of BARC provides the required radioactive sources at reasonable price. DRP, BARC provides the facility of radiation monitoring service to the users and also train the users for taking the necessary radiological safety aspects during the use of radioisotopes.

Studies on snow and glacier were probably carried out in India during as early period as Mughal period or earlier, but, systematic studies started with snow surveys by Dr. Church in 1947 [Bahadur et al.][96]. During 1969, the Indian National Committee in International Hydrological Programme appointed high level Committee on snow, Ice and Glaciers. Some studies like glacier mass balance, thermal profiling of ice body, hydrometeorological body observations, glacier dynamics, artificial melting of snow and ice, geomorphological and also the isotopic investigations were conducted and reports, papers, technical notes etc. on physical description,approach to the glacier, geological and geomorphological information,monitoring of meteorological parameters and advancement, recession of snout of the glaciers along with the mass balance and ice movement conducted by the conventional methods started coming up by a number of organisations like Geological Survey of India (GSI) and Department of Science and Technology (DST) etc.

At present, a number of organisations, departments andacademic institutions like India Meteorological Department (IMD), snow and Avalanche Study Establishment (SASE), Mineral Development and Exploration Division of Geological Survey of India (GSI), Survey of India (SOI),Department of Science & Technology (DST), Central Water Commission (CWC), National Remote Sensing Agency (NRSA), Physical Research Laboratory (PRL), and National Institute of Hydrology, Bhabha Atomic Research Centre (BARC) are involved in snow cover mapping and snow pack studies for determination and modelling of the water equivalent, runoff due to snow melt and impact of changing behaviour of the glaciers on runoff processes.

Indian contribution have been mostly around the Himalaya which contains nearly trillion cubic metre of water in its glaciers comparable to the total groundwater resource of the country. Nijampurkar et al.[97] dated the glaciers with environmental isotopes. The possibility of study the receding behaviour by isotopic technique was suggested. A review of the isotopic technique for snow and glacier hydrology has been made by Bahadur[98] and Jain et al.[99]. Nijampurkar[100] has also reported the investigations of Himalayan glaciers using radioactive and stable isotopes. It was reported that study of radioactive tracers can provide quantitative estimates in understanding the behaviour of glaciers in the past. Nijampurkar and Rao[101] carried out the studies pertaining the dynamics of the glacier ice, past accumulation rate of ice, climatic variations and chemical pollution using stable isotopes, natural and artificial isotopes and chemical tracers. Nijampurkar et al.[102] reviewed the glaciological studies in Himalayan using radioisotopes.

The works carried out in India, by use of environmental radioisotopes include dating of ice samples to obtain glacier flow rates by monitoring of beta-activity and measurement of Lead-210, Silicon-32.

The main works carried out and techniques of isotopes used in Hydrology in India are given but it is in no way a complete document.

FUTURE PROSPECTS IN INDIA

The Tarai and Bhawer 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 water has not been possible so far. Isotope techniques employing environmental stable isotopes, (^{18}O, ^{2}H), can be used for the identification of the recharge zone and evaluation of water available round the year in order to plan the future schemes to utilize the water.

The study of water balance and sedimentation rates in natural lakes in India using isotopes have not been attempted so far. Information is also required on the recharge zone and sources of supply of water to the lakes. Isotope techniques using environmental stable and radioactive isotopes can be used with advantage for obtaining above information for carrying out water balance and taking necessary measures for maintaining environmentally sound echo system and taking steps for maintaining ecological balance of the region. Water balance study of artificial lakes at the dam site has not been done.

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 and groundwater form a very important element of estimation of water availability and programme of proper planning for various uses. The information on surface water and groundwater interaction can be obtained with advantage by the use of stable isotope and artificial radioisotopes.

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

The construction of dams in mountainous region with basaltic foundation pose a problem of seepage and leakage through the foundation of the dam and bed of the 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 specially in northern India. The evaluation of water equivalent of snow and snow and glacier melt are important element of water resources estimation. Isotopic snow gauges have been used for estimation of 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 to be explored.

Evaluation of movement of soil moisture through the unsaturated zone of the porous media, recharge to groundwater and availability of soil moisture at different times in the top soil for agricultural production are very important problems. These problems can be handled with more reliability using gamma ray transmission and neutron scattering probes. Gamma ray transmission technique has been found to be very suitable for these studies through laboratory and pilot studies. There is a necessity 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 problems of salinity being experienced specially, in areas where old waters of the saline nature are available. This situation has been experienced in Uttar Pradesh, Punjab, Haryana and in Northern Rajasthan. The dating of deeper saline water and tracing out the saline zone using suitable radioisotopes can help in taking necessary safety precautions to save the deeper aquifers from the further salinization.

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

The National Institute of Hydrology has recently initiated studies in the area of nuclear application to hydrology. The study programme relate to the identification of recharge zone, surface water and groundwater interaction, lake water balance and sedimentation, soil moisture movement and recharge to groundwater, stream flow measurement in mountainous rivers and leakage/seepage from dams and irrigation works. The programme of the Institute is examined and recommended by a Working Group constituted for this purpose.

In order to give a boost and to have a coordinated effort, for planing activities in the area of application of nuclear techniques to water and related agricultural areas by the various organizations, there is a need of establishment of national committee on Nuclear Application in the Area of Hydrology and Water Resources and Applied disciplines to be coordinated by BARC.

ACKNOWLEDGEMENT:

The authors are thankful to Dr. S. V. Navada, H & T Section of BARC, Bombay for providing useful information and suggestions in the preparation of this chapter.

LIST OF THE VARIOUS ORGANIZATIONS, INSTITUTES ENGAGED IN THE USE OF ISOTOPES FOR HYDROLOGICAL STUDIES IN INDIA

1. Bhabha Atomic Research centre, Trombay, Bombay
2. National Geophysical Research Institute, Hyderabad
3. Physical Research Laboratory, Ahmedabad
4. Nuclear Research Laboratory, Indian Agricultural Research Institute New, Delhi.
5. Central Water and Power Research Station (CWPRS), Pune
6. UP Irrigation Research Institute, Roorkee
7. UP Ground Water Department, Lucknow
8. Defence Laboratory, Jodhpur
9. Haryana State Minor Irrigation and Tube well Corporation, Karnal, Haryana.

10. Irrigation and Power Research Institute, Amritsar.
11. Maharashtra Engineering Research Institute (MERI), Nasik, Maharashtra.
12. Water Resources Development and Training Centre and Department of Hydrology, University of Roorkee, Roorkee
13. Centre for Water Resources Development and Management (CWRDM), Calicut, Kerala.
14. Ground Water Survey and Development Agency, Maharashtra
15. Department of Chemistry, IIT Kanpur
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