USE OF OXYGEN 18- ISOTOPE FOR SOIL MOISTURE MOVEMENT IN UNSATURATION ZONE

A

Dissertation

Submitted in partial fulfillment of the requirement for the

award of the degree of

of

MASTER OF SCIENCE

IN

PHYSICS
(Specialization in Applied Electronics)

By

SHWETA RANI

Under the supervision of

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Session 2015-2016

CANDIDATE'S DECLARATION

I hereby declare that the dissertation work, entitled **"USE OF OXYGEN-18 ISOTOPE FOR SOIL MOISTURE MOVEMENT IN UNSATURATION ZONE"** is an authentic record of the work carried out by me under the supervision of **Dr. Rajendra kumar, Prof. & Head, Dr. M.S.Rao** and **Dr. Sudhir Kumar** is being submitted for the partial fulfillment of the requirements for award of the degree of **Master of Science** in **Physics (Specialization in Applied Electronics).** The matter Presented in the dissertation has not been submitted by me for the award of any other **Degree/ Diploma** of this **Vishwavidyalaya** or any other **University/Institute.**

Date: 10.06.2016.

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Department of Physics

CERTIFICATE

This is certified that the dissertation work entitled **" Use of Oxygen-18 Isotope for soil Moisture Movement in Unsaturation Zone"** completed by **Shweta Rani**, M.Sc. Physics (session 2015-2016) is an authentic work and has been carried out by him / her in National Institute of Hydrology, Roorkee under my Supervision. I have gone through his / her work, which has been found satisfactory for the fulfilment of the requirement for the award of the Degree of **Master of Science** in **Physics (Specialization in Applied Electronics).**

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SHWETA RANI

Shweta.

NATIONAL INSTITUTE OF HYDROLOGY (NIH) INTRODUCTION

THE INSTITUTE

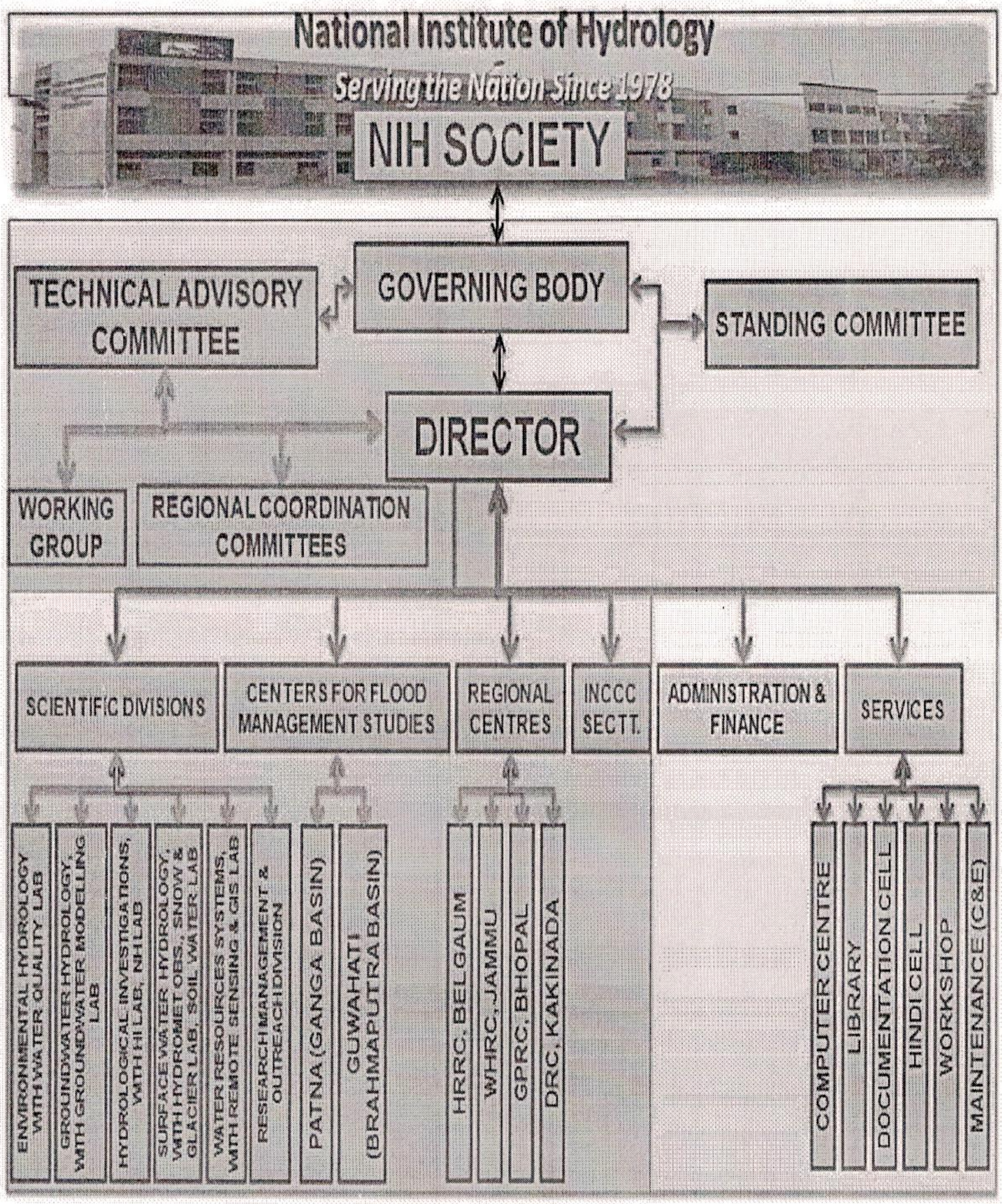
The N.I.H. was set up in 1978 with its Headquarter at Roorkee. It is an autonomous society under the **Ministry of Water Resource Government, of India.** It is that apex body for research and development in the area of Hydrology in India.

RESEARCH ACTIVITY AND FACILITIES

To cover the various scientific and technical activities in all aspects of Hydrology. Institute has a team of 85 well qualified and trained scientists besides supporting scientific, technical and administrative staff to carry out field and laboratory oriented studies. The Institute has established laboratories, created facilities and developed capabilities to cover almost all the aspects and area of Hydrology. The Institute has established a good reference library, large number of scientific book, journal, documented computer programmers, technical reports, Indian and foreign standard atlases, maps related to various areas of Hydrology are available in the library.

The Institute takes up research including laboratory and field studies in important thrust areas of Hydrology and water resource as under:

- Assessment of water resources
- Flood management
- Economical design for water resources project
- Drought and its management
- Water quality
- Soil erosion
- Nuclear Hydrology
- Hydrologic instrumentation etc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HYDROLOGICAL INVESTIGATIONS, WITH HI LAB, NH LAB
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CONTENTS

CHAPTER 1

BASIC ISOTOPES AND CLASSIFICATION

1.1 INTRODUCTION

Rutherford first demonstrated the existence of atomic nucleus. Since then a number of discoveries have been made by various investigators and a numerous facts have come to over knowledge about the atom, nuclei, and its constituents and properties.

Total 109 elements have been discovered which have different physical and chemical properties. Out of 109 elements, 92 occur naturally and 17 have been prepared artificially. These elements are found in the form of solids and gasses except Mercury - a metal and Bromine – a non-metal that is liquid at room temperature.[1]

Thousands and lacks of physical and chemical combinations (mixtures and compounds) have been discovered with amazing properties. Depending upon the specific properties of various atoms and molecules, a number of applications have been discovered in a variety of fields. Isotopes Hydrology is Comparatively a new field of research and deals with the use of different atoms of elements and molecules of compounds for various Hydrology investigations. Modern isotopes research is based on the discovery of the natural abundance of carbon-14 and tritium by WF Libby (1946) and the experimental and theoretical work carried out by H.C. Urey (1947). The development of sophisticated nuclear instrumentation has given a new direction to the investigations and research in the field of isotope Hydrology.

1.2 ISOTOPES

Isotopes are the atoms of same element having same atomic number (Z) but different atomic weight (A). In other words, the atoms of an elements having different number of neutrons(N) but same numbers of protons or elements are called isotopes. For example, Hydrogen has three isotopes having the same atomic number of 1 but different atomic masses weights of 1,2 and 3 respectively i.e.[2,3]

$_1{}^1H_0$ – Only one proton in nucleus and one electron revolving around the nucleus in an orbit.

$_1{}^2H_1$ – One neutron added to nucleus.

$_1{}^3H_2$ – One more neutron added to the nucleus.

Similarly oxygen has eleven isotopes, ^{12}O, ^{13}O, ^{14}O, ^{15}O, ^{16}O, ^{17}O, ^{18}O, ^{19}O, ^{20}O, ^{21}O, ^{22}O but ^{16}O, ^{17}O and ^{18}O all other isotopes are radioactive and their existence in nature is very small (half life vary from 150 seconds to few fem to seconds- of the order 10^{-15} seconds) therefore, we normally talk about only three isotopes of oxygen. The carbon also has three isotopes.

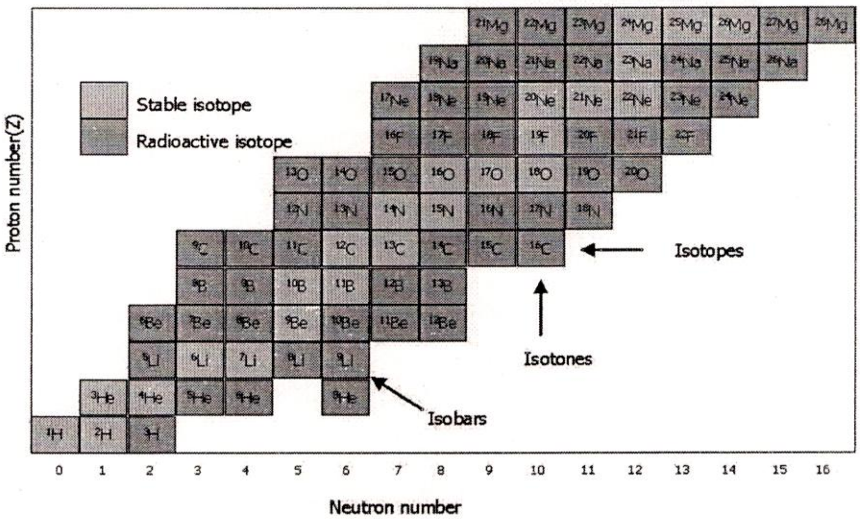


Fig.1.1 The isotopes of an element (equal z) are found in a horizontal row isotopes (equal A) along diagonal lines, isotopes (equal N) in vertical columns

1.3 CLASSIFICATION OF ISOTOPES

The phenomenon of isotope first came to light when it was observed that different radioactive bodies in the natural decay series were found to exhibit identical chemical properties. This led to further research in this field. The term isotope was first introduced in 1913 by Soddy for nuclides which have the same atomic number but different mass numbers. With the introduction of mass spectrograph by Aston by 1919, the discovery of isotopes of all elements known at that time was underway.

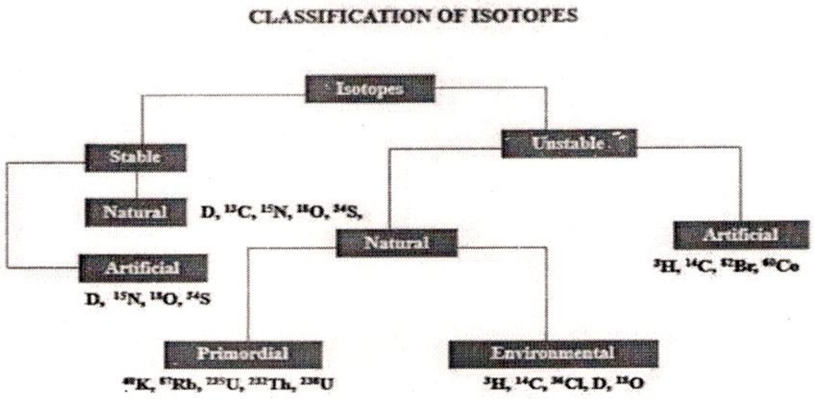


Fig.1.2 Classification of isotopes

1.3.1 Stable isotopes

Stable isotope have a stable proton - neutron combination and do not display any sign of decay. This stability comes from the amount of neutrons present in an atom. Stable isotopes maintain their nuclear structure without changing over time. Examples are ^{1}H, D, ^{13}C, ^{15}N, ^{18}O, ^{17}O .

1.3.2 Unstable isotopes

Unstable isotopes are those, which undergo spontaneous disintegration through the emission of different kind of radiation like alpha, beta, and gamma. The existence of isotopes was first suggested in 1913 by the radio chemist F. Soddy, based on studies of radioactive decay chains that indicated about 40 different species discribed as between uranium and lead, although the periodic table only allowed for 11 elements from uranium to lead. Examples are ^{3}H, ^{14}C, ^{238}U, ^{234}Th.

1.3.3 Natural isotopes

Natural isotopes are those isotopes, which are naturally present or being produced by the environment. In the periodic table the element contain three naturally occurring radioactive series. They are uranium series, actinium series and the thorium series. Natural isotope again classified into primordial and environmental isotopes.

1.3.4 Artificial isotopes

There are 20 elements that only have artificially produced isotopes, the majorities are heavier elements. The disturbances of the preferred neutron-proton ratio of the element by suitable target material by neutron or charged particle such as proton (p) deutrons (d) and helium nuclei (α) result in the production of radio isotopes. The specific activity of artificially produced radioisotope is a function of the flux of the bombarding particles, time of irradiation, the half life of radioisotopes, the natural abundance of target isotope and the capture cross section(ability to capture the bombarding particles) of the target material.

1.3.5 Primordial isotopes

Primordial isotopes are nuclides found on the Earth that have existed in their current form since before Earth was formed. Primordial nuclides are residue from ancient supernova explosions which occurred before the formation of the solar system. Only 288 such nuclides are known, out of which 255 are stable primordial isotopes and the rest being radioactive.

1.3.6 Environmental isotopes

Environmental isotopes may be defined as those isotopes, both stable and unstable which occur in the environment in varying concentration over which the investigator has no direct control. The environmental isotopes most commonly used in hydrology are the stable isotopes of Deuterium, Oxygen-18, Carbon-13 and radioisotopes of Tritium and Carbon-14. [4,5]

1.4 MEASURMENT NOTATION AND STANDARDS

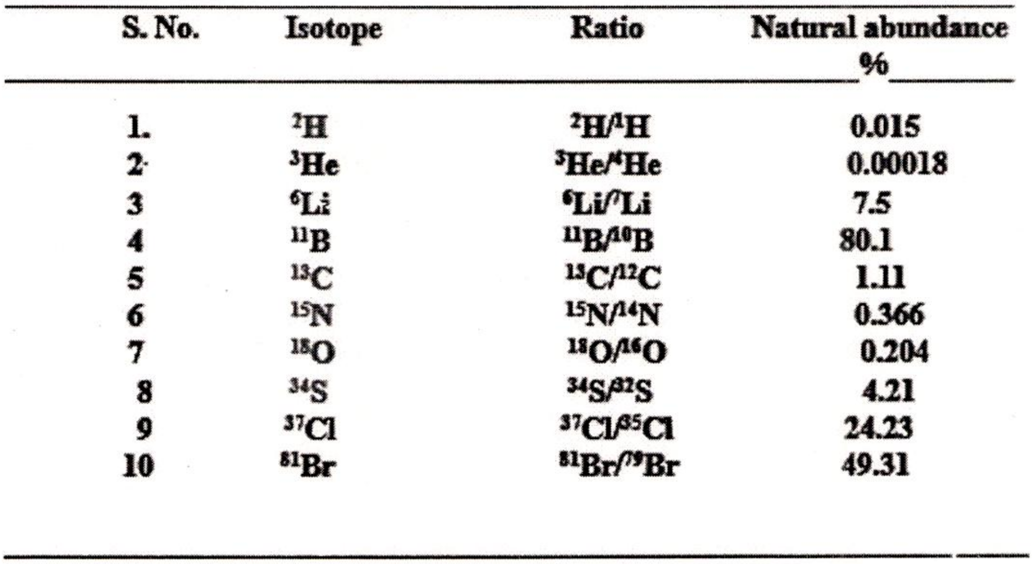
Each elements has a dominant light isotopes with nominal atomic weight (^{12}C, ^{14}N, ^{16}O, ^{32}S, ^{1}H) and one or two heavy isotopes (^{13}C, ^{15}N, ^{17}O, ^{18}O, ^{33}S, ^{34}S, ^{2}H) with a natural abundance of a few percent or less.

Table 1.1 Natural abundance of stable isotopes (atom%)

Isotopes		Abundance
Hydrogen	^{1}H	99.985
	^{2}H	0.015
Carbon	^{12}C	98.892
	^{13}C	1.108
Nitrogen	^{14}N	99.6337
	^{15}N	0.3663
Oxygen	^{16}O	99.6337
	^{17}O	0.0374
	^{18}O	0.2039

Accepted standards for other lighter isotopes with their absolute isotopes abundance values for these materials are given in Table 1.2.

Table 1.2 Stable isotopes with their natural abundance and reference standards used for ratio measurements.



S. No.	Isotope	Ratio	Natural abundance %
1.	^{2}H	$^{2}H/^{1}H$	0.015
2	^{3}He	$^{3}He/^{4}He$	0.00018
3	^{6}Li	$^{6}Li/^{7}Li$	7.5
4	^{11}B	$^{11}B/^{10}B$	80.1
5	^{13}C	$^{13}C/^{12}C$	1.11
6	^{15}N	$^{15}N/^{14}N$	0.366
7	^{18}O	$^{18}O/^{16}O$	0.204
8	^{34}S	$^{34}S/^{32}S$	4.21
9	^{37}Cl	$^{37}Cl/^{35}Cl$	24.23
10	^{81}Br	$^{81}Br/^{79}Br$	49.31

1.5 CHART FOR STABLE AND UNSTABLE ISOTOPES

The chart of the nuclide chart provides an overview of the existing isotopes and is an important source of basic information for isotopic sciences. The isotopes are mapped in plot of electron neutron number N versus proton number Z. Isotopes of a single element stand in rows. Stable isotopes of the light elements align roughly along the 1:1 diagonal, for heavier elements, there is always an excess neutrons over protons and decay mode for radioactive isotopes. In this chart the yellow square represent the stable isotopes and the green square represent the radioactive isotopes.

1.6 APPLICATION OF ISOTOPES IN HYDROLOGY

Use of stable isotope techniques in water resources studies has gained more attention in recent past. With the advancement of analytical techniques, methods based on naturally occurring, extremely low level of stable isotopes are successfully employed to solve many problems related to water resources management especially in groundwater as well as surface water sector.

1.6.1 Application of isotope techniques in groundwater studies

Dating of water at different points and depth of a Groundwater system enables the estimation of important characteristics of the aquifer like deposited water column, flow velocity, flow rate of the supplying body etc. Many environmental radioisotopes are used to age determination of the groundwater. Tritium (^3H) and radiocarbon(^{14}C) are found to be ideally suitable for dating though many other radiotracers are available. [7,8]

Detection and evaluation of groundwater pollution using isotope techniques are based on the fact that the isotopic composition of the substances dissolved in water is distinct in nature linked to their origin and do not undergo changes appreciably though in the case of ^{15}N, ^{34}S, ^{13}C etc. isotope.

Fractionation may occur and may modify the origin of labeling.

Isotopes which are of interest in groundwater pollution studies are

Stable isotopes : ^{13}C, ^{15}N, ^{34}S along with ^{18}O and ^{2}H.

Radioactive isotopes : ^{3}H, ^{90}Sr, ^{238}Pu, ^{244}Ce, ^{137}Cs.

Environmental isotopes play a key role in studying the problems concerning groundwater recharge like qualitatively to understand whether groundwater recharge occurs, i.e. whether it is a renewable resource which is particularly important in arid and semiarid regions. Then, quantitatively to determine the annual recharge of precipitation to the aquifer.

The rate of recharge of local precipitation to the groundwater could be studied using environmental stable isotopes Deuterium (^{2}H) and Oxygen-18 (^{18}O) in the unsaturated soil profiles taking advantage of their seasonal variation. Mainly tritium and environmental Carbon-14 were used to detect recharge which occurred in the groundwater.

^{34}S and ^{18}O of dissolved sulfates can be used to determine the origin of salinity. Sulfates of present day sea water has a mean for $^{34}\delta$ as 20.30% with respect to CDT as standard. Depending upon their geological age, sulfate of marine evaporation origin has about ten units on either side of the above figure.

The tracers used for velocity measurements mostly belong to inorganic, organic and radiochemical groups. The chloride ion as sodium chloride is a widely used tracer. However, this has serious limitations in regions of chloride rich soils or rocks. Brilliant Blue FCF is one of the tracers that belong to organic chemicals. The gamma-ray emitting isotopes like ^{82}Br (as NH4Br, ^{51}Cr as EDTA complex, ^{58}Co and ^{60}Co as Co(CN) complex, ^{131}I as NaI and ^{99}Tc as per TechNet solute from ^{99m}Tc are found to be good hydrological tracers. Though tritium (^{3}H)as treated water is considered to be the most ideal hydrological tracer but it emits only β - radiation whose in situ measurement is not possible. In the recent past, tracers like ^{80}Br and ^{116m}In as EDTA complex have been reported to be a reliable tool provided their natural level in groundwater is negligible.

1.6.2 Application of isotope techniques in surface water hydrology

Two elements tracers are found to be ideal for the lake dynamics studies. Deuterium as triturated water under controlled and well justified conditions can be used for the studies. A serious drawback with tritium is its long half-life (T1/2 is 12.42years).Bromine-82 as bromide like NH4^{82}Br is a suitable and safe tracer for investigation of water system. A few other radioactive tracer are also used for the studies on lake dynamics. Among them, a relatively short lived isotope ^{140}La as CDTA complex is important. Other long lived isotopes are:

Iodine -131, Scandium-46 as CDTA complex Cobalt-60 and Cesium-137 are also used in complex form. In the case of Cobalt-60, the tracer is present in the complex form as $[^{60}\text{Co (CN)6}]^{-1}$. It is the potassium salt, $K_3[^{60}\text{Co (CN)6}]$ in which Cobalt-60 is present as a tracer.[7]

Environmental radioactive isotopes have been successfully employed to find the sedimentation rate in lakes. Here, the radioactive isotopes are used not as a tracer of water but as sediment markers. The environmental radioactive isotopes enter the lake water as aerosols or by getting adsorbed on to the soil particles in the surrounding catchment and they enter the lake.

Isotopes used : ^{14}C, ^{210}Pb, ^{137}Cs

For investigation of leakage in dams and reservoirs, the environmental isotopes used are the stable an radioactive isotopes of water molecule namely, deuterium (^{2}H), tritium (^{3}H) and ^{18}O. Apart from these, ^{14}C is also found to be useful for the purpose.

The following are a few examples of radiotracers used for flow measurement in mountainous streams and rivers.

Tritium, Bromine-82, Sodium-24, Iodine-131

Here I mentioned some of the applications of isotopes in hydrological studies but in this project work, I mainly focused and studied the application of stable isotopes for the interconnection between ground water and surface water vice versa.

1.7 OBJECTIVES

The major objectives of the study are:

I. To familiarize and to understand the mass spectroscopic techniques used for the measurement of stable isotopes of water such as Deuterium and Oxygen-18

II. To investigate the soil moisture movement using oxygen-18 isotope.

CHAPTER 2

MASS SPECTROMETRY

2.1 MASS SPECTROMETER

Mass Spectrum is an analytical technique which can provide information concerning the molecular structure of organic and inorganic compounds. It is be used to determine directly molecular weight as high as 4000. It can be used as a qualitative tool to characterize different organic compounds. One can do analysis of mixtures (gases or liquids and in some cases solids) quantitatively. A mass spectrometer is also used to investigate reaction mixtures and in tracer work it is also useful in understanding kinetics and mechanism of un-molecular decomposition reactions. [8,9]

2.2 Principle

The compound under study is bombarded with a beam of electronics which produces an ionic molecule or ionic fragment of the original species. The resulting assortment of particles is then separated according to their masses. (The mass spectrum is actually a record of information regarding various masses produced and their relative abundance). One can place functional groups into certain areas of the molecule and see how they are connected to one another. Mass spectrum gives the largest amount of specific information about the substance to be analyzed.

In a mass spectrometer, molecules are bombarded with high energy electrons and converted to highly energetic positively charged ions (molecular ions or parent ions) which can break up into smaller ions (fragment ions or daughter ions). The molecular ions, the fragment ions and the fragment ions are separated by deflection in a variable field, according to their mass and charge a current (the ion-current) at the collector in proportion to their relative abundance. A mass spectrum is a plot of relative abundance against the ratio mass/charge (m/z)

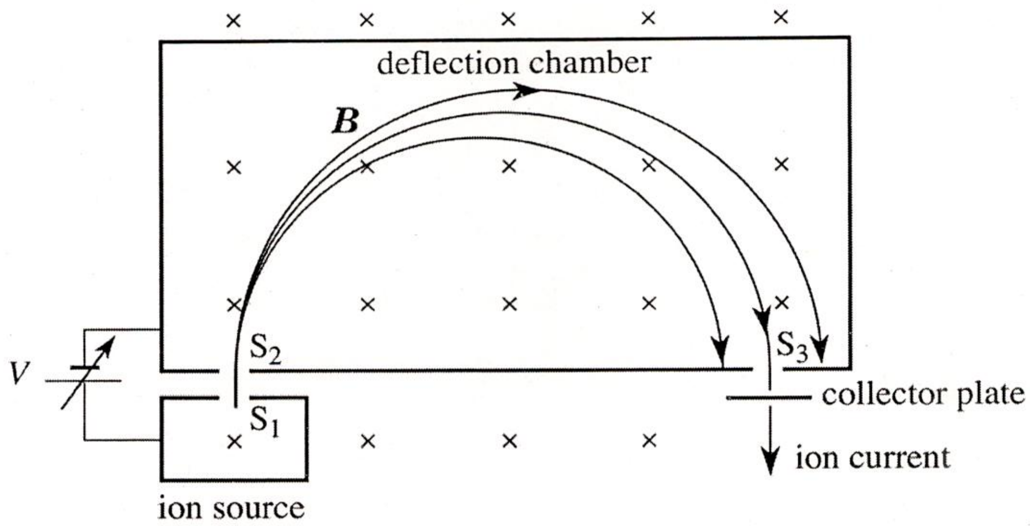


Fig.2.1 Schematic view of mass separation in a mass spectrometer

2.3 MASS SPECTROMETER AND ITS WORKING

A mass spectrometer ionizes the gas molecules and separates the ions into a spectrum according to charge to mass ratio, m/z using electric and magnetic fields. The relative abundance of molecules of different m/z are then found by measuring the currents generated by these separated ion beams. All the instruments have three basics parts an ion source, a mass analyzer and an ion collector assembly.

Atoms can be deflected by magnetic fields- provided the atom is first turned into an ion. Electrically charged particles are affected by a magnetic field although electrically neutral ones are not since molecules are so small, it is not convent to measure their masses, or grams, or pounds in fact, the mass of a single hydrogen atom is approximately 1.66 x 10^{-24} grams. We therefore need a more convent unit for the mass of individual molecules. This unit of mass is often referred to by chemists and biochemists as the Dalton (Da for short), and is defined as follows 1 Da=(1/12) of the mass of single atom of the isotope of carbon-12(C^{12}). The different functional units of a mass spectrometer are represented conceptually in block diagram (Figure 2.3).

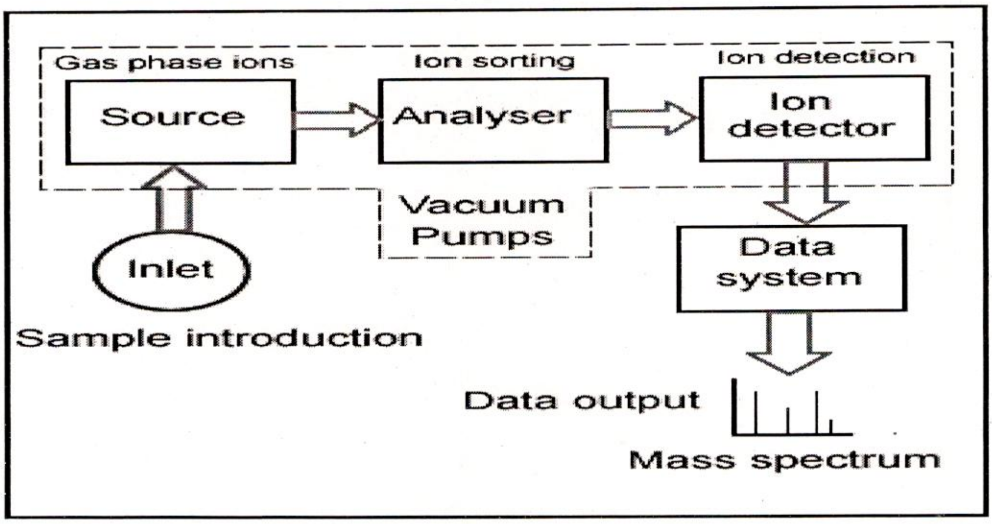


Fig.2.2 The composition of Mass Spectrometer

Formation of gas phase samples ions is an essential prerequisite to the mass sorting and detection processes that occur in a mass spectrometer. Early mass spectrometers required a sample to be a gas, but due to modern developments described below, the applicability of mass spectrometry has been extended to include samples in liquid solutions or embedded in a solid matrix. The sample, which may be a solid liquid, or vapor, enters the vacuum chamber through an inlet. Depending on the type of inlet and ionization techniques used, the sample may already as ions in solution, or it may be ionized in conjunction with its volatilization or by other methods in ion source.

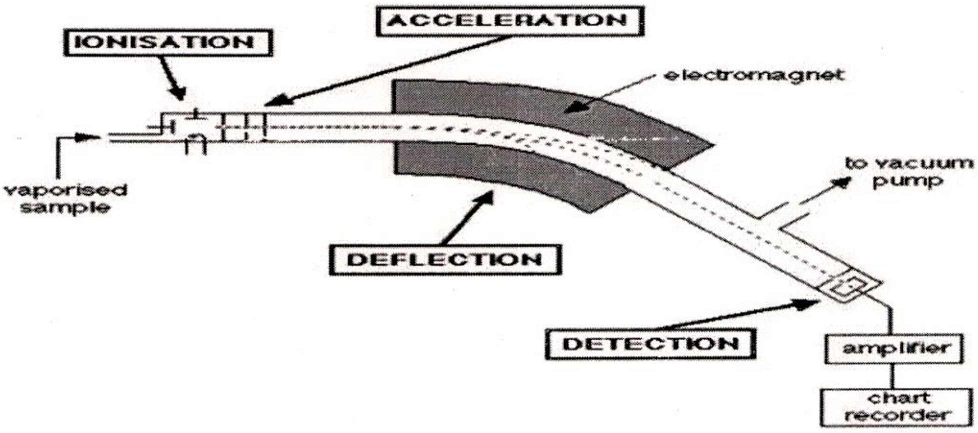


Fig.2.3 Isotope analysis in a mass spectrometer

The gas phase ions are sorted in the mass analyzer according to their mass-to-charge (m/z) ratio and then collected by a detector. In detector the ion flux is converted to a proportional electrical current. The data system records the magnitude of these electrical signals as a function of m/z and converted this information into a mass spectrum.

The sequence of operations with in the mass spectrometer can be explained using the schematic diagram that take place in the mass spectrometer.

2.4. Components of mass spectrometer

Inlet system

The sample is converted into gaseous state. It is also ensured that the sample enters the lionization chamber at a constant rate. The achieve this, the system is usually heated. Less volatile substances are pre-heated in the flask. The rate at which the sample is introduced into an ionizing chamber remain constant so that the relative abundances of different species can be determined.

Gases are introduced through a glass bulb to a metering reservoir (pr. 30 - 50 torr) and then expand into an expansion reservoir (3 litres,10^{-3} to 10^{-1}torr), liquids are handled by hypodermic needle-injection through a silicone rubber dam. For mass spectrometry, a sample size of the mole is required only a few percent of this will actually enter the ionization chamber, and only 0.1% of this ionized in the chamber.

Ion source (lionization chamber)

From the inlet system the sample enters the ionization chamber where a beam of electron (of average energy 50.8ev) is put a molecules of the samples. The molecules become ionized by the expulsion of electron. The recombination of the fragments can be avoided by maintaining the system at a low pressure. Electrons are produced from a electrically heated filament and are accelerated to the anode. When the energy of e^- beam is appropriate singly charged molecular ions are formed.

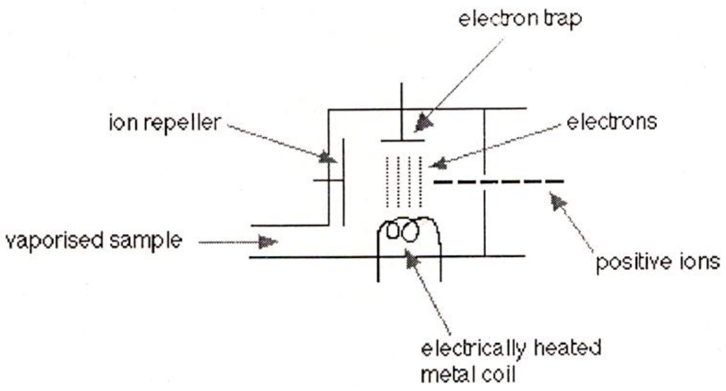


Fig.2.4 Conversion of gas molecules into positive ions in the ionization chamber

The electro static accelerating system

The +ve ions formed, in the ionization chamber are withdrawn by electric field which exist between the first accelerator place and the second repeller plate. A strong field between accelerator place and the second repeller plate of 400 - 400 V accelerates the ions with various masses to their final velocity, all the singly charged ions will have same energy. KE = 1/2 mV^2 = ev. Mono energetic beam of ions required for better resolution.

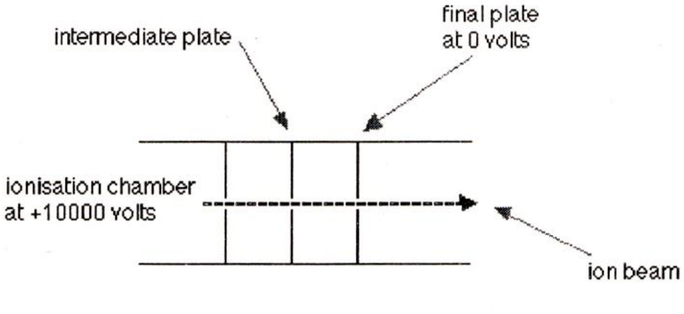


Fig.2.5 Arrangement of accelerating plates to acceleration of positive ions beyond the ionization chamber

The ion separator (Analyzer)

The ions are separated according to their masses. The characteristics of analyzer are.

1. Should have high resolution (can distinguish between closely spaced molecular weights)
2. Should have a high rate of transmission of ions.

When the slits are made narrow, resolution increases, but transmission decreases mass spectrometers are of different kinds based on the way by which they sort out the ions. The common is single focusing magnetic deflection.

The ion collector

The ion currents were detected by a photographic plates, Faraday cylinders, electron multipliers and electro meters are general employed. Currents below $10\text{-}1^5$ A are detected using a Be-Cu electro multiplier. It is observed that a photographic plate offers greater resolution than an electrical detector on the same instrument.

The vacuum system

Essentially a mass spectrometer consists of a tube in which high vacuum is maintained, with an ion source placed at one end of the tube and ion collectors at the other end. The middle part of the tube is curved and kept in a magnetic field normal to the curvature plane. The vacuum in the mass spectrometer should be at least 10^{-6}torr, but usually it is better by one or two orders of magnitude. At 10^{-6}torr, the mean free path of the gas molecules is about 150m, much more than the path that molecules and ions cover in the mass spectrometer. Therefore, the probability of collisions between molecules and ions is very slow. In the ion source, where the analyzing gas is admitted to the mass spectrometer, the gas pressure is much higher, of the order of $10^{-3}\text{-}10^{-4}$torr.

A good vacuum also reduces the background contribution to the ionic beam by reducing the amount of residual gases present in the mass spectrometer. The gas pressure in the mass spectrometer is measured by means of ionization gauges. The vacuum is normally obtained with rotary pumps and oil or mercury diffusion pumps, equipped with a cold trap (liquid nitrogen or dry ice). Recently, new low vapor- pressure oil diffusion pumps have been produced, by means of which a vacuum of $10^{-8}\text{-}10^{-9}$torr can be reached without a cold trap. Also, ion pumps may be used instead of diffusion pumps. Baking the whole analytical tube from time to time facilitates the attainment and maintenance of a good vacuum.

Applications

i. Molecular weights can be determined with high accuracy

ii. It is the most suited, analytical method to identify an analytic, by comparison of its mass spectra with libraries of digitized mass spectra of known compounds.

iii. In a particular organic molecule, it is possible to detect the places at which it prefers to fragment. From this the presence of recognizable groupings in the molecular can be deduced, and the structure of the molecules can be assigned.

Disadvantage

i. Even small amounts of imparities make the interpretation is very tough

ii. compounds which are unstable toward thermal effect cannot be analyzed (because only vapors can be introduced).

iii. It is a destructive method

CHAPTER 3

INFILTRATION AND RECHARGE TO GROUNDWATER

3.1 PROCESS OF INFILTRATION AND ITS MEASUREMENT (Using Flooding Type Double-Ring Infiltrometer)

It is well-known that when water is applied to the surface of a soil, a part of it seeps into the soil. This movement of water through the soil surface is known as Infiltration and plays a very significant role in the runoff process by affecting the timing, distribution and magnitude of the surface runoff. Further, infiltration is the primary step in the natural groundwater recharge.

Infiltration is the flow of water into the ground through the soil surface and the process can be easily understood through a simple analogy. Consider a small container covered with wire gauge as in Fig. 1.1. If water is poured over the guage, a part of it will go in container and a part overflows. Further, the container can hold only a fixed quantity and when it is full no more flows into the container can take place. This analogy, though a highly simplified one, underscores two important aspects, viz., the maximum rate at which the ground can absorb water, the infiltration capacity and the volume of water that it can hold, the field capacity. Since the in filtered water may contribute to groundwater discharge in addition to increasing the soil moisture, the process can be schematically modeled as in Fig. 1.1. This figure considers two situations, viz. Low-intensity rainfall and high intensity rainfall, and is self-explanatory.

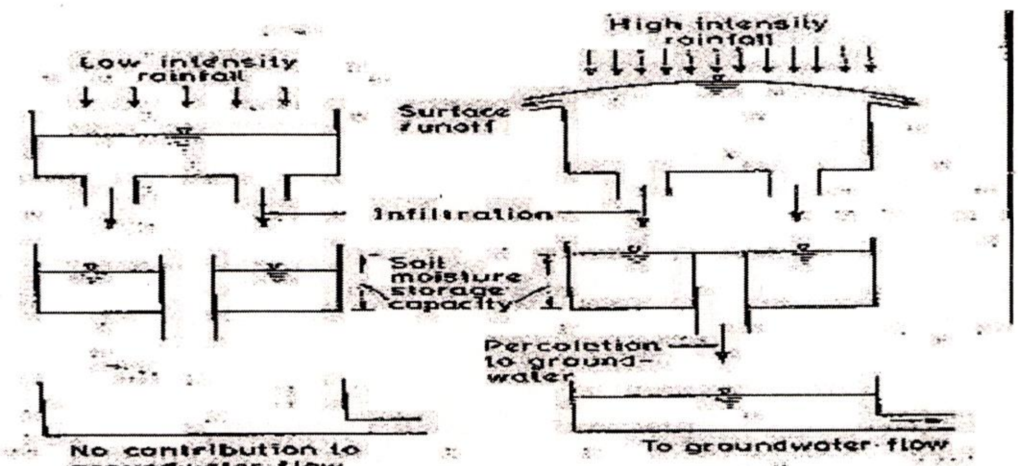


Fig.3.1 Infiltration model

Information about the infiltration characteristics of the soil at a given location can be obtained by conducting controlled experiments on small areas. The experimental set-up is called an infiltrometer. There are two kinds of infiltrometer:

This is a simple instrument consisting essentially of a metal cylinder, 30 cm diameter and 60 cm long, open at both ends. This cylinder is driven into the ground to a depth of 50 cm. Water is poured into the top part to a depth of 5 cm and a pointer is set to mark the water level. As infiltration proceeds, the volume is made up by adding water from a burette to keep the water level at the tip of the pointer. Knowing the volume of water added at different time intervals, the plot of the infiltration capacity vs time is obtained. The experiments are continued till a uniform rate of infiltration is obtained and this may take 2-3 hr.

The surface of the soil is usually protected by a perforated disk to prevent formation of turbidity and its settling on the soil surface.

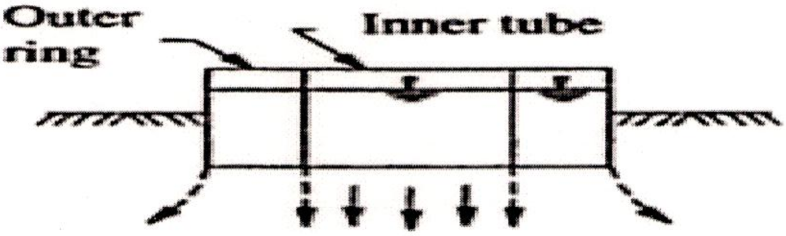


Fig.3.2 FLOODING-TYPE INFILTROMETER

A major objection to the simple infiltrometer as above is that the infiltered water spreads at the outlet from the tube (as shown by dotted line in Fig. **3.2.**) and as such the tube area is not representative of the area in which infiltration takes place. To overcome this a ring infiltrometer consisting of a set of two concentric rings (Fig. **3.3.**) is used. In this two rings are inserted into the ground and water is maintained on the soil surface, in both the rings, to a common fixed level. The outer ring provides a water jacket to the infiltering water of the inner ring and hence prevents the spreading out of the infiltering water of the inner tube. The measurements of water volume is done on the inner ring only.

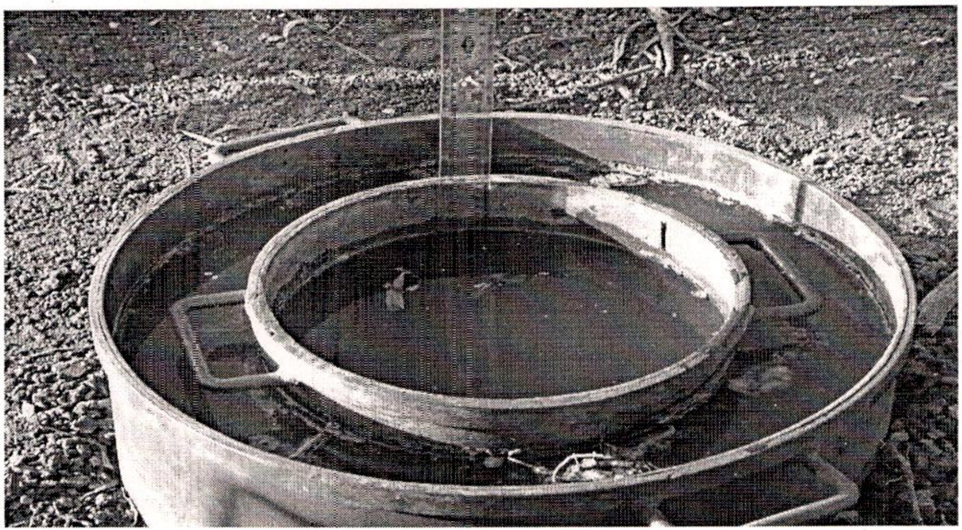


Fig.3.3 Double Ring

3.2 Methodologies for Recharge Estimation

A number of methodologies are used to estimate recharge. These can be classified as:

- Direct or indirect
- Physical, chemical, or isotopic;
- Methods based on the analysis of inflow, outflow, or aquifer response;
- Methods based on unsaturated of saturated zones; and

Methods based on numerical modeling of groundwater flow, soil-water flow, both soil and groundwater flows, or modeling of the hydrologic balance at plot, field, or watershed scales.

Additional classification also exist. Within each methodology, a number of estimation techniques are available. Here we combine these methodologies into two groups:

3.3 Physical Methods for Recharge Estimation

Physical methods rely on direct measurements of hydrological parameters, or on estimates of soil and/or aquifer physical parameters. Physical methods are frequently used to estimate precipitation recharge because they are quick, inexpensive, or straightforward. However, these methods are often problematic in arid and semi-arid region. There are several reasons for this:

- The low recharge fluxes largely depend on the vetoes zone physical parameters, and significant variations in fluxes may occur with small changes in these physical parameters. Unfortunately, it is almost impossible to detect such small changes in physical parameters.

The extreme temporal variability of arid climates means that long time series are needed to assess mean annual recharge rate.

- Spatial variability caused by changes in local topography, soil type, and vegetation requires a large number of measurement sites to assess the spatially averaged recharge rate.

Nevertheless, with prudent appreciation of their limitations, physical methods can be a helpful tool for evaluating precipitation recharge.

When characterizing groundwater recharge, a distinction between potential and actual recharge needs to be made. Potential recharge is soil-water that percolates below the root zone, whereas actual recharge is soil-water that reaches the aquifer. Most potential recharge water will be stored in the vetoes zone at negative pressures (suctions) and is not available for exploitation. In addition, it may still be lost later by an increase in vegetation rooting depth, capillary rise, or upward vapor transport. Conversely, actual recharge is the amount of water that in fact reaches the water table, and can be pumped.

3.3.1 Indirect Physical Methods

Indirect physical methods for estimating groundwater recharge consist of:

- Empirical methods,
- Water balance methods based on estimates of soil physical properties
- Numerical modeling methods

Empirical methods: In principle, one of the simplest methods used for estimating diffuse recharge, R, is by empirical expressions of the type

R+k1 (P-k2)

Where P is precipitation, and k1 and k2 are constants for particular area. Such expressions have been used with varying degrees of success. They are probably most useful for making first-guess estimates of recharge where annual recharge is fairly high (>50 mm per year), and thus should seldom be used in arid or semiarid regions.

Water balance methods based on estimates of soil physical properties:

Methods relying on estimates of soil physical parameters generally fall into the following classes:

- Soil-water balance,
- Zero-flux plane method,
- Estimation of water fluxes beneath the root zone using unsaturated hydraulics conductivity and the gradient in soil-water potential, and

Estimation of water fluxes in the saturated zone based on Darcy's law and flow-net analysis.

Additional methods also exist that may not fit well into one of these classes, such as gravity surveys for measuring changes in aquifer storage resulting from recharge events. Increased accuracy in measuring temporal variations in the earth's gravity field has recently allowed the use of gravity observations to deduce subsurface water mass changes resulting from precipitation and consequent recharge events.

- ❖ **Water Balance**: This group of methods estimates recharge as the residential of all other fluxes. The principle is that other fluxes can be measured or estimated more easily than recharge. Examples of water balance methods include:
- ❖ **Soil-moisture budgets**: rainfall and potential evapotranspiration are inputs to a soil-moisture accounting procedure, with actual evapotranspiration and recharge as the outputs.
- ❖ **River-channel water balances**: upstream and downstream flows are differenced to calculate recharge or-more accurately-transmission losses. (A related stream hydrograph analysis technique based on base flow-separation techniques is founded

on steady-state water-balance calculations, whereby the estimate of discharge based on base flow-separation or base flow-recession analysis of the stream hydrograph, must equal recharge. This technique is considered too empirical and approximate to give reliable quantitative estimates.)

- **Water-table rises**: the volume stored beneath a rising water table is equated to recharge, after allowing for other inflows and outflows such as pumping wells and aquifer through flow.

The simplicity of the latter method made it a popular one. However, calculating the volume of water stored between lowest and highest water table positions over a study period interval involves reliable estimates of the aquifer's **specific yield values**, which may be difficult to obtain

The advantages of water-balance methods are that they use readily available data (rainfall, runoff, water levels), are easy to apply, and account for all water entering a system. The major disadvantage is that recharge is the residual or remainder of all other hydrologic components in the water balance equation, and constitutes only a small differences between large-number components, such as precipitation and evapotranspiration. Errors can be high, with the errors in all other fluxes accumulating in the recharge estimate. For example, high river flow can often only be estimated to ±25%. If recharge is 25% of flow, the error in estimating it is ±100%.

Other disadvantages include the difficulty of estimating other fluxes in the water balance equation. For example, evapotranspiration cannot be measured easily, yet it is often the largest outward flux. Physical properties like specific yield are central to some water-balance methods, such as those based on water-table rises, but are not easily defined or measured.

Zero-Flux Plane Method:

The zero-flux plane (ZFP) method relies on locating a plane of zero hydraulic gradient in the soil profile. Recharge during a time interval is obtained by summation of the changes in water content below this plane. Unfortunately, the method breaks down in periods of high infiltration when the hydraulic gradient becomes positive downward throughout the profile.

This is when recharge fluxes are likely to be highest. Use of this technique can give good estimates of recharge for periods during the year when the ZFP exist.

Estimation of Saturated Water Fluxes:

An equivalent method for recharge estimation, based on saturated flow governed by Darcy's law, is simpler, especially when assuming steady state conditions and employing flow-net analysis. The only measurements needed are values of hydraulic head and hydraulic conductivity to construct a quantitative flow net. This consists of a set of intersecting lines of equal hydraulic head values (known as equepotential lines) and flow lines representing two=dimensional steady flow through a porous medium. Two-dimensional, vertical flow nets constructed along the general groundwater flow direction from water table and hydraulic head field measurements provide an approximate but straightforward way of identifying areas of recharge and discharge, and thus of estimating recharge.

- **Numerical Model for Estimating Recharge**:

  Different types of models are available for estimating groundwater recharge:
  - Numerical models that solve one, or three-dimensional forms of the water flow or Richards equation,
  - Parametric hydrologic models that use a numerical or analytical relationship between infiltration or precipitation and recharge,
  - Groundwater flow models, and
  - Combined or integrated watershed and groundwater models.

Numerical modeling methods take transient flows and storage changes into account and can include spatial variability of physical properties, of which hydraulic conductivity is one of the most important. However, data requirement and computing load are both high. Such models are used to estimate model parameters, in this case recharge, based on known values of hydraulic head. Such an approach is known as a solution of an inverse problem. This is in the contrast to the forward or direct problem, where model parameters are considered known and hydraulic head is computed.

Should one process the analytical expressions for hydraulic head and transmissivity in the groundwater flow equation, determination of recharge would be a trivial exercise of calculus in computing the derivatives of the groundwater flow equation. However, hydraulic heads are always measured with a degree of inaccuracy. Differentiating such noisy data leads to large errors in recharge estimation.

Integrated watershed and groundwater models allow a complete analysis of the land-based hydrologic cycle, thus providing the means for evaluating the impact of Land use, irrigation development, and climate change on both surface water and groundwater resources. Such models allow predictions of the impact of management changes on total water supplies, including recharge. The seasonal variation of water table levels and recharge can be more accurately predicted by the soil-moisture accounting system employed in the integrated model than by using only a groundwater model This increased flexibility, however, comes at the expense of increased complexity and the increased flexibility, however, comes at the expense of increased complexity and the expertise needed to use integrated watershed modeling effectively. Although integrated models require extensive data, such integrated modeling constraints the adjustment of model parameters during calibration because overall water budget must be observed. Whereas traditional methods used to calibrate groundwater models may include adjustments to recharge rates, in an integrated model recharge is completely constrained by the overall water budget for the surface-water system. In addition, stream-aquifer interactions, including stream-derived recharge, are constrained by the generated amount of surface runoff to streams. This, in turn, impacts on the stream stage and thus the driving forces for stream-aquifer interaction.

The principal advantages of the numerical methods are that attempt to represent the actual physical process of interest, and that they allow predictions of future recharge regimes resulting from different land uses and climatic changes. These advantages are often countered by the need to make simplifying assumptions in order to reduce the computational effort. For example, numerical models of the soil zone usually assume a single-porosity medium with no spatial variations in properties. In practice many soils may have dual porosity, with preferred pathways during high saturation: in other words, at times of recharge. The correct timescale for such models depends on the rate of fluctuation of heads, varying from seconds for rainfall into soil to seasonal or longer spans for seepage between aquifers. Effectively addressing the multiple temporal (as well as spatial) scales involved in recharge estimation constituents a major problem in modeling recharge process.

In addition to such obstacles and uncertainties, large data requirement often make application of numerical models difficult.

3.3.2 Direct Physical Methods

In contrast to the numerous indirect physical methods, there is only one direct method for estimating diffuse recharge. This involves the construction of a lysimeter.

Lysimeter comprise enclosed blocks of disturbed or undisturbed soil, with or without vegetation, that are hydro logically isolated from the surrounding soil in order to assess or control various elements of the water balance. There is also only one direct method for estimating indirect recharge associated with surface water bodies in direct hydraulic connection with an underlying aquifer. This involves the use of seepage meters inserted in the streambed or lakebed that can provide direct point measurements of localized recharge.

Lysimeters are expensive and permanent instruments. They are typically filled with disturbed soils, which generally have water content profiles that differ to some degree from those found in surrounding soils. Drainage can occur only when a water table develops at the base of the lysimeter, unless solution sampler (such as ceramic cup extractors) and a Vaccum system are installed at the base. This last factor, however, is unlikely to be a problem if the lysimeter is relatively deep and the vegetation is shallow-rooted. While lysimeter have been useful in quantifying drainage at waste sites under arid conditions, they have limited ability to document the spatial variability produced by natural and human-induced changes in surface and subsurface flow pathways.

Construction cost and logistics limit size and depth to generally no more than a few square meters and a 3 m depth, although lysimeter as deep as 18 m have been constructed. Because lysimeter are effective for the study of recharge mechanisms, and yield the high-quality data needed in computer model calibration for simulating the water balance, some specialists recommend that more lysimeter-recharge studies be undertaken worldwide in a variety of climatic and soil conditions. However, the initial construction costs and the long-term monitoring requirements represent a serious extended commitment.

Seepage meters were originally developed to measure canal seepage losses. They involve a seepage bell or cylinder that is pushed into the canal-bed sediment, the infiltration rate being measured by constant or falling head techniques. Their advantages include being:

- Lightweight and easily transportable,
- Relatively cheap,
- Simple to operate,
- Rapidly measurable,

Difficulties are encountered in gravelly or stony sediments, or in sandy sediments, which may be washed from around the seepage cylinder by eddy currents and sediment disturbance, or because of an ineffective seal around the inserted seepage cylinder. The number of measurements per unit of area needed to arrive at a reasonable average depends on the degree of heterogeneity in the seepage loss at the specific site. In conclusion, the seepage meter gives a rapid and direct measurements at low cost, but the figures obtained are only point measurements.[6,7]

CHAPTER 4

METHODOLOGY AND LOCATION OF STUDY AREA

4.1 METHODOLOGY

Deuterium Tagging Method

As it is clear from its name, deuterium, an isotopes is used as a tracer to trace the movement of water as it fulfills the requirement of an ideal tracer. An ideal tracer should have the following characteristics:

The tracer should behave same as normal water and should not be lost or reiterated due to adsorption or ion exchange. Generally anions and neutral molecules are better in this regard to cat ions.

1. The tracer should have a high detection sensitivity.
2. The health and handling hazards should be minimum.

3H / Deuterium as Tracer

1. It behaves similar to normal water as it is a molecule of water.
2. It is a pure beta emitter of low energy (18.6 keV) and belongs to the lowest radio-toxicity class. (for 3H).
3. It can be measured with a high detection sensitivity.
4. It has comparatively long half-life (12.23 years) and hence useful for soil moisture movement studies. The long half-life makes it possible to store the tracer in the laboratory and no particular shielding is required.

Source of Errors and Precautions

The use of deuterium tagging technique may lead to the various source od errors due to different practical problem involved. The main source of errors can be broadly be categorized in three steps, used to perform this study.

1. Conducting field experiment.
2. Estimation of deuterium and volumetric moisture contents.
3. Estimation of recharge to groundwater using experimental data.

Conducting Field Experiment, the following steps are involved which should be dealt very carefully to minimize the possible errors.

- Selection of representative field (site).
- Marking of site for relocation.
- Quantity of activity and injection of tritium at certain depth.
- Relocation of site, collection and storing of soil samples.

The procedures to be followed in the steps mentioned above, although purely depends on the practice and common sense of the user of this technique but the following criteria can be adopted in order to minimizes the possible errors and variations that may occur in case of different users.

1. Selected site should represent the area i.e., it should have the topographical and geomorphological features similar to the nearby area.
2. Sites should be plain for all practical purposes as this techniques is not valid for hilly and very high sloppy areas.
3. The sites should be at a place where the marking points like tree, electric poles or other similar type of natural or manmade identification marks exist in maximum possible directions at some distance (not very close to site). Otherwise, the identification marks will have to be fixed by the user.

4. Besides the identification marks already existing at some distance from the deuterium injection points, few additional marks, like iron nails should be fixed at very close distance, say 1 or 2 m around the injected point in order to reduce the inaccuracy that may occur in the measurement of long distances of natural or manmade identification marks.

5. The availability of rainfall and/or irrigation data should be ensured before the selection of a particular site.

6. For correct estimation of the recharge to the ground water, the site should be selected in both type of fields i.e., cultivated and uncultivated fields.

7. Deuterium should be injected directly at the specified depth using a syringe, plastic pipe and metallic pipe.

8. 2 ml of deuterium having specific activity at least 25 to 40 should be injected at a depth well below the root zone and sun heating zone, say 70 cm for temperate region to 100 cm for arid region, in all the five holes, each 10 cm apart after making a set of injection points. The holes should be completely filled with soil after injecting tritium in order to reduce the direct loss pf injected tracer due to evaporation and also to avoid the direct entry of water.

9. Layout of the experimental site should be prepared very carefully for the relocation of the site.

10. The site should be relocated very precisely and soil sample should be collected at the interval of 10 cm either using a hand auger or any other coring device having sampling tubes.

11. In order to minimize the contamination of soil sample at lower depths, all precautions should be taken at the time of lowering the sample collection device so that it could not touch to the side walls of the bore hole.

12. In order to minimize the loss of trotted water content due to evaporation, the soil samples should be kept in air tight plastic bags to bring them to laboratory for various analyses.

4.2 LOCATION OF STUDY AREA

The site i.e. within the boundary of NIH main building near guest house 1 was selected. Deuterium injection were made in an open garden at site 15 feet from the pole (used as bench mark) and 70 cm below the land surface to avoid direct evaporation to the atmosphere.

TABLE 4.1: LIST OF EXPERIMENTAL SITES WITH OTHER DETAILS

Sr. no.	Name of the site	Date of Deuterium injection	Date of Deuterium Sampling
1	NIH	07-07-15	26-08-2015

4.2.1 DESCRIPTION OF STUDY AREA:

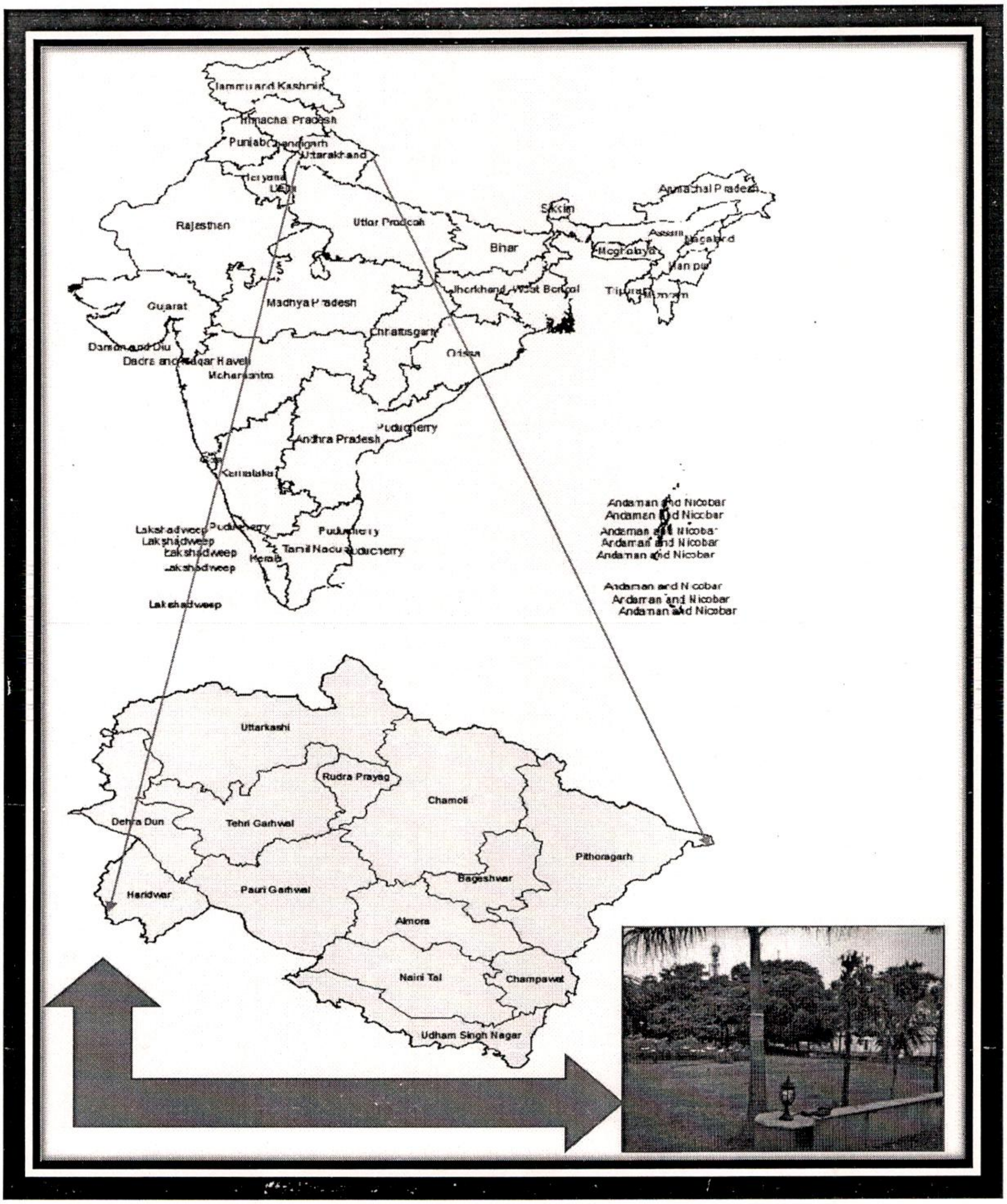
Topography

The study area is located near the NIH guest house 1 in an open garden within the NIH boundary in Roorkee.

The study area is a part of the Indo-Gangetic alluvium, located in the district Haridwar of Uttarakhand within the latitudes and longitudes of 29^{o} 50' 24" to 29^{o} 54' 36" N and 77^{o} 50' 24" to 77^{o} 55' 48" E.

The town is situated on the right bank of the river Solani, a tributary of the river Ganga, and skirted in the north by a piedmont zone of Siwalik foothills. The Upper Ganga Canal, which was built in 1854, originates at Haridwar and is branched into Deoband branch, Muhammadpur and Basera distributaries. The main canal is 230 km long and is disserted with many cross drainage structure. Most of the area gets benefited from these canal systems, which somehow, neutralize the lowering trend of the water table. Its flow through the Roorkee town divides the town into two parts.

THE STUDY LOCATION AREA LOCATED IN INDIA MAP



4.2.2 Laboratory view in NIH

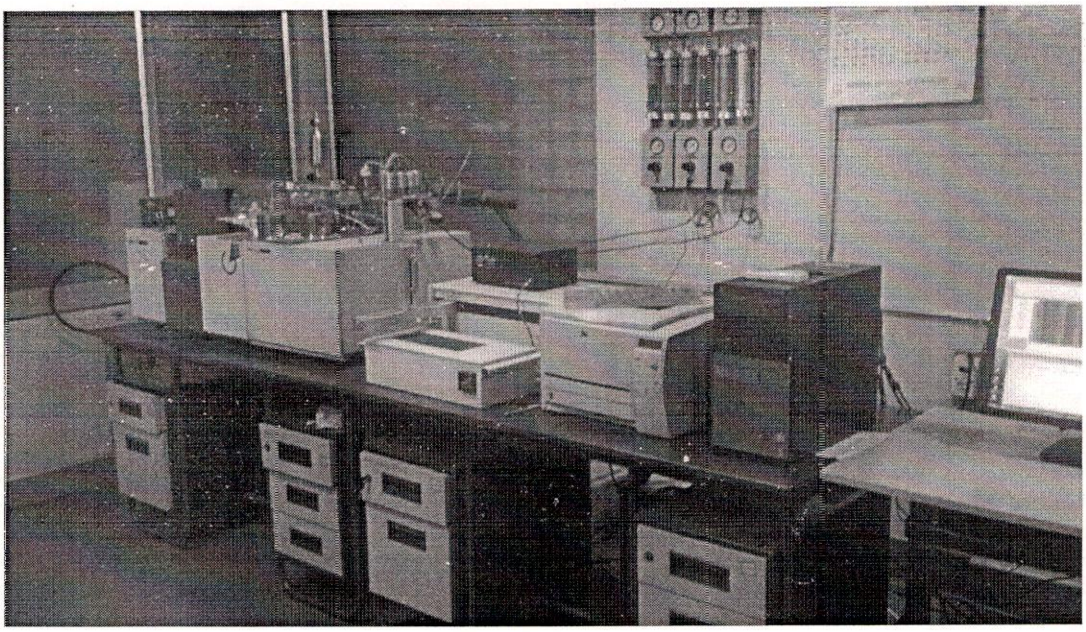


Fig.4.1 Laboratory view in NIH Roorkee

Temperature

The region experiences higher temperature during the months of May and June, with average maximum of 40° C and minimum of 5° C.

Soil

In general, the subsurface geological formations, as evident from the geological sections and individual lithologs, are composed of top soil made up of surface clay underlain by strata composed of sandy horizons, occasionally mixed with gravel beds and clay beds often, characterized with the present of Kankar.

The Roorkee town is mainly an urbanized area within its city limits. The drinking water demand of the city rests almost completely on its groundwater resources.

CHAPTER 5

RESULT AND LABORATORY EXPERIMENTS

5.1 Estimation of Oxygen-18 isotope and Volumetric Moisture Contents

Volumetric moisture content, the following steps are involved, which should be taken very carefully:

1. Measurement of volume and weight of the soil samples.
2. Gravimetric analysis of the soil samples.
3. Vacuum distillation of the soil samples.
4. Measurement of O-18 value in mass spectrometer.

The points mentioned above are quite familiar and precautions, which should be taken during the steps mentioned at sl.no.1 to 3, are very common. [10-12]

5.2 Field Experiments

Field experiments consisted of O-18 injections at various sites in the study area before on-set of monsoon seasons and carrying out sampling immediately after monsoon.

Deuterium injection in the field

The selection of site for the study was done, considering only the type of surface soil and accessibility of the area. Deuterium injections were carried out at one site.

Deuterium injections made at one site during July 2015. The site was fixed by choosing appropriate bench marks (i.e. using ropes tied between two poles).

The set of injection consisted of one central injection on the line and four injection in a circle of radius 10cm around it. This is done in order to make sure that the tracer is not lost due to a possible slight misalignment in pin-pointing the injection point while sampling the site. The drive rods (10mm dia) were first hammered into the soil, for making deep holes at the site of 80cm in depth. The drive rods were then pulled out and stainless steel pipe (injection pipe) was inserted into hole. Heavy water having deuterium of 10% concentration was injected. Heavy water was prepared in the Isotope Hydrology laboratory, National Institute of Hydrology, Roorkee by evaporative enrichment method. About 4 permil of oxygen and Deuterium of 10% concentration was injected in each hole with the help of plastic syringe at site through the injection pipe care being taken that there was minimum disturbance to the natural condition of the soil due to the injection. Each hole was completely filled up with the soil after deuterium injection. After that the site were left for its normal use.

Fig.5.1 Deuterium injection

Sampling

The soil sampling was carried out at the time of injection and immediately after the monsoon i.e. during the month of august 2015. Soil samples were collected layer by layer (10 cm sections) with the help of a hand auger of 2" diameter starting from ground surface to about 100 cm. The soil samples were carefully collected and packed in properly scaled polyethylene bags so that there was no exchange of the moisture with the atmosphere and brought to the laboratory for the analysis.

Fig.5.2 Sampling

5.3 Laboratory Experiments

5.3.1 Soil moisture content

The moisture content of the soil samples on wet weight basic was estimated by gravimetric method using infrared moisture balance.

Fig.5.3 Lab work

Wet weight of each soil sample was determined by weighting the sampling using electronic balance. After that small amount of soil sample (approximately 10 gm) was kept on the infrared moisture balance in order to dry the sample due to the radiations of the equipment which gave direct value of soil moisture content (percentage by wet weight basis of the sample). Bulk density for each sample was determined by dividing the wet weight of the sample by the volume of each sample, which was equivalent to the volume of hand auger of known diameter for a particular depth of soil column. Volumetric moisture content for each soil sample was estimated by multiplying the moisture content obtained by infrared moisture balance on wet weight basis and bulk density of the soil.[13-16]

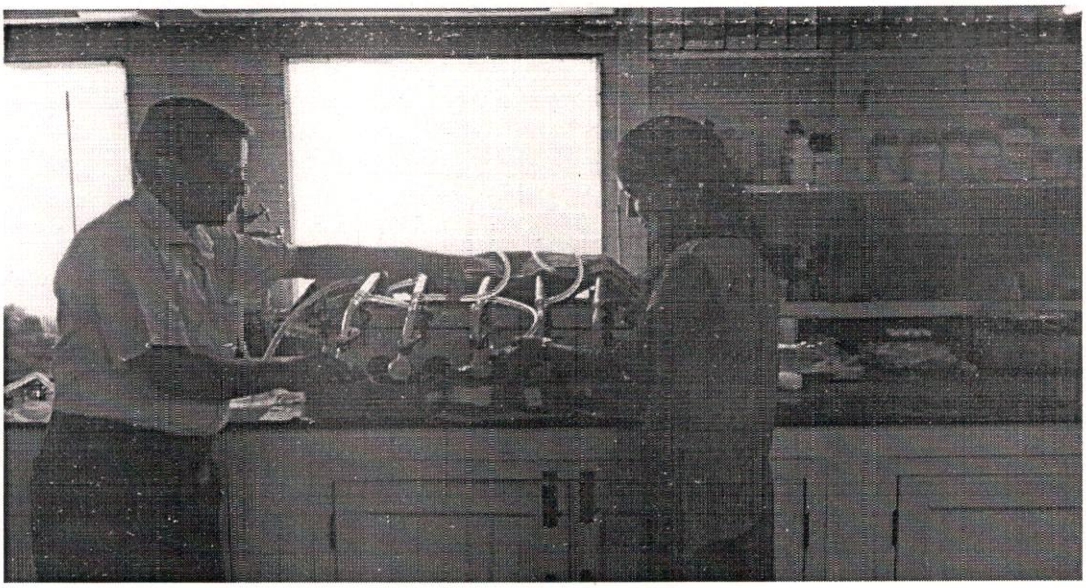


Fig.5.4 Soil moisture content

5.3.2 Water extraction from soil samples

After determination of soil moisture content for the soil samples collected from each 10 cm depth using infrared moisture balance, each sample was subjected to distillation under low pressure to avoid volatile impurities being collected along with the water. Water from the each soil sample was extracted and stored in the plastic/glass vials.

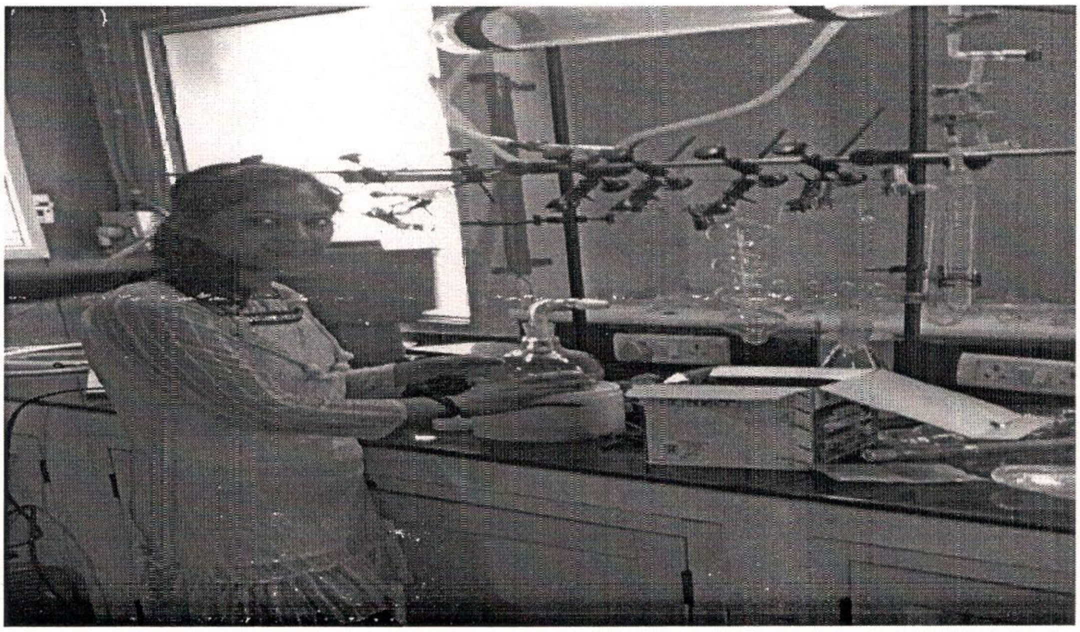


Fig.5.5 Water extraction from soil samples

5.4 RESULTS AND DISSCUSSION:

5.4.1 VOLUMETRIC MOISTURE CONTENT CALCULTAION

Table.5.1 Volumetric moisture content

Depth (cm)	Before moisture extraction	After moisture extraction	Weight of moisture (gm)	Volume of water	Volume of soil (cm^3)	Volumetric moisture content
0-10	132.08	123	9.08	9.08	60	0.1513
10-20	132.08	128	4.08	4.08	50	0.0816
20-30	132.08	126	6.08	6.08	50	0.1216
30-40	****	****	****	****	****	****
40-50	132.08	121.31	10.77	10.77	48	0.2243
50-60	132.08	75.1	56.98	56.98	56	1.0175
60-70	132.08	121.08	56.98	56.98	50	1.0175
70-80	132.08	120.84	11.24	11.24	34	0.3305
80-90	132.08	121.53	10.55	10.55	36	0.293
90-100	132.08	119.69	12.39	12.39	36	0.3441
100-110	132.08	122.17	9.91	9.91	52	0.1905
110-120	132.08	120.9	11.18	11.18	52	0.215
120-130	132.08	119.78	12.3	12.3	50	0.246
130-140	132.08	121.08	11	11	50	0.22
140-150	132.08	119.82	12.26	12.26	50	0.2452
150-160	132.08	122.49	9.59	9.59	48	0.1997
160-170	132.08	125.47	6.61	6.61	48	0.1377

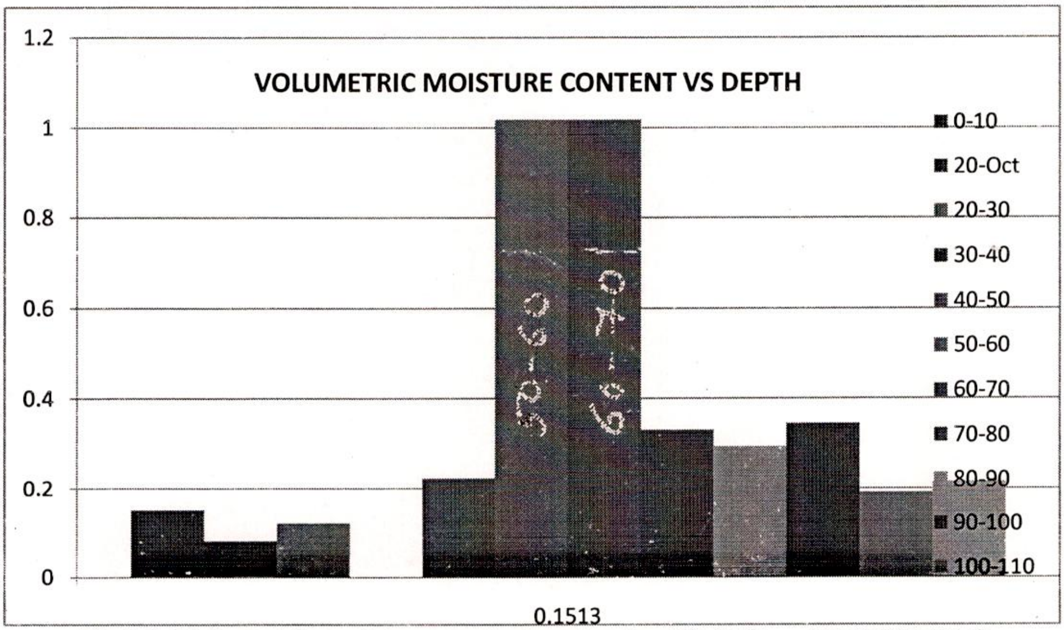


Fig.5.6 Volumetric moisture content vs depth of Soil Core ID KGN-C4-S

5.4.2 RESULT FOR OXYGEN CALCULATION OF SOIL CORE KGN-C4-S

(Lat: 29.8697; Long: 77.8934)

Table.5.2 Deuterium calculation of soil samples

S N	LOCATION	SAMPLE ID	$\delta^{18}O$	Lab Code 1	Lab Code 2
1	NIH Library	KGN-C4-S/ 20-30	-7.51	**CF 36724**	**54154**
2	NIH Library	KGN-C4-S/ 30-40	-3.92	**CF 36725**	**54155**
3	NIH Library	KGN-C4-S/ 40-50	-5.37	**CF 36726**	**54156**
4	NIH Library	KGN-C4-S/ 50-60	-5.55	**CF 36727**	**54157**
5	NIH Library	KGN-C4-S/ 60-70	-5.26	**CF 36728**	**54158**
6	NIH Library	KGN-C4-S/ 70-80	-5.25	**CF 36729**	**54159**
7	NIH Library	KGN-C4-S/ 80-90	-4.05	**CF 36730**	**54160**
8	NIH Library	KGN-C4-S/ 90-100	-0.26	**CF 36731**	**54161**
9	NIH Library	KGN-C4-S/ 100-110	-3.63	**CF 36732**	**54162**
10	NIH Library	KGN-C4-S/ 110-120	-4.76	**CF 36733**	**54163**
11	NIH Library	KGN-C4-S/ 120-130	-7.43	**CF 36734**	**54164**
12	NIH Library	KGN-C4-S/ 130-140	-5.94	**CF 36735**	**54165**
13	NIH Library	KGN-C4-S/ 140-150	-6.16	**CF 36736**	**54166**
14	NIH Library	KGN-C4-S/ 150-160	-7.68	**CF 36737**	**54167**
15	NIH Library	KGN-C4-S/ 160-170	-6.32	**CF 36738**	**54168**
16	NIH Library	KGN-C4-S/ 170-180	-6.98	**CF 36739**	**54169**
17	NIH Library	KGN-C4-S/ 180-190	-6.82	**CF 36740**	**54170**

The plot $\delta^{18}O$ depth is shown in the figure show shifted tracer (enriched peak of value close to 0%) by about 20 cm (which is) due to the infiltrated rain water.

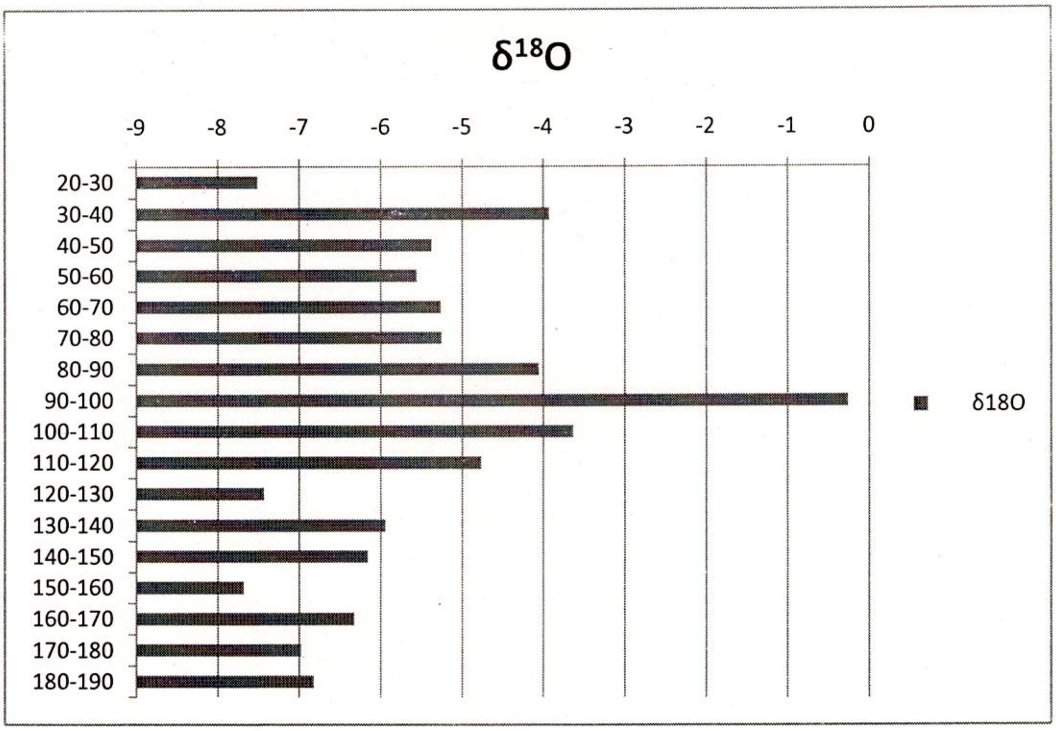


Fig.5.7. Plot of $\delta^{18}O$ of soil moisture vs depth. Also shown the shift in the injected tracer. (observation in Core ID KGN-C4-S).

SUMMERY & CONCLUSION

The conventional method of recharge measurement or analysis of infiltration process using isotopes is based on Tritium Tagging Technique. Since, tritium is radioactive and hazardous to environment, in the present project a novel idea was invoked to use stable isotope of water (which is 100% non-hazardous) as an alternate to tritium. The feasibility of stable isotopes for soil moisture movement has been examined in the present project by replacing tritium injecting water by highly enriched stable isotope water. The enriched stable isotope water was prepared in the laboratory by evaporation enrichment technique. For feasibility study, water enriched at a level much higher than environmental stable isotope level of water was used as tracer to track the infiltration process. The movement of tracer along with infiltrating rainfall was tracked by extracting and measuring the stable isotope composition of soil moisture. The success of the study provided a new window in stable isotope use in groundwater recharge study. The hypothesis of use of stable isotope in infiltration process and its observation through field study is one of the first kinds of its study in India. However, the Tritium Tagging is still superior at present then the Stable Isotope tagging due to its ultra high signal to noise ratio. Improvement of S/N in Stable Isotope signal in the tagging technique still requires further improvement in the procedure to make it as a standard method to use routinely for recharge studies. Although the feasibility of the technique is demonstrated the technique requires lot of improvement which can be taken up in future course of action.

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