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Water Resource Management through Isotope Technology in Changing Climate

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Abstract The water system plays an indispensable role on the planet earth for the survival of living species as well as for the sustainability of ecosystem. However, numerous factors like population growth, industrial activities, rapid urbanization, depletion of aquifers, climate change, several anthropogenic activities, geogenic activities etc. influence the water system. Therefore, the proper management of water resources has become the need of the time because its management and study will be much helpful to cater the safe water for the increasing population globally. In such direction, isotope technology has been emerged and established as an efficient scientific tool to combat the water related issues like ground water recharge studies, its quality management, surface water studies, salinization and contamination studies etc. The present paper highlights the importance of isotope technology for the management of water resources in changing climatic conditions.

Keywords: *water resource management, isotope technology, ground water recharge, salinization, climate change*

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1. Introduction

Water is one of the important natural resources for sustaining the life. The demand of fresh water has amplified manifold. Besides, climate change generally affects the water resources through changes in levels and distribution of snowfall, rainfall by the increase in air and water temperature and finally affects the ground water sources [1,2]. Hydrology is the science of water which deals with the occurrence, circulation and distribution of water on earth and its atmosphere [3,4,5]. In the current 21st century, not only the demand of fresh water has been increased but the natural disasters like flood, droughts etc. have also created the problem of safe water to global population. There is an massive stress not only on surface water sources but on ground water resources. Ultimately, the water level has declined in most of the parts of India [2] as well as in other countries. Unequal spatial and temporal distribution of rain has also made the situation more difficult. Most of the world's population is facing trouble for safe drinking water in sufficient quantity. Urbanisation has amplified this crisis in urban areas as well as in rural areas also. Any river basin and concerned aquifer system explain the spatial boundaries of water resources of specific area. In hilly terrains, springs are the principal water resources for the mass population in addition to ground water resources. A major part of population in Uttarakhand, which is one of the hilly states of India, resides in hilly areas and approximately 90 % of the rural population depends on the natural water resources like springs, lakes, rivers etc. [7,8,9].

Though, ground water is dynamic and replenishable but upto a definite boundary. Ground water can be recharged directly through local precipitation i.e. either rain fall or snow fall. Consequently, the harvesting of rainwater has become a vital subject for the development and management of groundwater. The recognition of source and recharge areas in hilly regions is important to the appropriate measures for longer sustainability. The requirement of fresh water for domestic, agricultural and other important purposes in mountains is being satisfied by the springs for a long time but now a days, these springs are meagre, have low discharge and sometimes vanish due to climatic circumstances. Thus, generate a lot of hardships to the local people particularly during summer season. Isotope technology provides the hydrological knowledge for a large area and is a key method in water resources management and assessment. The role of Isotopes in hydrological investigations has been recognized by world scientific community [6,10,11,12]. The present article specially explains the isotope hydrology and application of isotopes in water resource management, in ground water recharge, in ground water salinization and contamination studies etc.

2. Isotopic Composition of Water and Isotope Technology

Fundamentally, springs are derived from seepage water which is flowing through the shallow weathered and cracked zones in mountains. Even though, several conventional methods exist to study the different hydrological processes for a variety of water resources [5,10,13,14,15,16]. The use of isotopes i.e. environmental and artificial radioactive isotope has been recognized as an effective approach to solve the crucial hydrological difficulties [4,12,17,18,19,20]. δ^2H and $\delta^{18}O$ isotopes of water are included into geological and biological systems in an expected way [21,22,23] and being used as tracers in different hydrological, archaeological, ecological and forensic studies [24]. The environmental isotopic methods coupled with conventional hydrogeological and geochemical information have become more beneficial to recognize the recharge area of a specific source.

Commonly, the use of isotopes of the elements of water molecule like ^1H (protium), ^2H (deuterium), ^3H (tritium), ^{16}O, ^{18}O and that of carbon [^{12}C, ^{13}C, and ^{14}C], which occur as constituents of dissolved organic and inorganic materials, have increased most frequently in hydrological investigations. Furthermore, the environmental stable isotopes of hydrogen (^2H), oxygen (^{18}O) and radioactive isotopes of hydrogen (^3H) and carbon (^{14}C) complete the purpose in spring investigations. Difference in stable isotope composition of hydrogen and oxygen in water molecule has effectively been employed in hydrological studies [3,17,25,26,27,28]. The stable isotopes of water are affected during ground water recharge and by a variety of isotopic processes. Sometimes the elucidation of isotopic data is complicated due to some other concurrent processes [17,29].

The stable and radioactive environmental isotopes make possible the research of diverse hydrological routes on a much larger temporal and spatial scale through their natural variation in a system where as the use of artificial tracers is usually efficient for site specific and local applications [30,31]. The Global network for Isotopes in precipitation (GNIP) is monitoring water isotopes since 1961 [11] and GNIP dataset has enough temporal and spatial density of the stations in most of the parts of the world to provide the foundation of spatial modelling [32] except some of the regions of the world [33]. West et al. [34] studied the spatial analysis of hydrogen and oxygen stable isotopes i.e. isoscapes in ground water and tap water across South Africa. The authors exposed a logical spatial structure in δ^2H, $\delta^{18}O$ and d, as well as in isotopic offsets between ground water and tap water samples. Isotopes specially chemical and isotope tracers are unique and effective tool for the assessment of ground water sustainability like identification of potential water resources, recharge characterization, impact of pollutants and hydrological changes. Aina Su and co workers [35] studied the sustainability of intensively exploited aquifer systems in the north china plain by multiple environmental tracers.

3. Isotopes in Water Resource Management

For the safe drinking water quality as well as for water resource management, the development and successful execution of isotope technology has become very important. Isotopes provide very important information for the healthier management of water resources. Isotopes either stable or radioactive originate from environment as well as from reactor are regularly being used as tracers in several hydrological investigations like aquifer-aquifer interconnection, interrelation of surface water-groundwater, source of groundwater salinity, source of ground water pollution, effectiveness of artificial recharge, source of recharge, estimation of recharge to the groundwater, study of lakes and geothermal water etc [10].

The precipitation, evaporation and condensation are the important physical process of hydrological cycle. During evaporation process from ocean, lighter isotopes of H and O come into vapours whereas the heavier isotopes condense during condensation process preferably. Therefore, isotopic variation due to these processes occurs in water molecules. Simultaneously, some other important metrological factors like humidity, temperature, equilibrium of the process also affect the isotopic variation significantly. Isotope Ratio Mass Spectrometer (IRMS) measures the real variation in isotopic composition in meteoric water minutely. Bhabha Atomic Research Centre (BARC) Mumbai has effectively applied the Isotope Technology in the area of water resource management to resolve the water related issues in the country. The frequently used isotopes for various hydrological investigations have been reported in Table 1.

Table 1. Isotopes used for various hydrological investigations [10]

Element	Isotope	Ratio	% Abundance in nature	Use in Hydrology
Hydrogen	^2H	$^2H/^1H$	0.015	Origin of water
Oxygen	^{18}O	$^{18}O/^{16}O$	0.204	Origin of water
Carbon	^{13}C	$^{13}C/^{12}C$	1.11	GW dating
Nitrogen	^{15}N	$^{15}N/^{14}N$	0.366	Source of Pollution
Chlorine	^{37}Cl	$^{37}Cl/^{35}Cl$	24.23	Source of Pollution

4. Environmental Isotopes in Hydrological Studies

The movement of water in hydrological cycle can be studied by using both stable and radioactive environmental isotopes in isotope hydrology. Stable isotopes in water i.e. δ^2H and $\delta^{18}O$ are the key indicators of hydrological and ecological pattern and development [3,36]. Different types of water specially in geothermal areas may occur like Meteoric Water: originates from precipitation; Juvenile Water: This water is never been a part of hydrological cycle and originates from Earth's mantle or core; Ocean Water: This water may enter the geothermal systems; and Magmetic Water: Associated with magma through equilibrium. The meteoric water originated from different geothermal areas and possesses different isotopic composition. Normally, the mean annual isotopic δ values of precipitation are closely related to the local mean annual air temperature i.e. the lower the value of temperature, the lower will be the amount of heavy isotope. Subsequently, more negative values of $\delta^{18}O$ and $\delta^{2}H$ will be in colder areas. In the same way, the rainfall at higher altitude will be isotopically lighter in comparison to plain areas. The continental effect can also have an efficient role in isotopic composition.

A small change occurs in the concentration of hydrogen and oxygen isotopes occurs in each stage of hydrological cycle and has been considered as a unique fingerprint property. Environmental isotopes from atmosphere have been found to involve in hydrological cycle. The stable isotopic ratio of hydrogen and oxygen in groundwater is based mostly upon isotopic variations in precipitation. Vienna Standard Mean Ocean Water i.e. V-SMOW has been known as the international standard to exhibit the hydrogen and oxygen isotopic ratios of water molecule [37]. Moreover, the stable isotope composition is expressed as δ values in per mil i.e. parts per thousand (‰).

The hydro-geochemistry of geothermal water resources can be performed with the help of environmental stable isotopes. The higher amount of ^{18}O in ambient water was occurred due to the rock-water interaction at more than 150 °C temperature in hot water sources. According to Gonfiantini [38], δH and $\delta^{18}O$ values are generally reported relative to Standard Mean Ocean Water (SMOW) [25] or Vienna – SMOW (VSMOW) standard. Lower δ values explain the sample as depleted whereas enriched samples possess higher δ values w.r.t. a reference. Evaporation and condensation processes affect the stable isotopic composition of water. Therefore, recharge water in a specific environment will have a specific isotopic signature. Moreover, the isotopic signature behaves like a natural tracer for water movement. The ground water from different origins possesses their isotopic signatures over geological period due to sluggish exchange of isotopes between colder ground water and associated rocks. The evaluation of ground water in a mixture of a variety of groundwater and source of dissolved components in it can be explained with the help of δ values of various isotopes ^{2}H, ^{18}O, ^{34}S and $^{87}Sr/^{86}Sr$ ratio. Although, there are enormous complexities in various components of a hydrological cycle but $\delta^{18}O$ and δH in meteoric waters execute in a predictable manner and correlate to define a global meteoric line (GMWL) [25,39]. Deviation of local meteoric water lines (LMWLs) from GMWL facilitates the identification in local climatic and geographical conditions of hydrological processes.

5. Interpretation of Ground Water Recharge

German researchers Seeyan and Merkel [40] have determined the source of ground water and surface water, ground water recharge mechanisms in semi-arid Shaqlawa-Harrir basin in Kurdistan region of Iraq with the study of stable isotope (^{2}H, ^{18}O) and ^{14}C determination. The depletion in $\delta^{18}O$ content of some water samples has been found due to higher altitude of few recharge sites i.e. due to altitude effect. Scientists have reported that the environmental isotope techniques are much helpful to identify the source and the mechanism of recharge [19,41,42], ground water renewability [43,44] and hydraulic inter-actions [45,46], recharge areas and transit times of the aquifer [47,48]. Generally, isotopes are useful either as tracers or as age indicators in hydrological investigations. In this direction, Zuber [49] has defined a tracer and reported that a tracer possessed at least one property which distinguishes it from the traced material. Stable and radioactive natural isotopes of the atoms of water molecule as well as the atoms of the compounds dissolved in water are found very useful in hydrological and hydro-chemical studies of river waters. Now it is evident that, ^{1}H - protium and ^{2}H - deuterium are two natural stable isotopes of hydrogen and ^{16}O, ^{17}O, ^{18}O are three stable isotopes of oxygen. Moreover, out of nine isotopically different water molecules, only three viz. ^{2}H ^{16}O, ^{2}H ^{18}O and $^{1}H^{2}H^{16}O$ occur in nature as easily detectable class.

Some researchers [50,51,52] have reported that the information about the location and altitude of the recharge area due to rock-water interaction along the flow path can be studied with the help of analysis of rare earth element like Yatrium analysis in association with stable isotope ratios. The flow paths and residence time at the catchment scale can be examined by the isotope measurements with regional hydrological modelling. Isotopic studies are very useful in the management of ground water and its safety [6,53,54]. Rocks are categorized on the basis of hydro-geological, pedagogical and geo-hydraulic properties i.e. water storage and hydraulic permeability. Besides this, the period and climatic conditions of ground water recharge can be studied by radionuclide dating and stable isotopic analysis which helps in the determination of ground water origin. Furthermore, two factors are significant upon which ground water flow and the natural hydro-chemical processes depend. First one is geological-ecological structure and second is petro-logical composition of the lithosphere which affects the hydro-chemical properties of ground water. Rain water infiltrates directly into the ground or through inflow of surface water besides this some of the groundwater comes from the magma. Usually, the ground water flows in rocks aquifers through pores, fissures and cavities. The aquifer's configuration depends on the hydro-geological structures. The water rock interactions can be explained with the help of carbon isotopes. The isotopic and chemical compositions of ground water clearly explain the mineralogical constitution of rocks surrounding the aquifers. Therefore, the location of recharge area and source of ground water such as marine, fossil, magmatic etc. can be explained with the help of both these properties. Besides, the carbonate, nitrate, sulphate etc. chemical components and water rock interaction can also be explained.

The discharge of ground water takes place to the surface when the saturation zone strikes the surface. Further, percolation and flow of ground water occurs into streambeds or in the form of discharge at springs. After a long time of recharge event, the discharge of ground water generally occurs at the opening of a drainage basin. Evaporation, condensation, various chemical reactions, microbial metabolic process like desulfurication, nitrification and denitrification are associated with isotopic fractionation of water molecule during the ground water percolation. Mook [54] reported that the processes of filtration proceed throughout semi-permeable membrane of clays during rock water interactions under suitable geothermal conditions and finally isotopic exchange of hydrogen and oxygen isotopes occur. To manage a ground water system, the quantitative evaluation of temporal as well as spatial allocation of ground water recharge is the essential requirement. The recharge of ground water is an important issue in regional scale hydrological models and aquifer-system analysis. The estimation of ground water recharge can be discussed more significantly on the basis of water balance concept. Mass balance method for the estimation of ground water recharge was used for the first time by Mtinnich in 1983 with anthopogenic ^{3}H. For such type of study, a height equivalent theoretical plate model was used for the modelling of hydrogen status in unsaturated part.

6. Ground Water Salinization and Contamination Studies with Isotopes

The ground water quality in urban areas, around industrial units, coastal areas etc. is deteriorating day by day. Generally, salinization threatens the ground water quality, particularly in coastal parts. Water quality in arid and semi-arid regions is deteriorating slowly due to the salinity problem in most of the aquifers of the area. Such type of problem is occurring because the salinization occurs often either due to the movement of formed saline water by over-exploitation of inland aquifer system or due to the flow of saline water from coastal aquifer system during heavy withdrawal of fresh water i.e. rock water interaction. The problem of salinization is increasing day by day due to the huge irrigation practices, and application of fertilizers and other chemicals in agriculture. The exact cause of ground water contamination can be identified with Isotope Techniques [55]. Mongelli and co-workers [56] have studied ground water salinization process in coastal aquifers of north western Sardinia part of Italy through hydrogeochemical and isotopic approach. The authors reported that the salinization in Nurra region of the NorthWestern Sardinia was related to marine water intrusion caused by aquifer exploitation. The origin of Groundwater salinity as well as the hydro-geochemical processes in the confined Quaternary aquifer of the Pearl River Delta of China has been accessed by Wang and Jiao [57]. Under the work, the authors studied the major ions (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, NH_4^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}), performed isotope ($\delta^{18}O$, $\delta\,^{2}H$, ^{3}H, $\delta\,^{13}C$ and ^{14}C) analysis and reported that sea water was the main salinity source for ground water.

The isotopes of nitrogen are important as anthropogenic tracers and are helpful to establish the source of organic contamination in ground water body [58]. Researchers have reported that isotopic ratio of chlorine i.e. $^{37}Cl/^{35}Cl$ describes the ground water pollution [59,60].

7. Conclusion

During the past decades, the climatic conditions have significantly affected the water resources worldwide. World scientific community have worried for the sustainability of water resources. It is evident from above discussion that Isotope technology is very significant method to sustain and management of water resources as well as plays a key role in water resource identification, ground water pollution studies, ground water recharge, rejuvenation of springs and salinization studies of ground water. The future demand of safe drinking water can be resolved by adopting this technology not only for urban areas but for rural communities also. Consumption of safe drinking water will protect the human health against fatal water borne diseases and finally increase the prosperity of the people. In India, Bhabha Atomic Research Centre (BARC) Mumbai; National Institute of Hydrology (NIH) Roorkee and Himalayan Environmental Studies and Conservation Organization (HESCO) Dehradun etc. are working for the studies of water resources with isotopic methods. Definitely, the research of isotope technology has become a boon to resolve the water related problems of the country and can be adopted not only in hilly terrains but in plain areas also.

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