STUDY OF WATER ISOTOPE APPLICATIONS AND HYDROLOGICAL PROCESS RESEARCH

Vikas Keshari
Research Scholar
Department of Engineering
OPJS University, Churu, Rajasthan.
vikas07ch89@gmail.com

Dr. Deepak Dalal
Associate Professor
Department of Engineering
OPJS University, Churu, Rajasthan.

Abstract: *Water's stable and radioactive isotopes track water molecules throughout the water cycle. Since laser absorption spectroscopy can quantify stable isotope ratios at better resolutions, water isotope studies have increased in the previous decade. This Special Issue addresses the latest water isotope methods, applications, and hydrological process interpretations and adds to the rapidly developing isotope data store needed to manage future water resources. We are pleased to present this collection of 14 papers on the use of water isotopes to study hydrological processes worldwide, including local and regional studies on precipitation dynamics or the use of water isotopes in conjunction with other hydrochemical parameters to pinpoint hydrological and geochemical processes in surface water, snowmelt, soil water, groundwater, and xylem water.*

Keywords: *surface water; water management; water cycle; isotope hydrology; measurement traceability; precipitation (rain and snow); groundwater; networks and data bases; statistical evaluation*

Introduction

Evaporation, transpiration, condensation, precipitation, runoff, and infiltration move water through Earth's spheres, supporting all life. Fresh water is essential to the world economy. Cities have always been built around reliable water supplies, and a large share of fresh water is utilised for irrigation and other agricultural operations to feed people.

Stable (16O, 17O, 18O, 1H, 2H) and radioactive (3H) isotopes in water molecules allow tracking of water molecules from precipitation to surface and groundwater to drinking water. They are used to measure water, solute, and particle exchanges between hydrological compartments during hydrological processes and track water's source and flow paths.

Over the last decade, water isotope studies in hydrological systems have increased. Since 2007, hydrological studies have used new measurement methods like tunable diode isotope ratio infrared laser absorption spectroscopy—LAS—to measure stable isotope ratios with smaller sample sizes.

The closed Special Issues "Radioactive Isotopes in the Hydrosphere," "Advances in Isotope Tracer Techniques for Tracing and Quantifying Hydrological Processes," and "Isotopes in Hydrology and Hydrogeology" published most of the papers.

Precision measurements are needed to give fresh data that is equal to conventional isotope ratio mass spectrometry or similar in space and time.

Thus, this SI welcomed papers on statistical data evaluation methods and specific topics like measurement traceability (comparison of different measurement techniques), conceptual network development, and long-term maintenance of local to regional networks.

Contributions

The overview divides contributions into two categories: isotopes in precipitation and more complex hydrological and hydrogeological studies. It's remarkable that all of the contributions cover precipitation isotopes, and five of them go into deeper depth regarding networks of monitoring with longer and more frequent precipitation measurements. Precipitation is the primary supply of water for catchments and plays a major role in the water cycle, hence isotopes are vital. Other research employs precipitation isotope data for more complex hydrological and hydrogeological analyses. Those studies describe isotopic sampling networks that collect and analyse precipitation, surface water, and groundwater data. Some investigations collected snow, ice, snowmelt soil water, or xylem water.

This SI contains international research publications. The sole SI review paper on stable isotopes of water and nitrate addresses analytical methods, hydrograph separation, and background. It also addresses nitrate measurement in stream water pollution. Other publications include case studies sampled at a single place, within a study area of a few square metres to a few tens of square kilometres, or on a regional size of more than 1000 km.

Some articles examine data sets for Chile, China, or Iran. IRMS or LAS were also utilised to measure isotopes. Some research uses many data sources. Although authors usually provide information about the instruments they used and the analytical precision, it is not always clear how the instruments were calibrated, how the data were normalized, or how the precision was calculated.

Isotopes in Precipitation

Each SI article includes precipitation isotopic composition. This section discusses regression model-based local meteoric water lines (LMWL) and precipitation dynamics.

Boschetti et al. calculated the LMWL with a confidence interval for this region using isotopic data from 32 Chilean sites from diverse sources using error-in variables (EIV) regression. EIV and OLSR have similar slopes. The authors believe the innovative EIV-LMWL is more accurate and suitable than OLRS or other regression models when x-axis measurement errors are violated.

Kong et al. meta-analyse precipitation isotopes from 68 Chinese sites. They grouped the country into five moisture-source-based regions based on precipitation isotopic composition and seasonal changes. Using monthly data, the OLRS model generated LMWLs for each region. O-temperature and 18 Areas' O-precipitation gradients were also discovered. The study suggested isotopic usage in hydrological and paleoclimate investigations.

Heydarizad et al. collected isotopic data from multiple sources for 32 Iranian and 4 Iraqi locations. They used the OLRS, considered local air masses and moisture sources, and created three LMWLs for Iran. They verified the LMWL and identified key moisture sources for those water resources by comparing it to current karstic spring and surface water isotope data from around Iran.

Krajcar Broni'c et al. focused on a long-term precipitation isotope record in Zagreb, Croatia, unlike previous works. Reports contain stable isotope data, tritium activity concentration, air temperature, and precipitation totals. A statistical study showed a considerable rise in yearly air temperature, bigger variability in annual precipitation quantities. Over 20 years, H levels have risen while tritium activity has somewhat reduced. Crawford et al.'s regression models calculated the LMWL, but no significant changes were detected.

Use of Water Isotopes in Complex Investigations

This section summarises the most important results of previous articles using water isotopes in difficult hydrological and hydrogeological research.

Porowski et al. examined sources and biogeochemical activities in a peatland-affected aquifer in Poland's Kampinos National Park. Chemical and isotopic analyses indicated the primary groundwater dissolved sulphate sources. The air sulphates from pyrite oxidation and evaporate sulphate mineral dissolution were also detected. Water isotopes were used to calculate groundwater recharge and atmospheric inputs.

Van Lam et al. used isotopic methods to study Vietnam's Red River delta groundwater. The authors computed the LMWL using the OLSR following short observations of local precipitation and precipitation water isotope data. They also detected the isotope composition of groundwater, ocean, and surface water and analysed the region's water resources' origins and methods. They also studied salt water incursions and aquifer relationships.

Sing et al. built a short-term observation station in the Sutri Dhaka glacier basin in the Himalayas using rain, snow, ice, and snowmelt samples and water isotope analyses. The authors utilised precipitation data to determine moisture sources and LMWL. A stable isotope-based three-component hydrograph separation was used to quantify ice-melt and snowmelt runoff.

In the Qinghai-Tibet Plateau's Naqu River basin, Chen et al. adopted Sing's approach. They created a short-term sample station to collect precipitation, snowmelt, and groundwater for isotope analysis to study runoff sources and regional variation. The authors calculated the LMWL and river water line using the linear connection without explaining the regression procedure. Finally, utilising water isotope data for hydrograph separation, they computed runoff from rains, snowmelt, and groundwater.

Tsuchihara et al. examined groundwater isotopic and hydrochemical distribution in a few Japanese alluvial fans utilised for rice fields. They used a self-organizing map (SOM) and an unsupervised training approach of a Kohonen artificial neural network model to represent groundwater hydrochemistry spatially. The SOM divided groundwater into four types and identified water sources. Their work affects groundwater management. Tsuchihara et al.'s conclusions, data interpretation, and systematic, organised sampling technique are fascinating for future water resource management.

Markovi et al. exploited stable isotopes and hydrochemical characteristics to improve the conceptual model of a Croatian alluvial aquifer, a major drinking water source. As with Krajcar Broni'c et al., the authors computed the area's LMWL using Crawford et al.'s regression models and found no significant changes. The authors also derived groundwater 6 and pore water isotope composition data using water isotope data and water head data in a multi-objective calibration strategy to restrict soil hydraulic property parameterization. The model was tested using sandy soil pore water data from two

Montreal, Canada, sampling sites. After estimating yearly groundwater recharge without continuous monitoring data, they found that water content and pore water isotope data from a single measurement may calibrate the model. The results show that groundwater recharge studies may be undertaken with fewer long-term monitoring observations and targeted sampling.

Conclusions

We must comprehend geosphere water exchange to successfully manage water resource environmental issues. The water molecule's isotopic makeup, found in numerous water cycle compartments, functions as a natural fingerprint to track its path. This special issue on water isotopes in hydrological processes contains 13 original research papers and one review. Precipitation isotopes are mentioned in every presentation, either in detail or as part of water resource case studies. Some writers use the multi-parameter technique, combining isotope and geochemical characteristics, to answer issues. Tsuchihara et al.'s self-organizing map technique illustrates the latter.

The use of proper terminology, the improvement of water isotope data traceability to provide results comparable in space and time, the reporting of "raw" data and detailed explanations in accordance with FAIR data practise, and the reporting of reused isotope data sources remain challenges for the future. The upcoming Water MDPI Special Issues, "Application of Stable Isotopes and Tritium in Hydrology," "Isotope Hydrology," "Application of Isotopic Data to Water Resource Management," "Geochemistry of Groundwater," and "Applying Artificial and Environmental Tracing Techniques in Hydrogeology," cover these topics well. The Guest Editors are considering releasing "Use of Water Isotopes in Hydrological Processes, part II" in 2021 to build on this SI's success. A collection in the latest SI may inspire working groups in the COST Action "water isotopes in the critical zone: from groundwater recharge to plant transpiration (WATSON)", CA19120, which has recently commenced. An SI might also address the Action's priorities.

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