

APPLICATION OF STABLE ISOTOPES IN THE STUDY OF WATER RESOURCES AND SEDIMENTATION PROCESSES

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Abstract. Understanding the groundwater regime, the interaction between surface water and groundwater, and the factors that influence these processes requires a deeper knowledge of groundwater recharge to prevent overexploitation and further deterioration of resources. Nationwide isotope studies provide critical insights that were previously unavailable in the country, limiting advances in understanding the water cycle and effective water management. The method primarily focuses on stable isotopes of water molecules (^{18}O , ^2H , ^3H , etc.) as tracers of water origin and movement, offering information that cannot be obtained through conventional techniques. These include the residence time of groundwater, the elevation of recharge zones, the contribution of snowmelt to rivers and operational wells, and the identification of paleowaters formed under past climatic conditions. Isotopic analyses also help determine groundwater origin, flow pathways, and possible contamination sources, thereby contributing to the sustainable assessment and protection of groundwater resources.

Key words: Stable isotopes, Mean transit time.

Introduction

Understanding the groundwater regime, the interaction between surface and groundwater, and the factors influencing their quantity and quality are crucial for ensuring a safe water supply for the population. Deepening our understanding of groundwater recharge is essential to prevent overexploitation of resources and deterioration of the current situation. The method primarily utilizes stable isotopes (^{18}O , ^2H) as tracers to study the origin and movement of water. These isotopes provide insights into various processes such as the movement of water in underground horizons, the source of underground water, the contribution of snowmelt water to rivers or operational wells, and the identification of ancient waters formed under past climate conditions. Isotopes also help trace the origin of groundwater and pathways of contamination, facilitating the assessment and protection of groundwater resources sedimentation process. These studies have been emphasized in recent projects conducted in central and eastern Georgia, with direct involvement from this scientific group.

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Methods

To assess groundwater resources and sedimentation process, understand the impact of climate change on their dynamics, it's essential to observe the entire natural water cycle using stable isotopes. This includes studying glaciers and snowmelt waters, monitoring atmospheric precipitation, and examining surface and deep groundwater across the entire region.

For this purpose, monthly isotope measurements were conducted at eight meteorological stations, four river monitoring stations of the Environmental Agency of the Ministry of Agriculture and Environmental Protection. They are part of the Global Network of Isotopes in Precipitation and Rivers (GNIR) encompasses the Rioni (Ambrolauri), Mtkvari (Tbilisi), and Alazani (Telavi) stations. In parallel, the ecological monitoring network of the Geological Department includes 34 observation wells and 6 springs (Fig. 1).

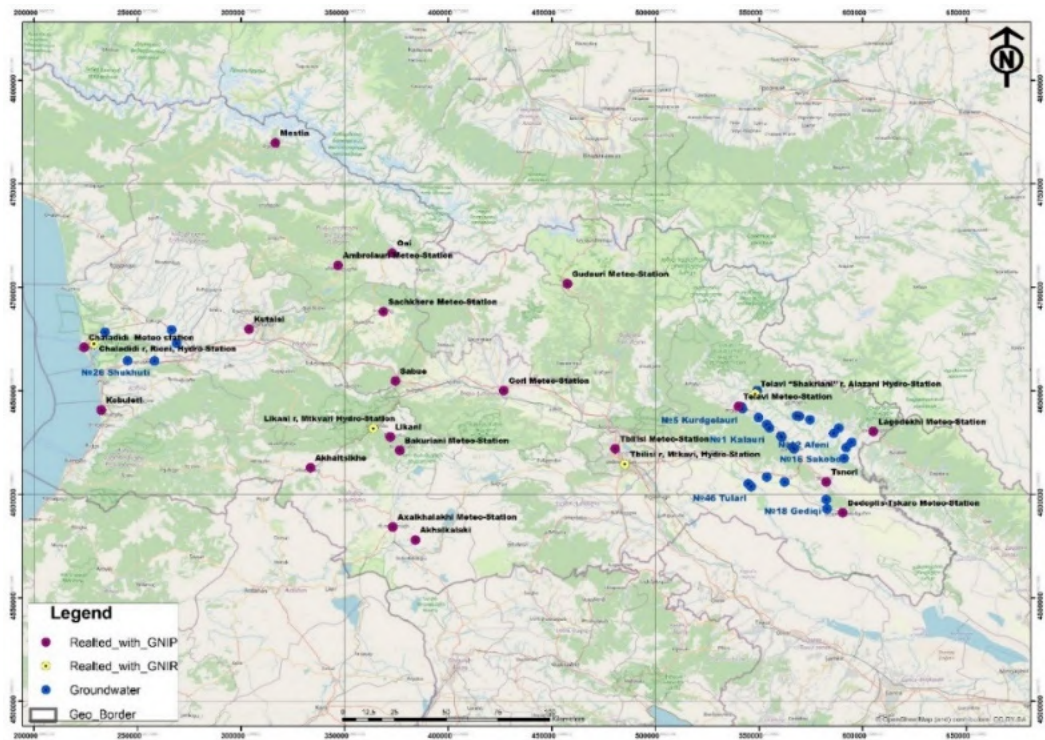


Fig. 1. Location monitoring stations.

The data collected will be utilized to analyze the temporal variation of stable isotopes and geochemical parameters, including background values, seasonality trends, etc.

As noted above, an important parameter of watershed hydrological behavior is the time lag between precipitation input and its subsequent discharge into the river. This parameter, known as the mean transit time (MT, or mean transit time), was first conceptualized in the 1980s [1–3].

A clear pattern is observed in the isotopic data: atmospheric precipitation is characterized by the lightest, or “youngest,” isotopic composition. As water contributes to river discharge and moves downstream, its isotopic signature becomes progressively “heavier,” reflecting mixing and flow pathways within the watershed. This shift provides valuable insight into the direction and dynamics of water flow.

Based on these indicators, it is possible to estimate the “travel time” of water flow within the catchment. This is achieved through comparative analysis of isotopic compositions. Specifically, the isotopic signature of atmospheric precipitation recorded at a meteorological station can be compared with that of river water at a gauging station or with groundwater sampled from observation wells in the study area (Fig. 2, Fig. 3).

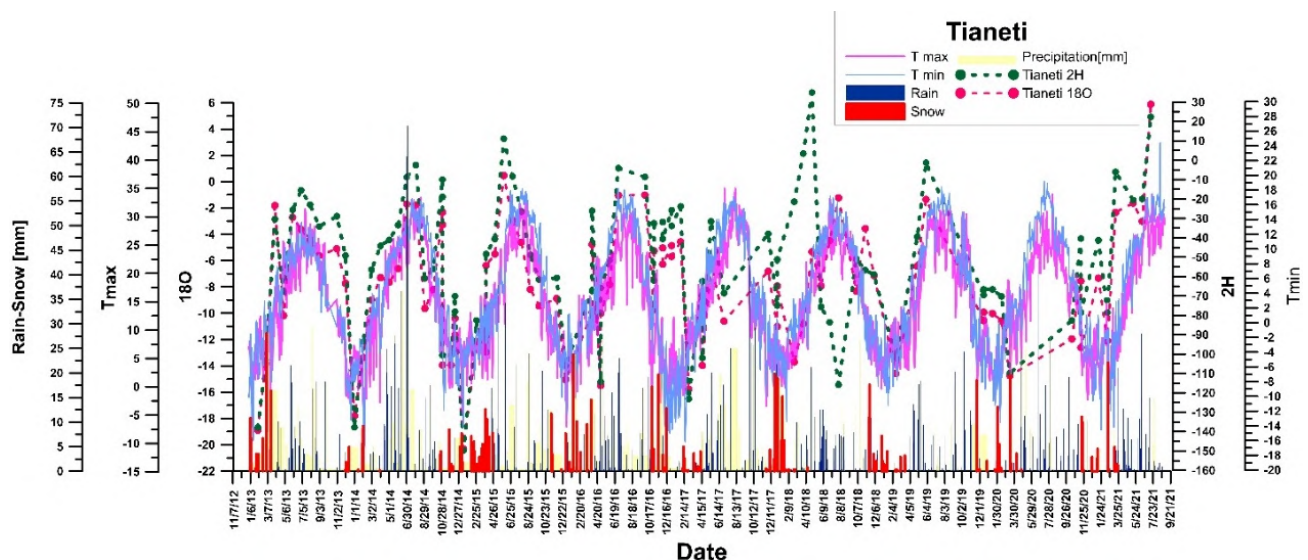


Fig. 2. Parameter variations at Tianeti Meteorological Station.

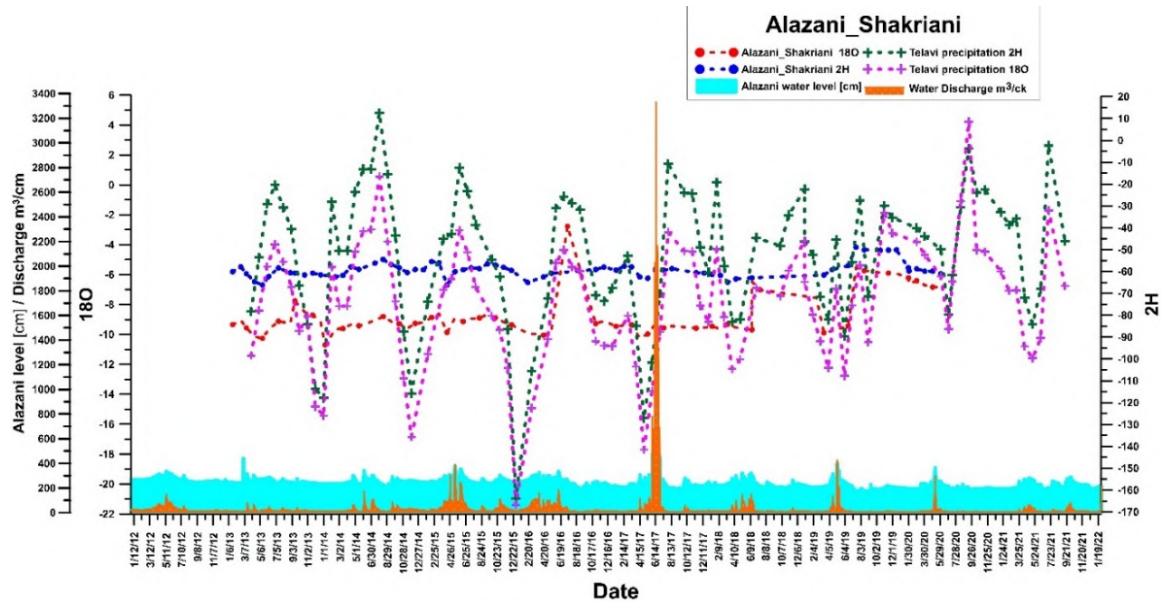


Fig. 3. Variations of parameters at Shakryani Station.

To estimate the mean transit time of groundwater, the “sinusoidal curve method” based on an exponential model was applied. Sinusoidal curves were constructed using isotopic data from individual stations, and comparative analysis was performed. Specifically, the isotopic composition of precipitation at the Tianeti station was compared with that of river water at the Shakryani station (near Telavi). The Tianeti station is located at a higher elevation within the Alazani River catchment, providing a representative input for up-stream precipitation (Fig. 4).

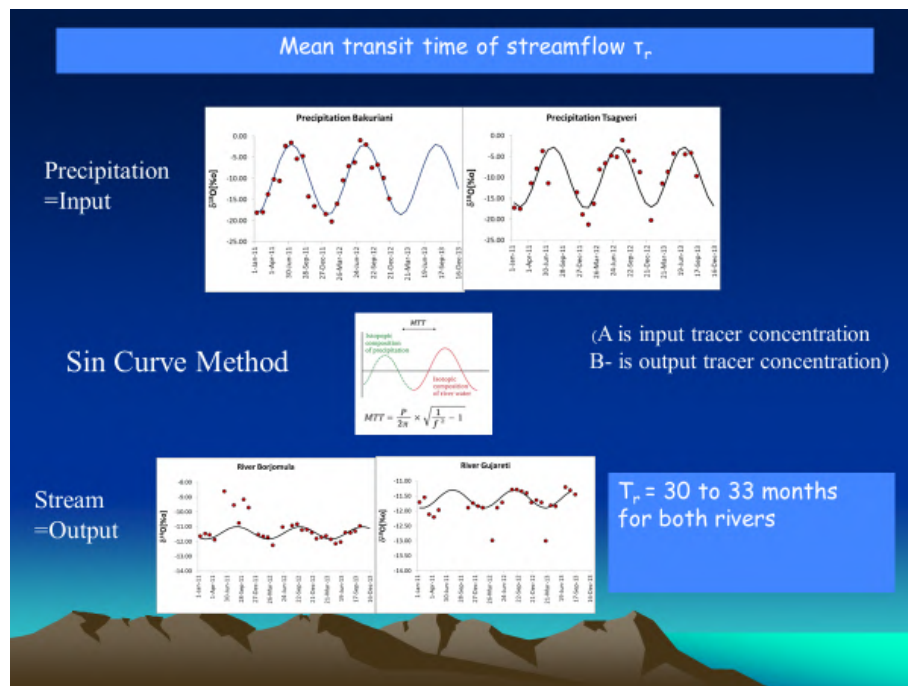


Fig. 4. Sinusoidal variation of monthly precipitation isotopes at Tianeti Station and monthly isotopes in the Alazani River.

To estimate the travel time of water, the average isotopic composition of precipitation at the Tianeti station was used as the “input” data, while the isotopic composition of the Alazani River near Shakhvani was used as the “output” data. The relationship between input and output was determined using the following diagram and formula (Fig. 4):

Where P is the period of the sinusoidal input (e.g., 12 months for annual variations), $f = B / A$, where A is – isotopic value of precipitation and B is – isotopic value of river water

Using this sinusoidal wave method, the travel time of water – from infiltration into the soil at Tianeti to its discharge into the Alazani River near Shakhrani – was estimated to be approximately one month.

Conclusion

For the first time in Georgia, this study analyzes the spatial and temporal variations of stable oxygen and hydrogen isotopes in atmospheric precipitation and river runoff. Most of the data is included in the global database. Examining these variations and their distribution patterns allows for the determination of groundwater genesis, flow direction, and intensity.

References

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