Isotopic Characteristics and Water Interaction of Ifni Lake and Spring of Tifnoute Valley (High Atlas Mountains, Morocco, North of Africa)

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Abstract

Geochemical and isotopic investigations were carried out to indicate the interaction process between Ifni Lake water and high valley of Tifnoute springs. A total of 18 water samples were collected and analyzed.

The Ifni Lake constitutes a veritable water resource in the study area, and this water can be the origin of alimentation the springs located in the high valley the Tifnoute. This study aims to improve the interaction between Ifni Lake water and the springs of high valley of Tifnoute. It is mainly focused to identify the origin of groundwater recharge and mineralization. The environmental isotope (deuterium (δ^2H) and oxygen-18 ($\delta^{18}O$)) measurements allowed understanding the hydro geochemical process, the origin of the mineralization of the water. Also the results identify the relationship between the waters of Ifni Lake and the spring's water of high valley of Tifnoute. The isotopic compositions reveal that the origin of Ifni Lake water is meteoric, and the water infiltrates directly in the groundwater without any evaporation.

Keywords: Mountain water, isotopic process, Hydrogen and oxygen isotopes, lake-groundwater interaction

Introduction

Morocco is one of the countries that must cope with an important water deficit (Agoussine *et al*., 2004). Also, these regions are particularly sensitive to variability induced from climate changes (Agoussine *et al*., 2004, Born *et al*., 2008, Lgourna *et al*., 2014, Ait Brahim *et al*., 2015).

Groundwater and surface water constitute a single complex and interconnected system (Owor *et al*., 2011, Shaw *et al*., 2013). In many mountainous rural areas in Morocco, the springs water represents a source of drinking water. In the high valley of Tifnoute, the springs water are used for human consumption. Generally, water in this mountain area is characterized by low mineralization. Also this area is characterized by the highest mountain, and natural lake in Morocco. Water from Ifni Lake outflows by springs which are located just downstream from the lake. The people in the high valley of Tifnoute used spring water for drinking and irrigation (Kacem *et al*., 2016). The water isotopes (^{18}O, ^{2}H) are excellent tracers for determining the origin of groundwater; they are widely used in studying the natural water circulation and groundwater movement, also due to their conservative characteristics of moving with H_2O molecule (Adomako *et al*., 2011, Xin *et al*., 2011). Using the isotopic tracers is an effective approach for investigating the complex hydrological processes of groundwater range of spatial and temporal scales (Clark *et al*., 1997, Alyamani 2001, Gibson *et al*., 2005, Song *et al*., 2006, Carol *et al*., 2009, Wassenaar *et al*., 2011, Cui *et al*., 2012). Also spring, precipitation and surface water respond to the isotope signature of atmospheric water (Yurtsever 1981, De Oliveira 2010, Bozau 2013). The changes in stable isotopes overtime and in space can provide a better understanding of aquifer recharge and discharge (Aquilina *et al*., 2005, Barbieri *et al*., 2005, Tallini *et al*., 2014). In the study area the Ifni Lake constitutes a natural tower of water which aliments a majority of springs; this area has never been the subject of isotopic study. The aim of this work is to improve the ground-surface water interaction, using isotopic process. Moreover, stable isotope (δ^2H, $\delta^{18}O$) and chemical analyses reveal a clear relation between Ifni Lake and some springs water. The isotopic analysis of the waters allowed us to understand the hydro geochemical process, the origin of the mineralization of the water and also to identify the relationship between the waters of Ifni Lake and the spring's water of high Tifnoute Valley.

Materials and methods

Study area

The high valley of Tifnoute is located in the Moroccan High Atlas between latitudes 30°59′ and 31°5’ North, and longitudes 7°56′ and 7°48′ West (Figure.1), one of the interesting area in the National Park of Toubkal. The area is characterized by semi-arid climate with important precipitations, and dendritic hydrographic network (Figure.1). The high valley of Tifnoute catchment it’s characterized by highest elevations, a greater degree of slopes (Kacem *et al*., 2014), and irregular terrain (Kacem *et al*., 2017).

Geologically, the study area is dominated by volcanic and metamorphic rocks which essentially are: andesite, basalt, granite and rhyolite. In the Tifnoute Valley, part of the ancient massif, three units of plutonic rocks have been defined (Toummite 2012): the Askaoun intrusion showing quartz diorites and granodiorites, intrusion of Imourkhssen, formed of coarse-grained granite, and Ougougane intrusions made of fine-grained granite.

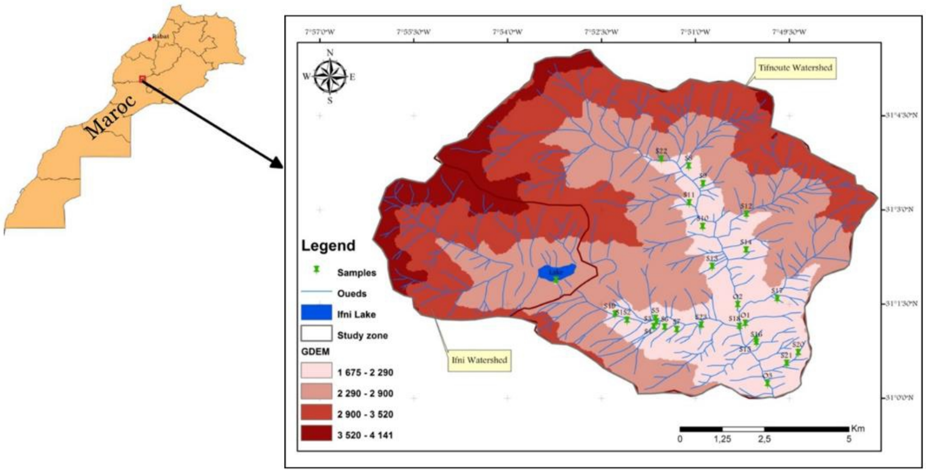


Figure. 1. Map of location of the study area and water samples

Observations and hypotheses

The springs and surface waters constitute the very important water resources in the high valley of Tifnoute. Ifni Lake is the natural dam of water in this area, which alimented the important springs. Mainly, some springs waters located under lake level had similar chemistry composition of Ifni lake water.

The relationship marked between the Ifni Lake and springs water is very particular, due the path followed in underground. The water accumulated in the lake provide from the melting of the snow in the mountains. This water become visible in the near springs named Tinkhar N'ifni and Tamda using an underground path.

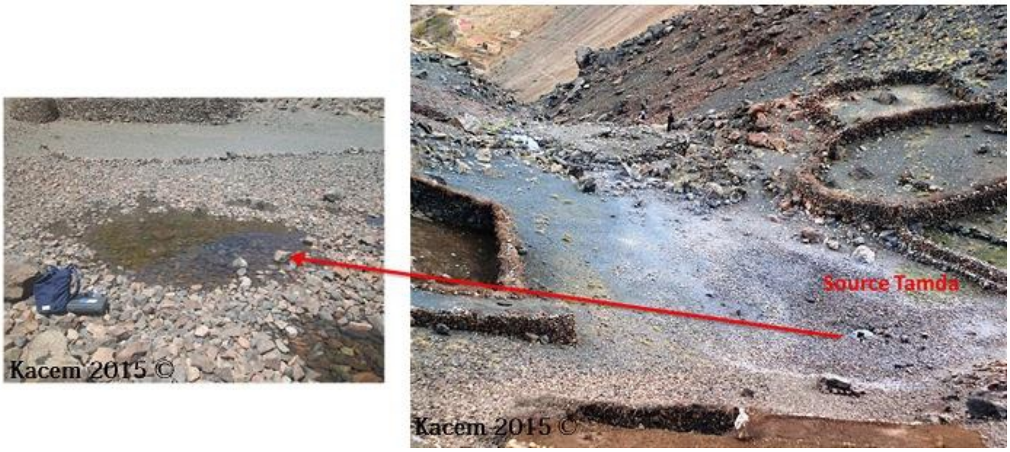


Figure.2. Photograph showing the Tamda spring (2192m of altitude)

Tamda is the name of a small topographical water depression according to the local population (Figure.2). It's located at 2192m of altitude in the south East of the lake. When water reaches a level at Ifni lake (Reference rock situated at an altitude of 2320 m), the water gushes a week after in the *Tamda* spring (Figure.3). So, this suggestion can explain the relationship between Ifni Lake and *Tamda* spring water and the isotopic analysis was applied to verify this observation.

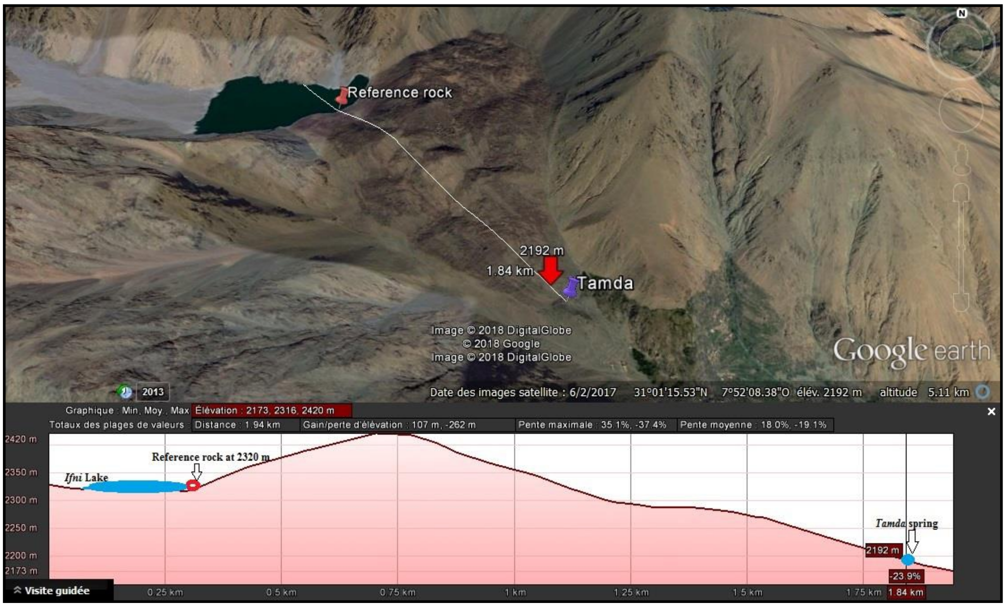


Figure.3. Relationship between Ifni Lake and Tamda spring water

Water sampling and analysis

A total of 18 water samples were collected from high valley of Tifnoute springs, and Ifni Lake during the period of May 2015. The spring's location was determined using a global positioning system (GPS) (Figure.1). Eventually, samples were collected in glass bottles for stable isotopes analysis. The samples were preserved and transported in laboratory.

The environmental isotope (deuterium (δ^2H) and oxygen-18 ($\delta^{18}O$)) were analyzed for the water samples using cavity ring-down spectrometry (Picarro L2120). The values are expressed in Standard Mean Ocean Water (SMOW) in per mill %.

Results and discussion

Generally, the spring waters in this mountain area are characterized by low mineralization (Kacem *et al*., 2016). The Ifni Lake is located at 2320 m in this mountain area; mainly this lake and spring waters are fed by atmospheric precipitation and snow. Ifni lake water is characterized by 80 µs/cm of conductivity, and 8.4 of pH. The water composition is rich in magnesium, calcium and bicarbonate ions. Isotopic data (Table 1) reveal the $\delta^{18}O$ values of samples range from -8.13 (S5) to -10.28 (S22) *vs* ‰ V-SMOW, whereas the $\delta\,^2H$ values range from -55.89 (S6) to -67.83 (S8) *vs* ‰ V-SMOW. The water sample collected from Ifni lake presents this isotopic content: $\delta^{18}O$=-8, 43 and $\delta\,^2H$= -59 ‰ (Table.1).

Table.1 Isotopic contents of water samples in the High valley of Tifnoute

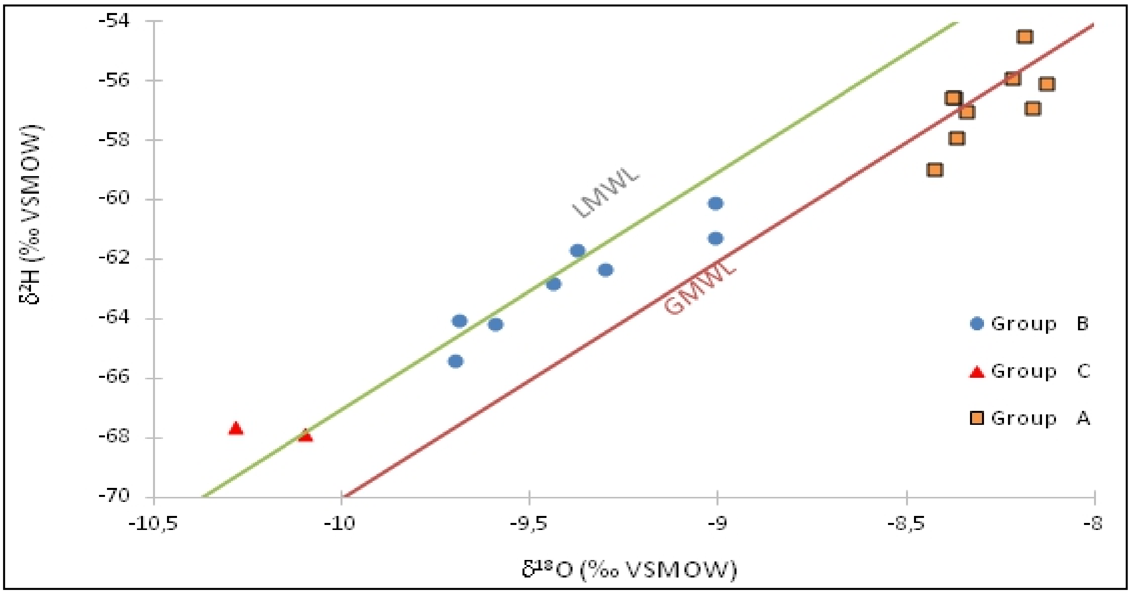
Water samples	$\delta^{18}O$ SMOW	$\delta\,^2H$ SMOW	Altitude (m)
Ifni Lake	-8,42475	-58,97725	2327
S1	-8,34175	-57,04875	2177
S5	-8,13075	-56,076	2059
S6	-8,22025	-55,8925	1962
S7	-8,371	-56,532	1895
S8	-10,099	-67,838	2202
S9	-9,3	-62,3355	2143
S12	-9,00875	-60,1065	2267
S13	-8,19	-54,50425	2076
S15	-9,011	-61,295	1775
S17	-9,37625	-61,70825	2073
S18	-8,37675	-56,5475	1885
O1	-8,3675	-57,93525	1716
O2	-9,6985	-65,373	1774
S19 (Tamda spring)	-8,1685	-56,91725	2183
O3	-9,4385	-62,7845	1717
S22	-10,28325	-67,6355	2142
S23	-9,59475	-64,12825	1872

The diagram (Figure.4) shows the water samples plot compared to the global meteoric water line (GMWL) (Craig 1961), and local meteoric water line (LMWL) (Ouda *et al.*, 2004). Usually, deviations in isotopic compositions away from meteoric water line may results from processes of evaporation (Domenico *et al.*, 1990, Drever 1997, Karakaya *et al.*, 2007). The results (Figure.4) show that the origin of waters is meteoric and it was infiltrate directly. The water samples can be classified into three groups according to their isotopic signatures:

- First group (Group A) is represented by the Ifni Lake and O1, S1, S19 (Tamda spring), S5, S7, S6, S13 waters; these samples are located under the (LMWL). The waters of this group are characterized by a low mineralization, so the waters infiltrated quickly and the interaction water-rock is very weak. These resultants demonstrated a strong relationship between Ifni Lake and this group of waters. Also, the Tamda spring and Ifni Lake waters can constitute a similar isotopic signature and chemistry composition. The suggestion about Tamda-Ifni lake water relationship can be confirmed by the results shown by the analysis of the environmental isotope (deuterium (δ^2H) and oxygen-18 (δ^{18}O)).

- Second group (Group B) is represented by waters of O2, S15, S9, S23, S12, S17 and the third group (Group C) is represented by the S8, S22 springs. These samples are located near the (LMWL) and are characterized by isotopic signature low of δ^{18}O composition, which indicates that the source of waters recharge comes from high altitudes and low temperatures recharges.

Figure.4. δ^2H versus δ18O diagram of water as compared to the global meteoric water line (GMWL) and the local meteoric water line (LMWL)

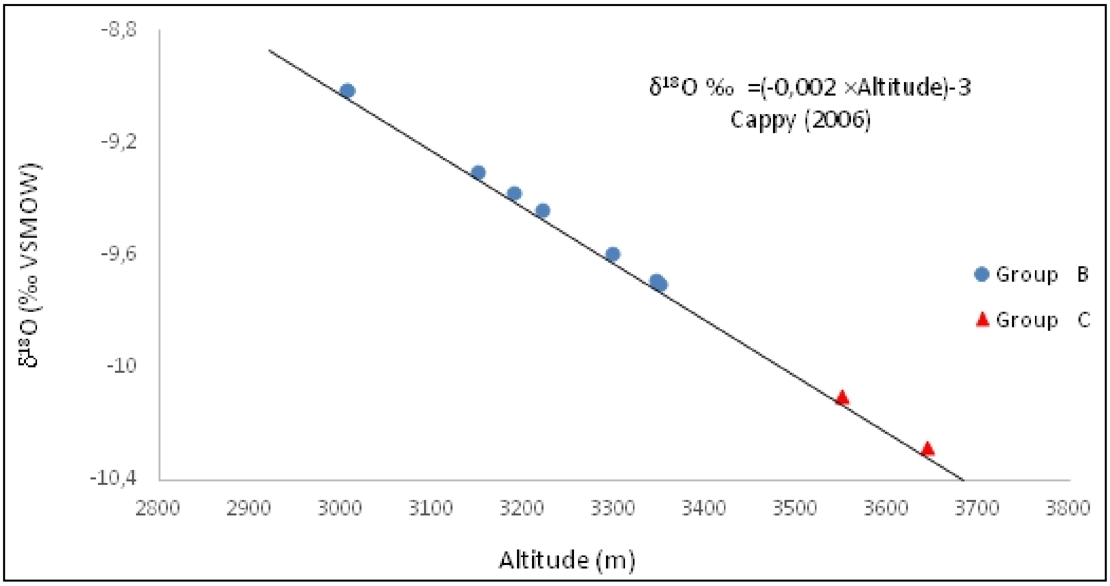


To identify the altitudes of the recharge conditions of these waters, the altitudinal gradient established by Cappy (2006) was calculated using the equation 1.

$\delta^{18}O‰ = (-0.002 \times \text{Altitude}) - 3$ (Equation 1)

The results (Figure.5) show that the waters originate from the high altitudes areas between 3000-3600m, come from the high Moroccan Atlas. Therefore, the springs would be recharged by the fissure water and precipitation.

Figure.5. Relationship between $\delta^{18}O$ in the water samples and their recharge elevation according to the altitude gradient of Cappy (2006)



Conclusion

The high valley of Tifnoute is a mountainous study area characterized by very important softly water resources. The Ifni Lake is a natural dam situated at 2320m, and aliments the spring's water in this region. To prove the relation between Ifni Lake waters and springs, the isotopic investigations were defined and different campaigns were organized to collect the maximum of information from population. The results showed that high precipitation water and the snow melt are the origin of Ifni Lake water. The **$\delta^{18}O$** and **$\delta^{2}H$** results indicating that the origin of water is meteoric and the recharge areas situated at 3600m altitudes, which correspond to the High Atlas Mountains (Jbel Toubkal).

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