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 (δ2H) and oxygen-18 (δ18O)) 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 (18O, 2H) 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 H2O 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 alimenta 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 (δ2H, δ18O) 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](image)

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 (δ²H) and oxygen-18 (δ¹⁸O)) 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 δ¹⁸O values of samples range from -8.13 (S5) to -10.28 (S22) vs ‰ V-SMOW, whereas the δ²H values range from -55.89 (S6) to -67.83 (S8) vs ‰ V-SMOW. The water sample collected from Ifni lake presents this isotopic content: δ¹⁸O=-8, 43 and δ²H=-59 ‰ (Table.1).

<table>
<thead>
<tr>
<th>Water samples</th>
<th>δ¹⁸O SMOW</th>
<th>δ²H SMOW</th>
<th>Altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ifni Lake</td>
<td>-8.42475</td>
<td>-58.97725</td>
<td>2327</td>
</tr>
<tr>
<td>S1</td>
<td>-8.34175</td>
<td>-57.04875</td>
<td>2177</td>
</tr>
<tr>
<td>S5</td>
<td>-8.13075</td>
<td>-56.076</td>
<td>2059</td>
</tr>
<tr>
<td>S6</td>
<td>-8.22025</td>
<td>-55.8925</td>
<td>1962</td>
</tr>
<tr>
<td>S7</td>
<td>-8.371</td>
<td>-56.532</td>
<td>1895</td>
</tr>
<tr>
<td>S8</td>
<td>-10.099</td>
<td>-67.838</td>
<td>2202</td>
</tr>
<tr>
<td>S9</td>
<td>-9.3</td>
<td>-62.355</td>
<td>2143</td>
</tr>
<tr>
<td>S12</td>
<td>-9.00875</td>
<td>-60.1065</td>
<td>2267</td>
</tr>
<tr>
<td>S13</td>
<td>-8.19</td>
<td>-54.50425</td>
<td>2076</td>
</tr>
<tr>
<td>S15</td>
<td>-9.011</td>
<td>-61.295</td>
<td>1775</td>
</tr>
<tr>
<td>S17</td>
<td>-9.37625</td>
<td>-61.70825</td>
<td>2073</td>
</tr>
<tr>
<td>S18</td>
<td>-8.37675</td>
<td>-56.5475</td>
<td>1885</td>
</tr>
<tr>
<td>O1</td>
<td>-8.3675</td>
<td>-57.93525</td>
<td>1716</td>
</tr>
<tr>
<td>O2</td>
<td>-9.6985</td>
<td>-65.373</td>
<td>1774</td>
</tr>
<tr>
<td>S19 (Tamda spring)</td>
<td>-8.1685</td>
<td>-56.91725</td>
<td>2183</td>
</tr>
<tr>
<td>O3</td>
<td>-9.4385</td>
<td>-62.7845</td>
<td>1717</td>
</tr>
<tr>
<td>S22</td>
<td>-10.28325</td>
<td>-67.6355</td>
<td>2142</td>
</tr>
<tr>
<td>S23</td>
<td>-9.59475</td>
<td>-64.12825</td>
<td>1872</td>
</tr>
</tbody>
</table>

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 result 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 (δ²H) and oxygen-18 (δ¹⁸O)).

- 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 δ¹⁸O composition, which indicates that the source of waters recharge comes from high altitudes and low temperatures recharges.

Figure 4. δ²H 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.

\[ \delta^{18}O_{\%o} = (-0.002 \times \text{Altitude}) - 3 \quad \text{(Equation 1)} \]

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 aliment 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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References:


