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TECHNICAL NOTE

Climate change and water availability in north-west Algeria: investigation by stable water isotopes and dendrochronology

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Since the 1970s, rainfall has declined along the North African coast, while the demographic pressure has increased. Supplementing the rainfall data and water level of the Béni Bahdel dam, water isotopic signature and tree ring analyses were used to better understand the effects of climate change (lower rainfall, higher summer temperature) and the water circulation in the Tafna River basin in north-west Algeria. Changes are recommended in water storage and afforestation policies and irrigation techniques.

Keywords: water resources; riparian vegetation; Tafna basin; karst; Algeria

Introduction

The Tafna River, the closest stream in north-west Algeria to the border with Morocco, takes its source around the Tlemcen Mountains (1400 m). The Tafna basin, with a surface area of 7250 km^2 (Dahmani *et al.* 2003), is located in a sub-humid to semi-arid region, with rainfall ranging from 300 to 700 mm/year. Many of the river's tributaries are intermittent streams. Two areas can be distinguished: the higher south composed of chalk plateau and wetter condition due to the altitude, and the north consisting of drier lowland. For the water needs of Oran city, a dam was first built on the Tafna River around 1940, just on the edge of the upper plateau. The excess water was to be used to irrigate the lower lands. At that time, the mean rainfall value was 560 mm/year, so the dam could regulate a volume of 74 million m^3/year. But since then, the mean rainfall dropped to 450 mm during 1940–1974, and after the dry period of the 1970s, even further, to 342 mm for 1975–2005 (Adjim *et al.* 2005).

Population growth in Tlemcen and Maghnia has presented two types of problem. The first concerns water supply for population, industry and irrigation. All surface water and shallow groundwater, already scarce, are being fully exploited, and more recently there has also been deep pumping. The second impact on rivers is pollution, which has reached all the lowest river courses. Effects become more obvious during low flow, and some rivers become only fed by wastewaters (Gagneur 2006).

Also, especially in the lower part of the Tafna River basin, since the 1970s many wells and small rivers have become dry, and significant dying of poplars (*Populus alba* L.) has been observed. At first, the tree loss was attributed to an increase in insect infestation, but

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a recent study (Labiod *et al.* 2007) reveals that the original cause of this degradation in poplar health was the lack of water.

Here with the help of the stable water isotope, we try to understand the water circulation along the Tafna basin, its storage within the karst system, and how it affects the riparian vegetation, important for the water bioremediation. We also investigate an older forest to gain insight on the climate change effect on vegetation growth.

Materials and methods

Water stable isotopes

In order to determine the water origin, the tributaries and springs of the Tafna River as well as different groundwaters were sampled, put in capped vials (10 mL for water) and sent to Iso-Analytical Ltd, Sandbach, UK. Oxygen-18 analysis of the samples was performed in triplicate by equilibration with carbon dioxide in septum-capped containers. Deuterium analysis of the samples was performed in triplicate by equilibration with hydrogen gas catalysed by platinum in septum-capped containers. The head spaces of the containers were subsequently measured on a continuous flow isotope ratio mass spectrometer system (Europa Scientific ANCA-GSL and GEO 20–20 IRMS). The equipment was calibrated by using two water standards that are traceable to the primary reference standards V-SMOW2 (Vienna-Standard Mean Ocean Water) and V-SLAP2 (Vienna-Standard Light Antarctic Precipitation) distributed by the IAEA, Vienna. A third traceable water standard was analysed alongside the samples to check the accuracy of the data.

The results are expressed in per mil on the V-SMOW/SLAP scale, for oxygen:

$$\delta^{18}\,O_{V\text{-}SMOW2}\,(‰) = ((18O\,/\,16Osample)\,/\,(18O\,/\,16Ostandard)\,-1) * 1000;$$

and for deuterium:

$$\delta^{2}H_{V\text{-}SMOW2}\,(‰) = ((^{2}H\,/\,^{1}H_{sample})\,/\,(^{2}H\,/\,^{1}H_{standard})\,-1) * 1000.$$

Dendrochronology

Different trees were cored over the Tafna basin, from the riparian white poplar (*Populus alba*) to older conifers (*Juniperius oxycedrus*, *Pinus halepensis*) with an increment borer of 5 mm wide by Suunto, Finland. When possible, some trees were cut to provide whole disks to confirm wood core results. The woods were than sanded and the tree ring widths were read with the help of a LINTAB by RINNTECH, Germany. The aim was to determine the change of tree annual growth over the time.

Results

Figure 1 gives the general morphology of the Tafna with its numerous tributaries originating around the Tlemcen Mountains. The first stable isotope sampling in 2006 (Lambs and Labiod 2006) on ^{18}O compared the variation between the upper basin river and sources, and the sources around the city of Tlemcen. The more negative values (i.e. more depleted in heavy isotopes) showed water coming from a colder area, in general at a higher altitude.

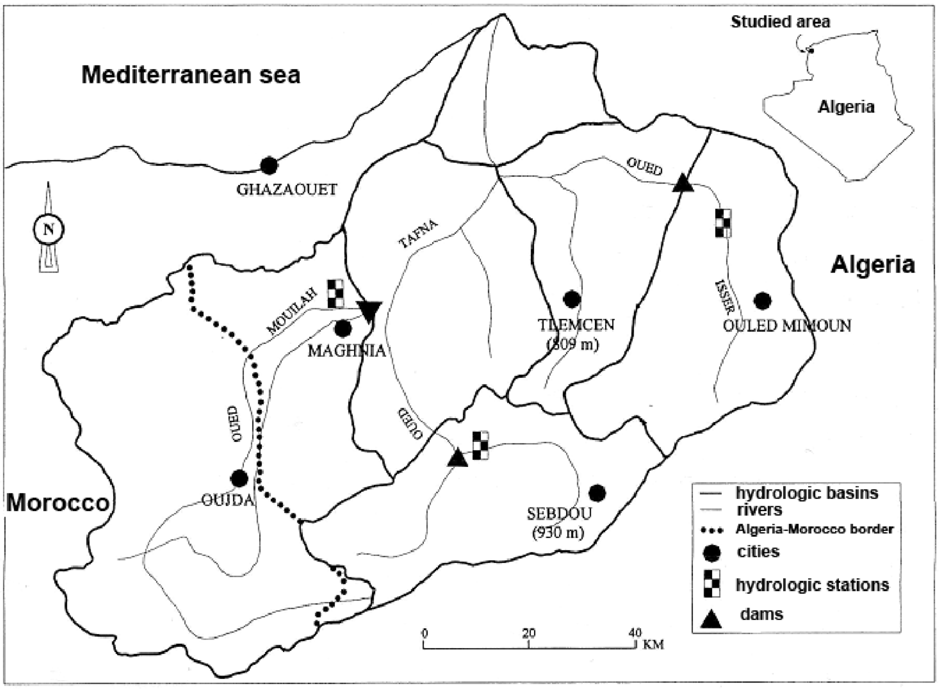

Figure 1. The Tafna River basin.

The mean values for the two sites differ by about one unit (see Figure 2), respectively – 7.52 ± 0.26 and −6.51 ± 0.25, which show the different rainfall and snow origins. More surprising is the stable value over the season, even for the river plateau, thus confirming the importance of a karstic reservoir, with a buffer system of at least over 6 months. Interesting is the sampling in the Mansourah village, above and south-west of the city of Tlemcen, just on the edge of the plateau, where mineral water is produced. The agricultural well displays a δ^{18}O isotope value of −6.52, whereas at a deeper drilling (70 m) the mineral water has a higher absolute depleted value of −7.52, as the water in the higher Tafna. In this case a double groundwater should exist, one shallow with local water and a deeper one fed by higher-altitude water.

A second isotope investigation was undertaken in spring 2008, looking on both deuterium and ^{18}O along the Tafna River course, from the underground source until the sea estuary. The conductivity of the main spring and tributaries is very high since the beginning (around 600 μS), due to the time of residence and chalk soil, and increases downstream with the evaporation, pollution and salinity intrusion. The ^{18}O value for the lower basin ranges between −3.4 and −5.4. Except for the surface water of the Béni Bahdel dam, the water with the higher salinity (1100–2000 μS) has also lower excess deuterium (2.4–5.8).

All the higher altitude sources of the Tafna River system present similar ^{18}O values, depleted in heavy isotopes: Tafna itself −7.8, Khemis −7.6, Sebdou −7.2, Isser −7.4, and Chouly −7.4 on the Mouillah and −7.2 on the Morocco side. The worldwide and Atlantic reference for the water isotopic measurement is the Global Meteoric Water Line (GMWL) with a slope of 8 and a deuterium excess of 10 as defined by Craig (1961). But for the Mediterranean Sea, due to the closed basin effect, the deuterium excess is much higher,

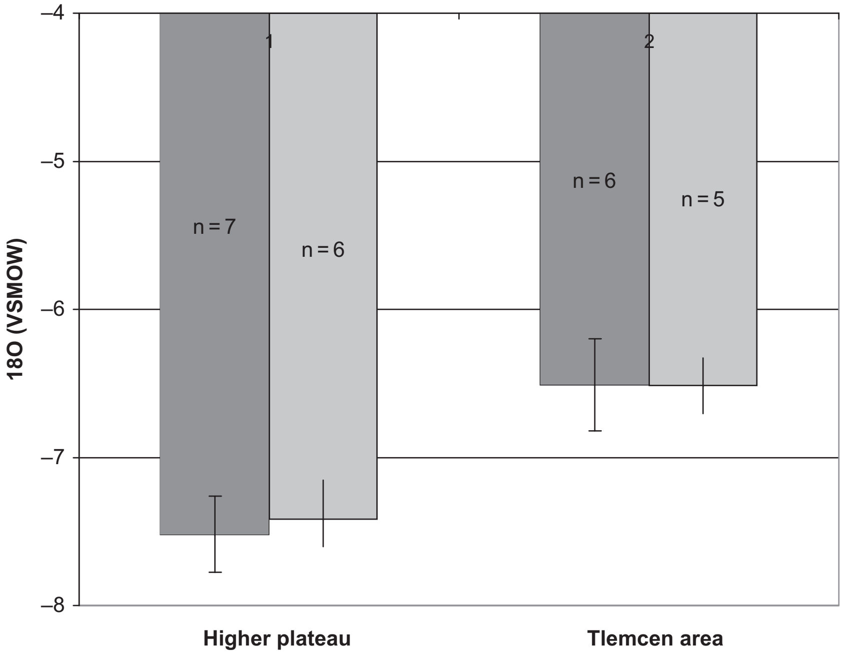

Figure 2. Comparison of the mean water isotopic value ($\delta^{18}O$) for the upper Tafna basin and the middle Tafna basin, Tlemcen area, during March 2006 (dark grey) and August 2006 (light grey); *n* represents the number of different water samples.

and for the western part of this sea basin, the Western Mediterranean Meteoric Water Line (WMMWL) value is around 14 (Celle *et al.* 2001). For the higher-altitude Tafna sources and tributaries, the deuterium excess ranges between 10 and 14, i.e. between the GMWL and the WMMWL, showing both the Atlantic and Mediterranean rainfall influence (see Figure 3). After the first dam at Béni Bahdel, the value for the Tafna River becomes less negative: (5, around the same as found farther west in Oued Nechef, which takes its source behind the city of Tlemcen, and also the value taken by the Isser River in its lower part. On the Tafna side after the other low-altitude dams, the isotopic value ranges from −4 to −3. The calculated deuterium excess shows higher evaporation for some places (value between 1.4 and 4.7) as well as for the Sebdou River (5.8) where the pollution and human influence are important as revealed by a high ionic content, with a conductivity of 900 µS.

The calculated slope of 6.2 from the Tafna sources until the downstream water sampling shows an important evaporation, as this water sampling was undertaken between February and April. This kind of sampling along the whole Tafna River is not possible in summer due to the drying of many river sections in the lower part of the basin.

The main riparian tree species is the white poplar. Until recent years, in the upper basin, trees growing very close to the river or close to irrigation canal had a high growth rate, mean value from 0.5 to 1 cm/year, whereas in the lower part a much lower rate was present, impacted by insect attacks. Most of the old trees display a lower growth rate since the reduction of rainfall in the 1970s and 1980s. No tree over 45 years old was found. To get a wider view of the rainfall influence on tree growth over the last decades, we had to focus outside of the riparian trees, i.e. on conifer trees. Over the city of Tlemcen, there is a nice Aleppo pine forest and more isolated trees as "oxycedar juniper" (*Juniperus oxycedrus*) and "thuya de Berbérie" (*Tetraclinis articulata*), some of these trees being

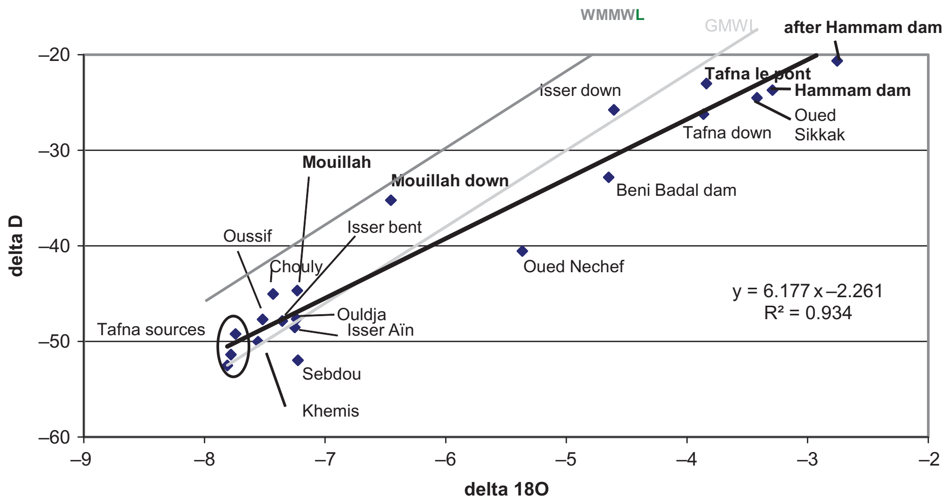

Figure 3. Deuterium and ^{18}O characteristics of the Tafna water during February and April 2008.

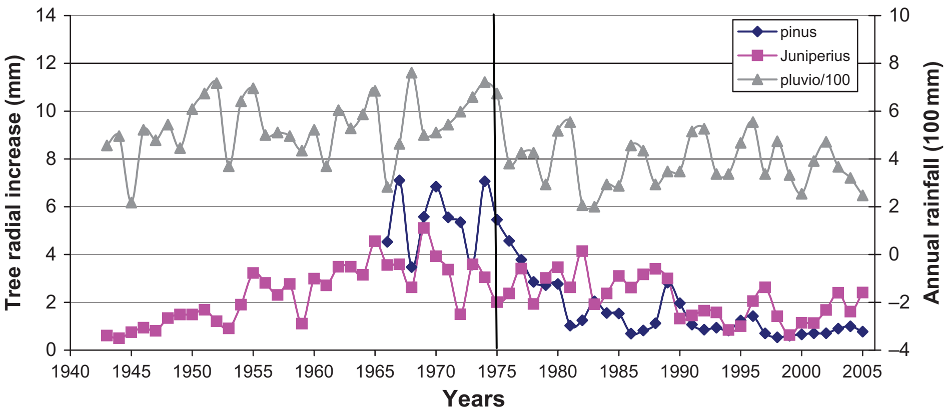

Figure 4. Comparison of the annual conifer tree growth (mm/year) on the forest above Tlemcen and the annual rainfall (in hundreds of mm/year), this last curve being shifted to avoid overlapping, showing the corresponding decrease since 1975.

over 100 years old. Figure 4 reports typical dendrochronological curves versus the annual rainfall. Here also, a decrease in growth could be seen since 1975.

Discussion

The Tafna basin was mainly investigated under geologic (Collignon 1986), limnologic (Gagneur 1994, 2006) and hydrologic (Dahmani *et al.* 2003, Adjim *et al.* 2005) approaches. With the absence of long meteorological series, the drying of the river and the karstic system, it was difficult to study the whole water circulation. The isotopic techniques allow one to follow the water circulation and determine the water origin even with a karstic system as in the upper basin, and to evaluate the evaporation process in the lower part. The first ^{18}O measurement in this area was made by Blavoux in 1984–1986, but seems to be shifted (about 1 unit more negative) with the values obtained later by other authors. This could have happened due to exceptional cold conditions during the sampling period or lower mean temperature values during the rainy seasons. The next and more complete isotopic analyses were published by Azzaz *et al.* (2008), and made in April 1991 on about 30 sources and wells on and around the Tlemcen Mountains. They show for the first time a double influence, that of the Mediterranean and the Atlantic, on the high-altitude rainfall, as seen by the deuterium excess value. We have confirmed this mixed origin for the headwaters of the main tributaries of the Tafna River, for whole of the Tafna basin and also for Morocco as well as the Mouillah tributary. Azzaz *et al.* also measured the resident time of karstic water, and found only a single source with a deeper reservoir and longer storage (around 25 years). From our own data, the absence of a seasonal effect shows that the water is stored for at least 6 months. The city of Algiers is the only Algerian station for the Global Network of Isotopes in Precipitation (GNIP) by IAEA. Rainfall isotopes data is available for 1998 and 2004. The evaporation slope that we have found over the Tafna basin (6.18) is intermediate between the one of Algiers (slope 4.81) and the closest GNIP station on the west part: Bab Bou Idir (7.34), a higher-altitude station in Morocco. This very low slope found for Algiers magnified the significant evaporation during these years.

This possible climate change is also seen in tree growth. The study of Labiod *et al.* (2007) has shown that numerous poplars in the lower basin present lower growth rate and higher insect attacks since the 1980s. The diminution of the riparian vegetation has a negative effect on flood buffering, local water vegetation and water bio-remediation. The agricultural surface land increases and with it the nitrate input, while the natural wetland purification area diminishes. This reduction of tree ring width was also observed in nearby older conifers around the city of Tlemcen. Other dendrochronological and tree disease studies have been recently done on century-old cedars in the Chréa forest a few hundred kilometres more east (Sbabdji *et al.* 2009). In that case also, a growth decrease was observed since the 1970s.

Conclusion

The upper Tafna River is not easy to study since it is formed by a wide karstic and cave system with an underground river up to 3.4 km long. Some water outflow from this system has even been found on the Morocco side. The total underground water of this system is estimated to be tens of billions of cubic metres and thus certainly buffers the seasonal rainfall fluctuation, but also prolongs the lack of water in the following years. This means that the real effect of the rainfall over the head basin will be only visible in the following year. The lower Tafna basin now has four additional dams that increase water evaporation and enhance sediment retention. The pimary aim of these dams was to improve the buffer capacity for the dry year, but now the rainfall is too scarce to fill the dam completely during the wet season. The drier and hotter weather condition over all North Africa and higher water needs will oblige water planners to think again regarding the distribution of water resources and the wastewater recycling. For instance, natural karstic system should be preferred for water storage as against open dams with their high evaporation. Also preserving the remaining forests and planting drought-resistant trees will reduce aridity. For agriculture, drip techniques would reduce water requirements. With the lowering of the groundwater table and lower river discharge, care must to taken to prevent salt intrusion from the sea or the numerous chots (salty lakes).

Acknowledgements

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