Contribution of stable isotopes of water ($^{18}$O and $^2$H) to the characterization of goulbi N’kaba valley aquifer, region of Maradi in the republic of Niger

Abstract

The Goulbi N’Kaba valley is located in the Maradi region, in the south-central part of the Republic of Niger. It contains an alluvial groundwater that is used for the supply of drinking water, for livestock, irrigation and mining. In addition, this valley is subject to the effects of climate change. A study is needed to know much about this water resource, a condition for a better match between the uses and the potentialities of the aquifer. The investigations on the physicochemical parameters and the stable isotopes of the water molecule (oxygen 18 and deuterium), made it possible to reach the following main results. The contents’ balanced averages in oxygen 18 and in deuterium in rainwater 2016, at the level of the zone of study, is respectively of: - 2.66 % vs SMOW for $^{18}$O and of 13.22% vs SMOW for $^2$H, so allowing to hold (retain) as input signal for the study of subterranean waters of the zone, the values of: -2 in 4 % vs SMOW for $^{18}$O and - 13 in 22 % vs SMOW for$^2$H. For waters of the alluvial aquifer, the contents in isotopes join between 6.76 and 2.09 % vs SMOW for the $^{18}$O, and between 41.30 and 18.81 % vs SMOW for $^2$H. The strongest values (> 3.5 % vs SMOW for $^{18}$O) are observed in upstream sectors and downstream, in particular at the level of the elbow of Iyataoua to Mayahi, indicating recent waters stemming from direct refills from rainwater little or not evaporated and/or indirect from evaporated waters, in particular those of the stagnant waters and runoff water. At the central sector level, the contents in $^{18}$O waters are situated between -7.65 and 5.21% vs SMOW, characterizing fossil waters in Niger, the contribution of which is very recent waters is very limited. In this sector, the alluvial aquifer does not seem to exist or would be confused with the underlying aquifer of Continental Intercalaire. In addition, the lack of correlation between chlorides and isotopic contents seems to confirm that chemistry is not related to evaporation. Finally, the lack of a significant relationship between the piezometric levels and the oxygen-18 levels also shows that the recharge is a function of the depth of the aquifer.

Keywords: Goulbi N’Kaba, alluvial aquifer, oxygen 18, deuterium, direct refill, input signal

Framework of the study

The Goulbi N’Kaba Valley has its source in Nigeria it crosses the center of the Maradi region and the extreme south-east of Tahoua and turns back to Nigeria. It is located between 13° 20 and 14° 00 north latitude and 6° 30 and 8° 10 east longitude (Figure 1). The climate of this semi-arid study area is characterized by two distinct seasons, one of which is dry, of long duration, 8 to 9 months (October-May) and the other of short duration (June to September). The rains are short and variable in time and space. For the period 1950-2015, the interannual averages are respectively 525mm at Maradi airport, 471mm at Tessaua and 368 mm at Dakoro. The average temperature varies from 18°C in December to March at 40.5°C in April and May. The prevailing winds are the harmattan in the dry season and the monsoon in the wet season. The annual average potential evapotranspiration can reach 2m.¹ The hydrographic network is being fossilized. However, only two tributaries originating in Nigeria (Goulbi El Fadama and Goulbi Nay Farou) have intermittent flows during the rainy season.² There are some temporary or semi-permanent catchments forming mainly in the Goulbi N’Kaba valley and its tributaries.

Geologically, the filling products of the Goulbi N’Kaba valley consist essentially of coarse and medium-sands with cobble, resulting from the alteration of the crystalline basement, the reworking of the Continental Intercalaire sandstone and the continental Hamadien (CI/CH), and ancient alluvium, surmounted by Aeolian sands. They vary in thickness from 25 to 40m and are based on CI/CH clay or silty clay sandstone or silty clay. These geological formations contain a free-ground aquifer, captured at depths ranging from 5m in the upstream sector, 30m in the central sector and less than 20m in the downstream sector. Logging rates are higher in the upstream and downstream sectors where the alluvial aquifer is shallower. The water conductivities range from 89.3 to more than 325µs/cm. The pH is slightly acidic but tends to become neutral in the downstream sector. The water temperatures of the alluvial aquifer turn around 30°C.

Materials and methods

The material used, includes data and tools:

Data: various documents including doctorate and master theses, topographic, geological and hydrogeological maps and satellite imagery; isotopic parameters were used.

Tools: various software (Excel and Word, Diagram, XLSTAT, Google Earth), GPS, digital camera, flasks, pillboxes, coolers. Tools used also include laboratory equipment for isotopic analyzes.
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The methodological approach is as follows:

**Sampling of rainwater and alluvial aquifer**

For the determination of isotopic levels, 80 samples of rainwater were collected at the stations of Gazaoua, Mayara and Dan Goulbi, well distributed along the valley. In addition, 30 water samples were taken from the alluvial aquifer.

**Analytical techniques:** The isotopic contents were determined at the Laboratory of Radio-Analysis and Environment (LRAE) of Sfax National School of Engineers in Tunisia. The technique used was laser absorption spectrometry, coupled with a liquid sample changer and a vaporization system. The results are expressed in delta for thousand vs SMOW, with an accuracy of ±1 ‰ for $\delta^2$H and ±0.2 ‰ for $\delta^{18}$O.

**Data processing:** For the isotopic contents of rainwater, the input signal and its comparison with Niamey input signals in Niger and Kano in Nigeria were determined, local meteorological lines of precipitation has been established.

For groundwater, the distribution of isotopic water contents and their comparison with the input signal have been established. Data were plotted on local and global meteoric lines and correlated with chloride levels and static levels.

**Results and discussions**

**Stable isotope content of rainwater**

**Spatial and temporal distribution:** The levels of $^{18}$O and $^2$H in rainwater of the year 2016, collected at the stations of Gazaoua, Mayara and Dan Goulbi range from -8.98 to +3.03 ‰ vs SMOW, for oxygen 18, with a balanced average of -2.79 ‰ vs SMOW, a standard deviation of 2.61 ‰ vs SMOW. For the deuterium, the grades are between -55.28 and +19.06 ‰ vs SMOW, with a balanced average of -15.33 ‰ vs SMOW, and a standard deviation of 18.16 ‰ vs SMOW.

The distribution over time of these levels in the three sectors that make up the study area (Figure 2) shows large variations in $^{18}$O. It also shows that early-season rains (May-June) and late-season rains (September-October) are more enriched in isotopes, while those in July and August (the core of the rainy season) are impoverished. These results are consistent with the work of some authors.

**Entry signal:** average annual in oxygen 18 and in deuterium balanced concentrations of the study area and those of other regions:

The balanced average in oxygen 18 and in deuterium levels of the 80 rain samples of 2016, at the 3 stations of the study area (Table 1), are: -2.66 ‰ vs SMOW for $\delta^{18}$O and -13.22 ‰ vs SMOW for $\delta^2$H.

In Niger and the subregion, some authors have found:

a. 0 -2.57 ‰ vs SMOW for $^{18}$O, and -17.47 ‰ vs SMOW for $^2$H, in the 2011 rains collected in the Korama bordering basin (Sandao, 2013);
b. 0-2.93 ‰ vs SMOW for $^{18}$O, and -13.76 ‰ vs SMOW for $^2$H, in rainwater from the Niamey University station.

c. 0-3.9 ‰ vs SMOW for $^{18}$O, and -21.7 ‰ vs SMOW for $^2$H at Kano, a locality about 250km south of the study area, for the periods of 1961 to 1966 and from 1971 to 1972 of the IAEA database (WISER 2011). Thus, from these different results one can retain as input signal for the study of groundwater of the Goulbi N’Kaba valley, the values of: -2 to -4 ‰ vs SMOW for $\delta^{18}$O and -13 at -22 ‰ vs SMOW for $\delta^2$H.

Table 1 Monthly balanced average levels in $^{18}$H and $^2$H of 2016

| Months   | Gazoua | Mayara | Dan Goulbi | Mean |
|----------|--------|--------|------------|------|
|          | $\delta^{18}$O | $\delta^2$H | $\delta^{18}$O | $\delta^2$H | $\delta^{18}$O | $\delta^2$H | $\delta^{18}$O | $\delta^2$H | $\delta^{18}$O | $\delta^2$H |
| May      | -3.59  | -19.37 | -1.66      | -5.46 | -1.75 | -8.28 |
| June     | -5.22  | -0.47  | -0.07      | -1.57 | -6.59 | -1.30 | -3.96 |
| July     | -4.67  | -3.10  | -2.46      | -13.79 | -3.34 | -18.32 | -3.49 | -21.05 |
| August   | -5.74  | -38.50 | -5.26      | -30.54 | -6.15 | -35.53 | -5.72 | -34.86 |
| September| -0.95  | 4.60   | 0.44       | 6.67  | -2.64 | -11.82 | -1.05 | -0.18 |
| Average  | -3.24  | -17.54 | -2.32      | -11.42 | -3.07 | -15.54 | -2.66 | -13.66 |
| Minimum  | -5.7   | -38.5  | -5.3       | -30.5  | -6.2  | -35.5  | -5.7  | -34.9  |
| Typical gap | 2.3   | 20.5   | 2.3        | 14.9  | 1.9   | 12.3   | 0.0   | 14.2   |

Diagram $^{18}$O vs $^2$H of rain water: The slopes of the lines characteristics of these two catchments. Similar or even higher levels were obtained in Dan Goulbi, 6.84 ‰ in Gazaoua), mean that the water vapors of rainwater from the Niamey University station, the WMR, Niamey and Kano stations.

Figure 4 2016 rain diagram (A- Mayara; B- Dan Goulbi; C- Gazaoua).

Figure 5 Local meteoric line (LML) of the Goulbi N’Kaba valley rainfall.

Comparison of the $^2$H vs. $^{18}$O lines and 2016 rainwater with those of the sub-region: In the Sahel, several local meteoric lines with slopes very close to those obtained for the rains of the Goulbi N’Kaba valley (Figure 6) have been calculated. Indeed, in Niamey, local meteoric lines are characterized by slopes between 6.7 and 7.8 and intercepts of 2.4 to 6.6 ‰. For the Korama basin, the straight line slope is of 7.33, with a deuterium excess of 5.71 ‰. In Burkina Faso in the region of Boromo, Mathieu and Bariac (1996) obtained a straight line slope of 7.7±0.3, and a deuterium excess of 7.8±4 ‰. For all Sahelo-Sudanian stations, Joseph et al. (1992) found a slope of 7.6 and an intercept of 7.1 ‰. The IAEA stations / WMO gave straight line slope and intercept respective origin of 7.8±0.3 and 6.3±1.2 in Bamako (Mathieu and Bariac, 1996), 7, 1 and 4.4 in Kano and 6.4 and 4.5 in N’Djamena (Favreau, 2000). The straight line slopes $^2$H vs $^{18}$O of rainwater from Goulbi N’Kaba Valley is well fit, to the local meteoric lines of Niger and the sub-region, which are lower than those of the DMM (Craig, 1961). These values show that the rains have the same origin (Guinean monsoon) and that they have evaporation more or less important during their displacement, their fall and / or their conditioning.

Figure 6 Presentation of the meteoric lines of the Goulbi N’Kaba valley rain waters, the WMR, Niamey and Kano stations.

$^{18}$O and $^2$H content of surface water

The average water contents of the Boagé and Batafadoua temporary catchments (located outside the valley) are respectively +21.36‰ vs SMOW for $^{18}$O and +87.01‰ vs SMOW for $^2$H (Table 2). These strong values reflect the highly evaporated nature of the waters of these two catchments. Similar or even higher levels were obtained for the Boagé and Batafadoua temporary catchments.
in the waters of the Teguey and Téra catchments\(^4\) in the Téra region (+30.69‰ vs SMOW for oxygen 18 and +138.4‰ vs SMOW for deuterium).

### Table 2 Stable isotope content of temporary catchments

| Sample no. | Sample name | \(\delta^2\text{H}\) (permil) | \(\delta^18\text{O}\) (permil) | \(\delta^2\text{H}\) (permil) | \(\delta^18\text{O}\) (permil) |
|------------|-------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| SI-7655    | NER/ Pool N°1 | 85.58                         | 9.25                          | 21.25                         | 0.2                           |
| SI-7656    | NER/ Pool N°2 | 88.44                         | 1.3                           | 21.48                         | 0.2                           |
| Mean       |              | 87.01                         | 1.13                          | 21.36                         | 0.0                           |

### \(^{18}\text{O}\) and \(^2\text{H}\) contents of the alluvial aquifer waters

**Spatial and temporal distribution:** The oxygen and deuterium oxygen contents of the alluvial aquifer (Table 3) range from -6.76 to -2.09‰ vs SMOW, with an average of -4.01‰ vs SMOW and a standard deviation of 1.3 vs SMOW for \(^{18}\text{O}\), and between -41.30 and -18.81‰ vs SMOW with an average of -27.91‰ vs SMOW, and a standard deviation of 5.6 vs SMOW, for \(^2\text{H}\). The distribution diagram (Figure 7) shows that in high water, 57% of the samples have \(^{18}\text{O}\) contents between -4‰ and -2‰ vs SMOW representing newly recharged waters. While in low water, it is 50% of the waters that are in this range. As a result, the proportion of old waters becomes more sensitive at low water. The spatial distribution of the stable isotope contents (oxygen 18) of the waters of the alluvial aquifer (Figure 8) shows that the recharge zones of the said aquifer would be at the level of the elbow formed by the Goulbi N’Kaba valley, Iyatoua to west Mayahi, and to a lesser extent, in the western departments of Dakoro and Guidan Roumdji (Kwakwara sector), where the valley receives, waters of the active tributaries of this area. In the central sector of the valley, the \(^{18}\text{O}\) contents of alluvial aquifer are between -7.65‰ and -5.21‰ vs SMOW, characterizing fossil waters in Niger,\(^4\) whose contribution in recent waters is very limited.

### Table 3 Stable isotope content of alluvial aquifer

| Designation | Total | High water | Low water |
|-------------|-------|------------|-----------|
|             | \(\delta^{18}\text{O}\) | \(\delta^2\text{H}\) | \(\delta^{18}\text{O}\) | \(\delta^2\text{H}\) | \(\delta^{18}\text{O}\) | \(\delta^2\text{H}\) |
| Maximum     | -2.09 | -18.81     | -2.16     | -20.70     | -2.09     | -18.81     |
| Minimum     | -6.76 | -41.30     | -6.76     | -41.30     | -4.91     | -34.93     |
| Average     | -4.01 | -27.91     | -4.31     | -29.42     | -3.87     | -27.92     |
| Typical gap | 1.3   | 5.6        | 2.1       | 12.2       | 0.9       | 4.7        |

The stable isotope contents of the waters of the alluvial aquifer seem to be characterized also by two mechanisms of recharge:

a. Direct recharge, from rainwater that has little or no evaporation, which corresponds to the input signal (contents in \(^{18}\text{O}\) between -4‰ and -2‰ vs SMOW). This recharge area is extended to the entire valley with the exception of the central portion where ancient waters predominate.

b. Indirect recharge, from evaporated water, especially stagnant water and runoff water, with \(^{18}\text{O}\) contents above -2‰ vs SMOW. This indirect recharge is also supported by the presence of rosaries of catchments that appear in these areas which respectively receive the waters of active tributaries from Nigeria in the Gazaoua sector, and active Koris waters flooding the valley in the area downstream. However, the contribution of these surface waters seems to be limited in time.\(^6\)\(^-10\)\(^14\)

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The 2016 precipitation water, collected at certain rainfall stations in the Goulbi N’Kaba Valley, has: balanced averages of -2.66‰ vs SMOW for 18O and -13.22‰ vs SMOW for the 2H. Their local line has for equation 3H = 6.57518 O + 2.87(R2=0.93). These data are close to those of the Niger rains of the Sahelian subregion. These are rains of mixed origin, oceanic (Guinean monsoon) and continental, which are subject to evaporation on their routes and/or their falls. Moreover, the comparison of this balanced in average to stable isotope contents of the alluvial aquifer water molecule and the transfer of these on the local line 3H vs18O made it possible to show that this alluvial aquifer contains recent waters reloaded directly and/or indirectly, waters where current recharge mixes with old and former dominant component waters. Areas of recharge and low recharge or zero recharge are identified which could contribute to the management of the alluvial aquifer and other aquifers in the Valley. At last, it was observed that the chemistry of the water is not due to any evaporation.15–16

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Conflict of interest

The authors declare there is no conflict of interest.

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