

Contribution of stable isotopes of water (^{18}O and ^2H) 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 ^2H , 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 ^2H . 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 ^2H . The strongest values (> 3.5 % vs SMOW for the ^{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 in 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 chemism 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

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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 $13^{\circ} 20$ and $14^{\circ} 00$ north latitude and $6^{\circ} 30$ and $8^{\circ} 10$ 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 Tessaoua and 368 mm at Dakoro. The averages 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 average annual potential evapotranspiration can reach 2m.¹ The hydrographic network is being fossilized. However, only two tributaries originating in Nigeria (Goulbi El Fadama and Goulbi May 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 325 $\mu\text{s}/\text{cm}$. 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.

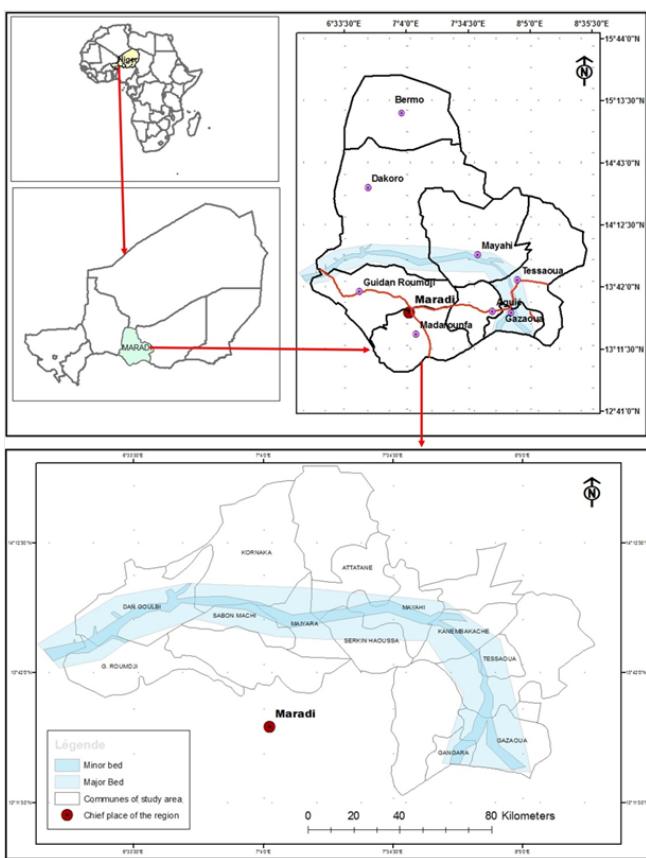


Figure 1 presentation of the study area.

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.³ The results are expressed in delta for thousand vs SMOW, with an accuracy of $\pm 1\text{‰}$ for $\delta^2\text{H}$ and $\pm 0.2\text{‰}$ for $\delta^{18}\text{O}$.

Data processing: For the isotopic contents of rainwater, the input signal and its comparison with Niamey input signals in Niger⁴ and Kano in Nigeria⁵ 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.^{6,7}

Results and discussions

Stable isotope content of rainwater

Spatial and temporal distribution: The levels of ^{18}O and ^2H

rainwater of the year 2016, collected at the stations of Gazaoua, Mayara and Dan Goulbi range from -8.98 to $+3.03\text{‰}$ 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 $+19.06\text{‰}$ 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.⁸⁻¹⁰

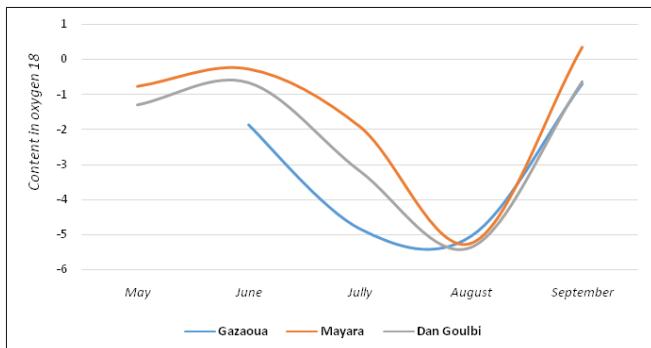


Figure 2 Variation in the stable isotope content of rainwater in 2016.

In addition, the oxygen content of the rains does not correlate with the heights of these rains (Figure 3). Thus, the high levels of stable isotopes found in the rain waters at the beginning and end of the rainy season seem to be related to significant evaporative recoveries and relatively low humidity levels in the air during these periods. The wide dispersion of oxygen 18 and deuterium levels in rainwater is characteristic of arid and semi-arid regions. It reflects a great variability in the climatic conditions that affect the region's rainfall.^{5,9,11}

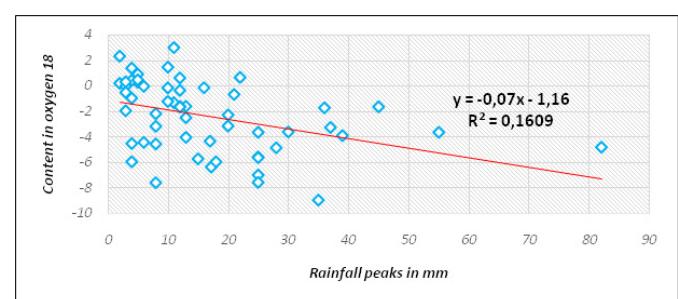


Figure 3 Variation of the stable isotope contents according to the 2016 rainfall heights.

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 $\delta^{18}\text{O}$ and -13.22‰ vs SMOW for $\delta^2\text{H}$.

In Niger and the subregion, some authors have found:

- 0 -2.57‰ vs SMOW for ^{18}O , and -17.47‰ vs SMOW for ^2H , in the 2011 rains collected in the Koroma bordering basin (Sandao, 2013);

- b. 0-2.93 ‰ vs SMOW for ^{18}O , and -13.76 ‰ vs SMOW for ^2H , in rainwater from the Niamey University station⁴;
- c. 0-3.9 ‰ vs SMOW for ^{18}O , and -21.7 ‰ vs SMOW for ^2H 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 $\delta^{18}\text{O}$ and -13 to -22 ‰ vs SMOW for $\delta^2\text{H}$.

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

Months	Gazaoua		Mayara		Dan Goulbi		Mean	
	$\delta^{18}\text{O}$	$\delta^2\text{H}$	$\delta^{18}\text{O}$	$\delta^2\text{H}$	$\delta^{18}\text{O}$	$\delta^2\text{H}$		
May			-3.59	-19.37	-1.66	-5.46	-1.75	-8.28
June	-1.60	-5.22	-0.74	-0.07	-1.57	-6.59	-1.30	-3.96
July	-4.67	-31.03	-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
Maximum	-0.9	4.6	0.4	6.7	-1.6	-5.5	-1.0	-0.2
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	2.0	14.2

Diagram ^{18}O vs ^2H of rain water: The slopes of the lines characteristics of the rains are less than 8. They are respectively 7.53 for the rains at Gazaoua; 6.32 at Mayara and 6.54 at Dan Goulbi. This indicates that these rains experienced evaporative punctures during the vapor phase, during non-equilibrium condensation and / or during the drop of water droplets (Figure 4). The values of excess in deuterium ($d = ^2\text{H} - 8 ^{18}\text{O}$, Dansgard, 1964), well below 10 (1.31 ‰ Mayara, 3.08 ‰ in Dan Goulbi and 6.84 ‰ in Gazaoua), mean that the water vapors causing the precipitation are not exclusively of oceanic origin. Thus, these very low values would indicate that these rains will be subject to recycling with other continental fumes. For the total precipitation of the 3 stations monitored in 2016 as part of the study of the Goulbi N'Kaba valley, the relation ^2H vs ^{18}O defines an equation straight line: (Figure 5). It is considered the local meteoric line (DML) of the Goulbi N'Kaba valley.

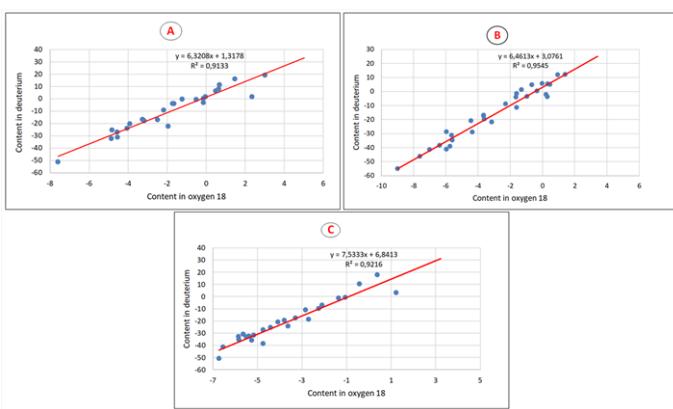


Figure 4 2016 rain water diagram (A- Mayara; B- Dan Goulbi; C- Gazaoua).

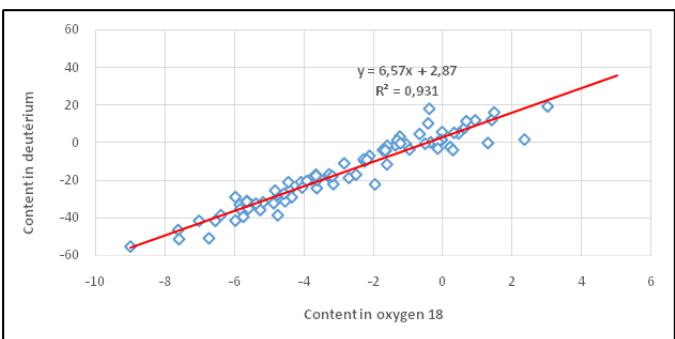


Figure 5 Local meteoric line (LML) of the Goulbi N'Kaba valley rainfall.

Comparison of the ^2H 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 ‰.^{12,13} For the Korama basin, the straight line slope is of 7.33, with a deuterium excess of 5.71 ‰.^{9,10} 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-Sudanese 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 ^2H 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.

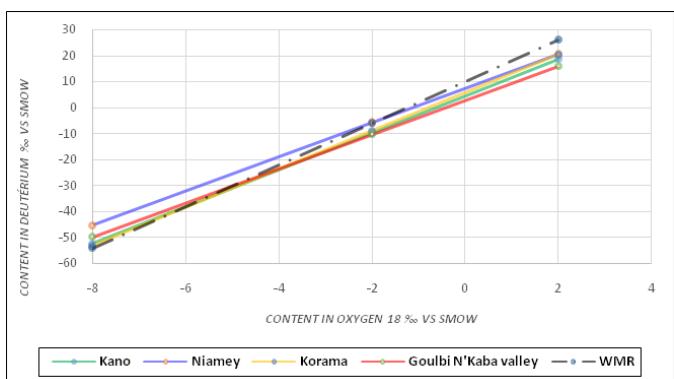


Figure 6 Presentation of the meteoric lines of the Goulbi N'Kaba valley rain waters, the WMR, Niamey and Kano stations.

^{18}O and ^2H 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 ^2H (Table 2). These strong values reflect the highly evaporated nature of the waters of these two catchments. Similar or even higher levels were obtained

in the waters of the Teguey and Téra catchments⁴ 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)	$\delta^2\text{H}$ (permil)	$\delta^{18}\text{O}_{\text{V}}$ (permil)	$\delta^{18}\text{O}$ (permil)
SI-7655	NER/ Pool N°1	85.58	0.9	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}O and ^2H contents of the alluvial aquifer waters

Spatial and temporal distribution: The 18 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 one standard deviation 1.3 vs. SMOW, for ^{18}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 the ^2H . The distribution diagram (Figure 7) shows that in high water, 57% of the samples have ^{18}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, Iyataoua 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}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:

- Direct recharge, from rainwater that has little or no evaporation, which corresponds to the input signal (contents in ^{18}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.
- Indirect recharge, from evaporated water, especially stagnant water and runoff water, with ^{18}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.^{6,8-10,14}

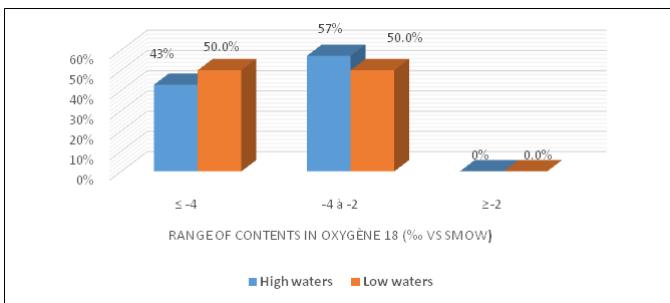


Figure 7 Diagram of distribution of ^{18}O contents of the waters of the alluvial aquifer.

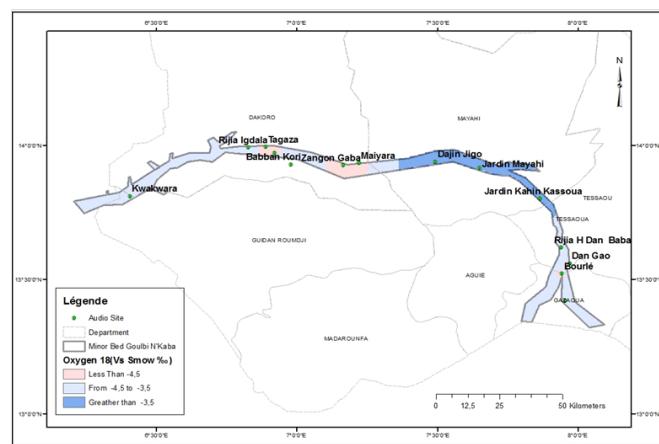


Figure 8 Distribution of stable isotope contents in the waters of the alluvial aquifer.

Correlation $\delta^{18}\text{O}$ vs water chlorides: The diagram Clvs $\delta^{18}\text{O}$ (Figure 9), of the waters of the alluvial aquifer, shows that these two parameters are not correlated ($R^2=0.135$). This would indicate that evaporation is at the base of the acquisition of water chemistry. This finding is also consistent with the low mineralization of the waters of the alluvial aquifer.

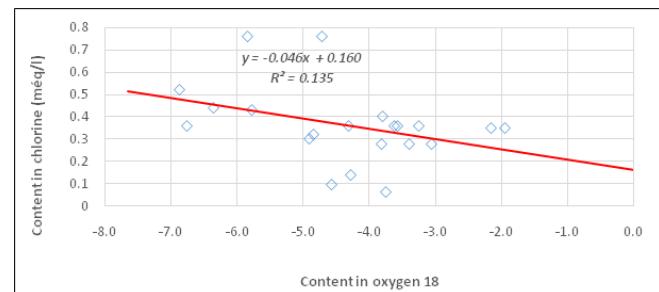


Figure 9 ^{18}O vs chlorine correlation of the alluvial aquifer waters.

Relationship between ^{18}O levels and static levels of structures catching the alluvial aquifer: The correlation between the static levels and the ^{18}O contents of the waters of the alluvial aquifer

(Figure 10) is not significant. This result indicates that the recharge depends on the depth of the aquifer.

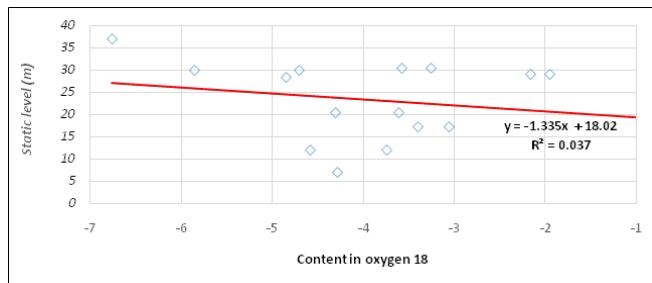


Figure 10 Relation between static levels and ^{18}O contents of alluvial aquifer.

Report of oxygen-18 and deuterium contents of alluvial aquifer on the $\delta^{18}\text{O}$ vs ^2H straight lines of global and local precipitation

The report of the oxygen -18 and deuterium contents of the alluvial aquifer on the ^2H vs ^{18}O diagram on the global and local meteoric lines (Figure 11), shows three categories of water:

- Recent waters (Group 1), with stable isotope contents comparable to those of the input signal. This group consists mainly of water from works between Gazaoua and Mayahi and those of the Kwakwara well in the western sector. These sectors would be recharge zones, par excellence of the alluvial aquifer;
- The old waters (group 2), depleted in stable isotopes, mainly collected by the boreholes as well as the well of Rijjalgdala (positioned in the valley), sectors west, Dakoro and central whose contents are between -7 e 6‰ vs SMOW;
- The mixing waters (group 3), with ^{18}O contents between -5.5 and -4‰ vs SMOW, collected by the upstream sector (from Gazaoua to Bougouzaoua) and also in the central zone (from Mayara to Mallé Sofoua). In these areas, the alluvial aquifer would be confused with the aquifer system of CI/CH.

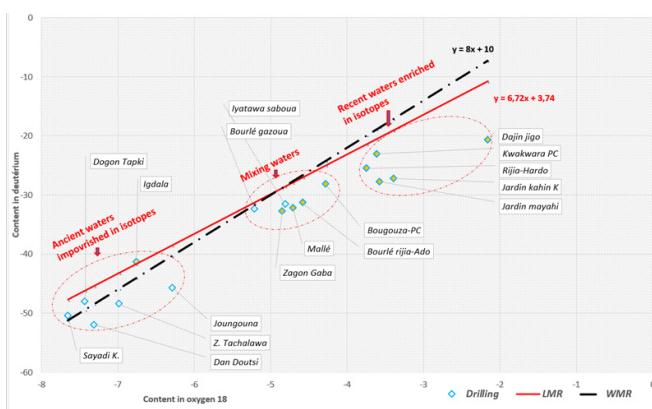


Figure 11 Contribution of stable isotopes to the characterization of alluvial aquifer.

Conclusion

The 2016 precipitation water, collected at certain rainfall stations in the Goulbi N'Kaba Valley, has: balanced averages of -2.66‰ vs SMOW for ^{18}O and -13.22‰ vs SMOW for the ^2H . Their local

line has for equation $\delta^2\text{H} = 6.57818 \text{ O} + 2.87$ ($R^2=0.93$). 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 ^2H vs ^{18}O 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.¹⁵⁻¹⁸

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Conflict of interest

The authors declare there is no conflict of interest.

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