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Summary of the Groundwater Recharge from the South West African Monsoon: A Transect from the Guinea Coast to the Hombori Mountains in Mali

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Abstract

There is an increasing demand on water supplies in semi-arid regions. There is an urgent need to better understand the recharge process of groundwater in these areas, but there an under-representatity of long-term data in these regions ay a global scale. we present the seasonal variations of groundwater over a two-three-year period over a 1500 km transect from the Gulf of Guinea coast to inland Mount Hombori in Mali. The results show a strong seasonal and inter-annual variability, with important evaporation processes for surface and shallow groundwater with rapid infiltration processes. The continental /latitude effect is low along the first 500 km in Guinea, and decrease slowly with the reduction of rainfall and air moisture in direction of Sahel.

Keywords : Groundwater recharge, African monsoon, stable isotope, Sahel region

1. Introduction

Global consideration on monsoon

The disequilibrium in heating system of water and land over the Earth's surface leads to change in moisture laden wind direction which in turn supports seasonality of monsoon rainfall. During the summer monsoon season (June - September), there is a large flow of air moisture from the ocean towards land. The availability of continuous flow of moisture over the humid tropical regions makes it a prominent zone of anthropogenic activities. The rapid pace of change in the humid tropical forest directly impacted the global climate [1]. However, the seasonal climatic variability over the tropics is caused by the monsoonal precipitation which is largely influenced by the Inter-Tropical Convergence Zone (ITCZ). As the ITCZs do not remain the same throughout the year, the tropical zones experience a wet summer monsoon and a dry winter monsoon as a part of the Hadley cycle. Consequently, the tropical regions exhibit less seasonal variability in stable isotope ratios (oxygen isotope ratio, $\delta^{18}O$ and hydrogen isotope ratio, $\delta^{2}H$)

of precipitation with temperature compared to other climatic regions, as the precipitation is predominantly convective in nature [2]. In addition, the small seasonal temperature variability in the tropical region results in lesser seasonal variability of $\delta^{18}O$ and $\delta^{2}H$ in precipitation [3]. Thus, it is nec variability essary to determine whether the isotopic variability in precipitation over the tropics is limited to the strong seasonality of monsoon moisture source, or strongly influenced by topography and the moisture feedback mechanisms over the continent. During heavy rainfall as monsoon onset, the abrupt increase of convective activity over the Sahel is associated with an abrupt change in the isotopic composition. Before the onset, when convective activity is scarce, the rain composition records the intensity and the organization of individual convective systems. After the onset, on the contrary, it records a regional-scale intra seasonal variability over the Sahel, by integrating convective activity both spatially and temporally over the previous days [4].

And in arid regions:

Recharge of groundwater in semiarid and arid regions is critical as water demand enhance and that surface water are scarce and unreliable [5].

Add few words on the study by [6], on precipitation-recharge relationships in sub-saharan Africa.

The case of West African monsoonrain forest—ught

The consequences of this drought on the continental water cycle were quite surprising. Indeed despite the precipitation deficit runoff in the major sahelian rivers [7] as well as water amount in ponds and lakes [8], and water table in southwest niger[10] (Favreau et al 20 have increased since the 60s (Sahelian paradox). The causes for this phenomenon are still debated and different explanations have been put forwards: land cover changes attributed to land use changes [11] and/or to post-drought modification of surface hydrology [12] and/or intensification of precipitation favoring runoff [13].

There is a lack of special and temporally continuous isotopic observations to understand tropical hydrologic cycle [14]. The Global Network of Isotopes in Precipitation (GNIP) from the IAEA Agency have try to establish a network, and in West Africa less than 10 stations sample the rainfall at monthly timescale. Except for the station of Bamako in Mali, the time series are short, and often evaporation process avoid to get reliable data for the short rainfall events.

To understand the groundwater recharge and rainout process along the West Africa monsoon path, we have sampled gro376undwater from Conakry (3737660 mm/y) via Kankan (1480 mm/y) to Hombori (376 mm/y) between 2014 and 2018. This 1500 km long transect (the see Figure 1a) starts from the wet tropical forest of the Guinea gulf coast to the limit of trees in Sahel. Over 250 waters samples have been measured.

Figure 1a: General map showing the location of the sampling sites in Guinea: Conakry and Kankan and Djidbé, and in Mali: Hombori. Details of the region highlighted by the rectangles are represent the detail maps given in the following figures. The mean annual rainfall (mm/year) of the area is given by the blue isohyetal contour lines.

2. Methods

2.1 Sampling sites

The sampling were performed between 2015 and 2018 on two main sites, the first in the area of Kankan in the North-East of Guinea and the second in Hombori in center East of Mali. All the details of the 209 sampling are given in Table 1.

Table 1: Studied area and kind of water sampled (GW= groundwater, SW= River and pond Water) with the geographic location, elevation range, distance to the Guinean Sea, number of samples (n) and date.

Place	Site	Country	Type[1]	Location	Elevation (m asl)	Sea distance (km)	n	Date
Conakry	City and islands	Guinea	GW	9°31'N, 13°42'W	2-8	0.5-5	3	April 2016
Kankan	City and surrounding	Guinea	GW & SW	10°23'N, 9°18'W	365-370	450	24	May-Sept 2015 & May 2016
	Djankana Forest	Guinea	GW	10°29'N, 9°13'W	367-376	470	2	May 2016
	Tintinoulen Forest	Guinea	GW	10°14'N, 9°11'W	428-435	448	4	May 2016
Kérouané	Mount Djidbé	Guinea	Springs	9°17'N, 8°56'W	575-1250	373	6	August 2017
Gbakore	Mount Nimba	Guinea	Springs & GW	7°45'N, 8°28'W	546-1752	275	10	September 2018
Hombori	Garmi	Mali	GW	15°14'N, 1°48'W	331	1385	14	June 2015 to Nov 2016
	Banguel	Mali	GW	15°16'N, 1°46'W	306	1387	14	June 2015 to Nov 2016
	Hombori 1-6	Mali	GW	15°17'N, 1°42'W	290	1390	6×12	June 2015 to Nov 2016
	Daribangui	Mali	GW	15°11'N, 1°33'W	286	1383	11	June 2015 to Nov 2016
	Kelma	Mali	GW	15°13'N, 1°34'W	280	1385	13	June 2015 to Nov 2016
	Tara	Mali	GW	15°16'N, 1°34'W	286	1390	14	June 2015 to Nov 2016
	Wami	Mali	GW	15°17'N, 1°33'W	281	1392	14	June 2015 to Nov 2016
	Bilantao	Mali	GW	15°17'N, 1°34'W	283	1393	14	June 2015 to Nov 2016
	Agoufou	Mali	GW	15°21'N, 1°28'W	293	1405	15	June 2015 through Nov 2016

[1] : Groundwater was sampled from open wells or boreholes screened through unconfined, superficial local aquifers.

<u>The Kankan site in Guinea</u>

Guinea extends from latitude 7° to 13° N, and longitudes 7° and 15 °W. Except the maritime area along the coast center around the main city of Conakry, the country is composed by plateau and mountains, where the Niger River and its higher altitude tributaries take their source. The main sampling place where around the city of Kankan (10°21'N and 9°18'W, elevation 370 m asl) in the North East of the country along the Milo River, one of the Niger river tributary. Additional sampling where performed more south and upstream near Kérouané at the feet of the Mount Djibé (9°10'N and 8°57' W, elevation from 540 to 1250 m), at near Nzérérékoré at Gbakore (7°45' N and 8°27' W, elevation from 550 to 1752 m asl) at the feet of Mount Nimba, the highest peak of West Afrika. A few groundwater were also sampling along the wetter coastline at Conakry (9°30' N and 13°43'W, elevation 8 m asl) and at the Los Islands.

The sampling has been undertaken in August and October 2015 during the monsoon period August for groundwater, pond and river water (n=30). In 2016, a few groundwater were sample at the coast near Conakry (n=3) in late April, and additional sampling in the area of Kankan (n=20) in May of groundwater and river water. To test the elevation effect, two additional sampling were performed in August 2017 at the feet of Mount Djidbé near Kérouané (springs n=6) and in September 2018 near Nzérékoré in the area of Gbakoré at the feet of Mount Nimba spring and groundwater n=10). In all, there is a total of 69 samplings.

During the water sampling, the water temperature and the water depth for the wells were recorded. In the laboratory, the conductivity as the isotopic parameters $\delta^{18}O$ and $\delta^{2}H$ were measured.

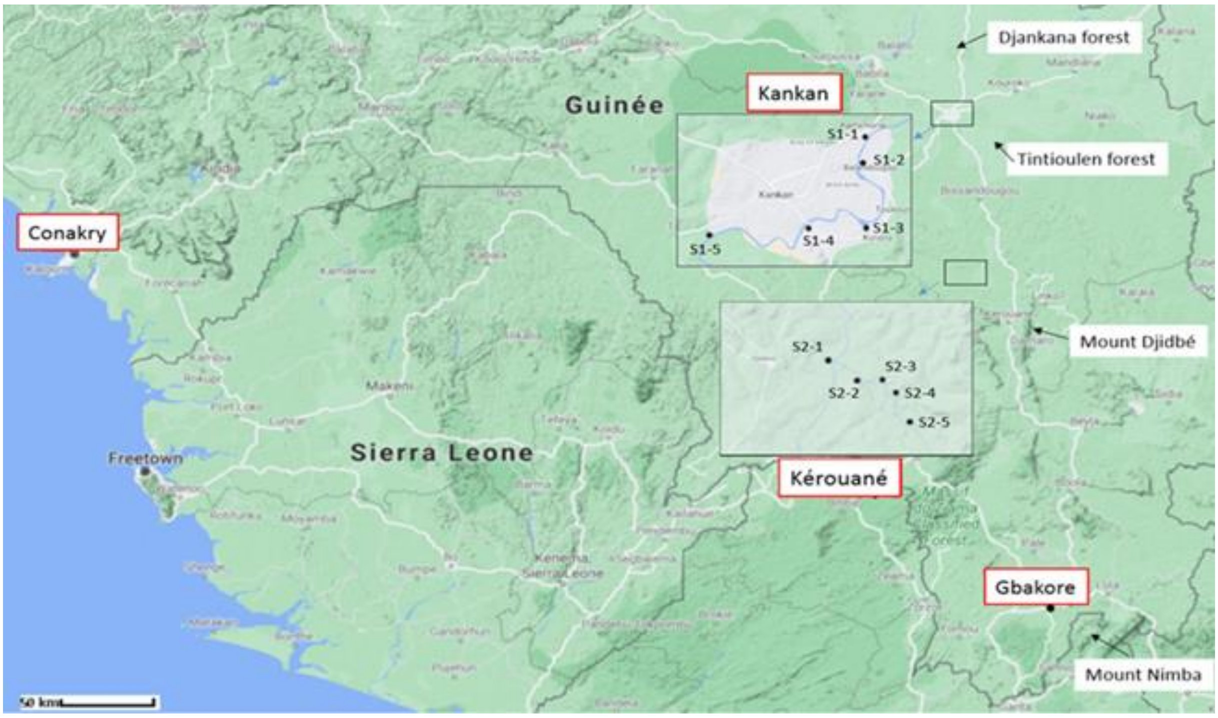


Figure 1b: Part of Guinea map showing the location of sampling site from Conakry at the coastline, to Kankan and Kérouané countryalong the Milo River, a major tributary of the Niger River. For these two last sites, an inlet give the location of the sampling places.

The Hombori site in Mali

Mali lies between latitudes 10° and 25°N and longitudes 13°W to 5°E. The northern part of the country is located in the Sahara Desert, whereas the central and southern parts belong to the sahelian and sudanian bioclimatic zones, respectively. The sampling sites were located in Sahel, at the village of Hombori (15°17’ N, 1°42’ W, elevation 295 m asl) and the surrounding small villages.

In the district of Hombori, the most striking character of the water resource is the diversity of local situations [15] (Gangneron et al., 2010): practically every village or pastoral camp has a particular relationship with the resource. It results from the combination of different factors: a) the geography of the district; b) the types of water availability (lakes, pools, shallow wells) and c) the types of human activities (pastoral, cultivation).

All the sampling sites are close to theMount Hombori (1155 m asl) w mountain hich is the highest in Mali. Sampling sites include surface water, traditional and modern wells, and boreholes.

Surface water such as the large Agoufou pond [9], near Hombori, is the main water resource that has always been used as drinking water for human and livestock, for washing, for several craft activities, and it is increasingly used for garden irrigation and fish breeding [16] ; [15] . Other water resources come from the water traditional and modern wells and borehole water. Eventually, the sampling were performed at 14 sites at Hombori and around the village of Hombori (see Figure 1c) in wells, boreholes, and Agoufou pond, thus covering the whole variety of water resources. Water was sampled, every month whenever possible, from May 2014 to January 2016. Finally, a total of 183 samples were collected over a 16-month period.

At the time of the water sampling, water temperature and water depth in the wells were recorded. In the laboratory, the conductivity and the isotopic parameters $\delta^{18}O$ and $\delta^{2}H$ were measured.

Figure 1c: Map of the area of Hombori in Mali, showing the 17 sampling places, located around Hombori mounts.

2.3 Isotope analysis

The samples were kept under room temperature until analysis of their stable isotope ratios ($\delta^{18}O$ and $\delta^{2}H$) on an Isoprime 100 continuous flow isotope ratio mass spectrometer (Isoprime, Cheadle Hulme, UK) coupled with a Geo-Multiflow for water–gas equilibration (Elementar, Hanau, Germany). The stable isotope ratios of oxygen and hydrogen are defined with δ notation and ‰ unit as suggested by [17] and redefined by [18].

The deuterium excess (d-excess) was calculated according to Craig's formula [19] as explained by, i.e., d-excess (‰) = $\delta^{2}H - 8 \times \delta^{18}O$.

2.4 Statistical analysis

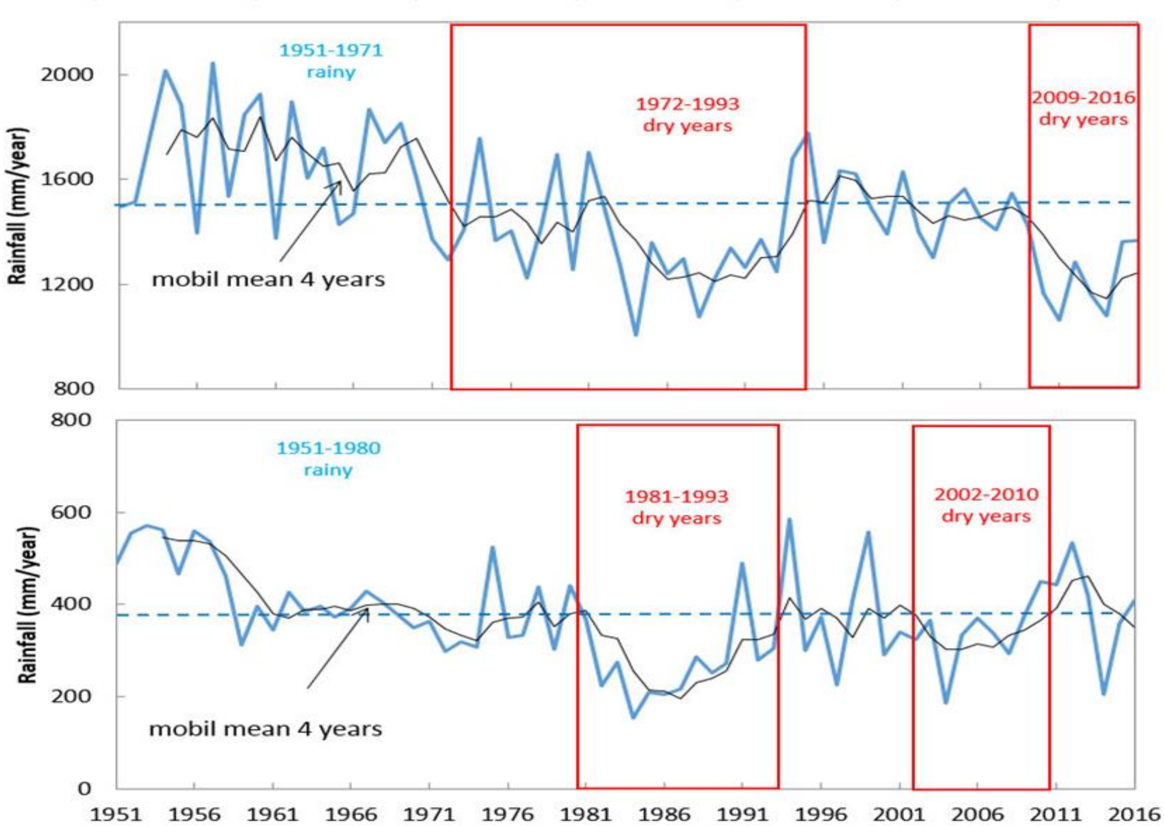
The simple mean, standard deviation and regression were calculated using Microsoft Excel 2016, whereas the multiple linear regression analysis was performed using Past v. 3.15. The dependent variable was the $\delta^{18}O$ values, and the independent variables were the elevation

(elevation effect), the distance to coastline (*continental effect*) and the annual rainfall amount (*rainfall amount effect*).

3. Results And Discussion

3.1 Rainfalls chronology analysis

For the area of Kankan, there is a global decrease of the rainfall amount since the fifties, with values starting at 2000 mm/year and lowering below 1500 mm in the last years. The slope of the decrease is around -6.7 mm/year for a global linear regression. The overall mean rainfall value for this period is 1480 +/- 241 mm/year. Outside this general drier condition's tendency, there is also succession of wetter and drier period at a decade scale. Some period like 1972-1993 and 2009-2016 (see Figure 2) present more severe rainfall deficit.



Figures 2: Variation of the annual rainfall (mm/year) between 1951 and 2016.

(a): for Kankan, the horizontal dotted line represents the mean value for this period: 1480 +/- 241 mm/year.
(b): for Hombori, horizontal dotted line represents the mean value for this period: 371 +/- 105 mm/year.

For the area of Hombori, the annual rainfall is about four time less than in in the area of Kankan, and the monsoon period is also shorter, 3-4 of rainy months in comparison with 6-8 rainy months at Kankan. Here in Hombori between 1951 to 2016, there is no real global annual rainfall decrease. The slope of the decrease is around -1.9 mm/year for a global linear regression. The overall mean rainfall value for this period is 371 +/- 105 mm/year. The first drier period for 1972-1993 is also seen, but after 2010 the annual rainfall, except in 2014 and 2015) is above the mean value. Only around the 2002-2010, some drier condition can be found.

3.2 $\delta^{18}O$ values

Figure 4a reports the isotopic composition of the groundwater (red circle) and rivers water (blue triangle) for the 30 sampling of 2015 during May to September for Kankan in Guinea. All the points are close to the Global Meteorological Water Line (GMWL) with no marked evaporation processes. During the monsoon, there is a shift to more depleted values, with a mean value for this period of $\delta^{18}O$ = -5,14 +/- 0.74 ‰ (n=10).

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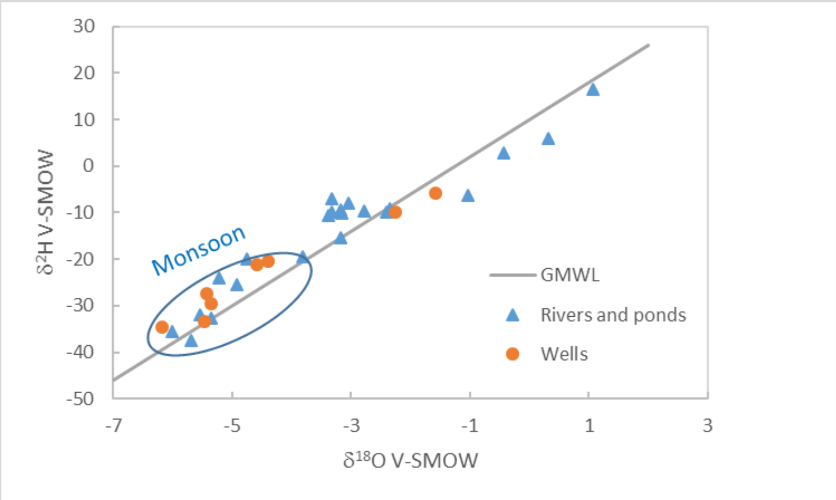

Figure 3a. Plotting of the $\delta^{18}O$ values against the $\delta^{2}H$ value relative to the Global Meteorological Water line (GMWL) for June to September 2015 in the area of Kankan. The blue triangle represent the Milo River, its tributaries and ponds, and the red circle the groundwater samplings.

In the sampling of May 2016, i.e. just before the monsoon, some moderate evaporation for the groundwater and more pronounced for the river water (see the blue lines on Figure 4b). Only the groundwater under the sacred forest which are natural protect area and not connected to the river Milo hydrology keep depleted and non-evaporated groundwater. Their high d-excess values (mean value 14.7) also reveals some water vapor recycling. The coastal groundwater display a mean values of $\delta^{18}O$ = -4.87 +/- 0.40 ‰, and is quite similar to the groundwater typical values find here more inland in the area of Kankan.

The altitude sampling of 2017 at the feet of Mont Djidbé (mean values of $\delta^{18}O$ = -5.13 +/- 0.51 ‰ n=6) and at Mont Nimba (mean values of $\delta^{18}O$ = -5.17 +/- 0.67 ‰ n=10) show a homogeneity on a quite wide scale for the monsoon signal. The given mean value and standard deviation are calculated for each group for the non-evaporated samples (see figure 3b).

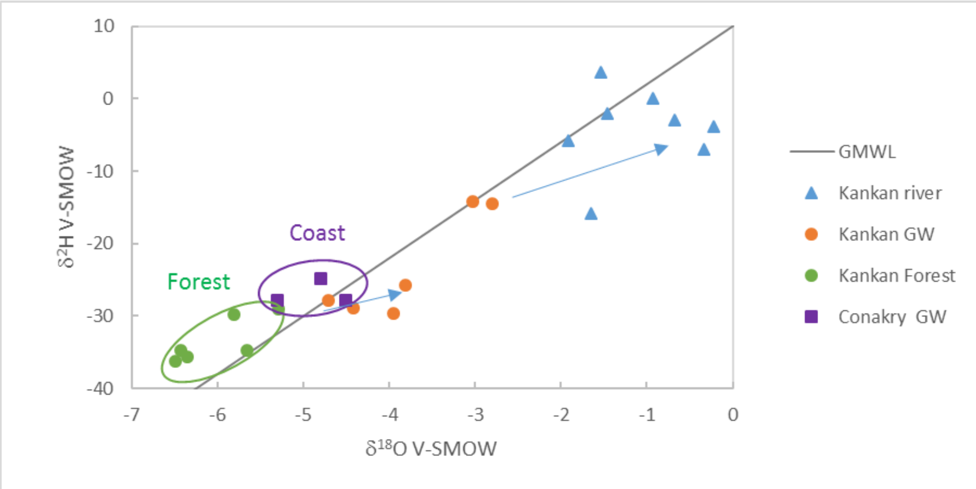

Figure 3b. Plotting of the $\delta^{18}O$ values against the $\delta^{2}H$ value relative to the Global Meteorological Water line (GMWL) for the May 2016 sampling (n=20) and the coastal groundwater taken in April 2016 near Conakry.

3.3 d-excess

Deuterium excess (d-excess) is a second-order stable isotope parameter measured in meteoric water to understand both the source of precipitation and the variation of moisture during transport. A value close to 10 suggests an equilibrium between the vapor-liquid transitions.

In the case of the Guinea sites, most points present high d-excess values (i.e >10), mainly the ones sampled during the monsoon period in 2015, some points taken at the feet of Mont Nimba and ones from the sacred forest around the area of Kankan (see Figure 4a). This high d-excess values shows water vapor recycling as it can occur during wet season and/or in forested area.

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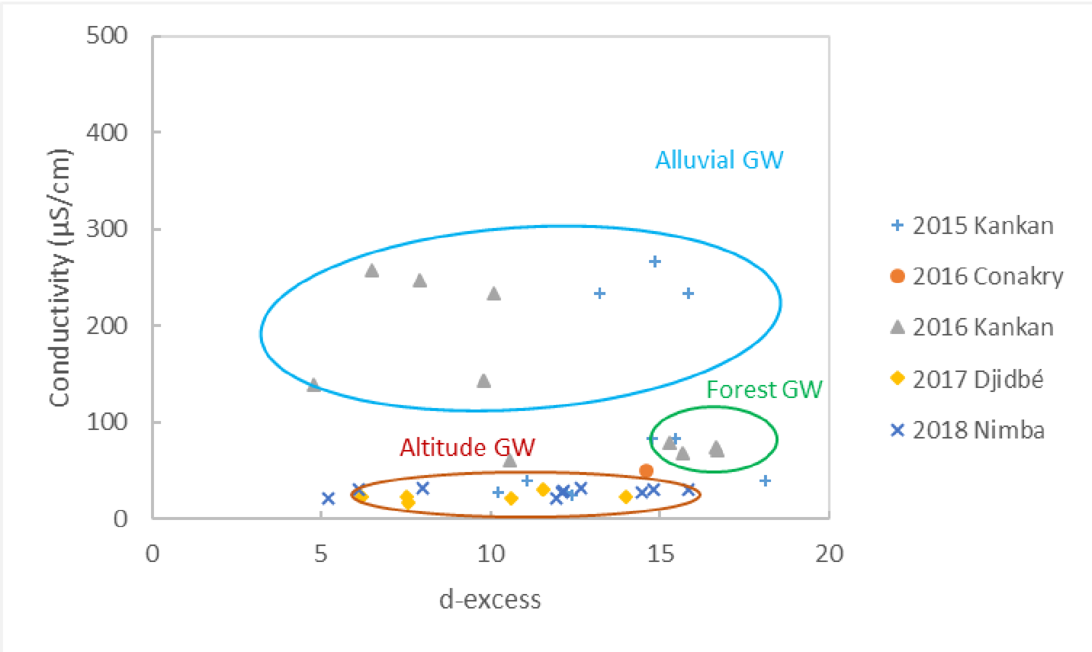

Figure 4a. Plotting of the d-excess values against the conductivity for the Guinea sites.

On the contrary, at the sites of Hombori, except the station of Garmi and the Hombori village, most of the stations display low d-excess values (see Figure 4b) suggesting more dry and evaporative conditions. This reveals that most of rainfall water have been post evaporated before infiltration to the local groundwater. The high measured conductivity values are coming from the progressive mineralization of the rainwater infiltration on its way to the groundwater, income of wastewater (case of Hombori 1) and from the water concentration due to the evaporation process detected by low d-excess values. In the first case, it can be related with the soil.

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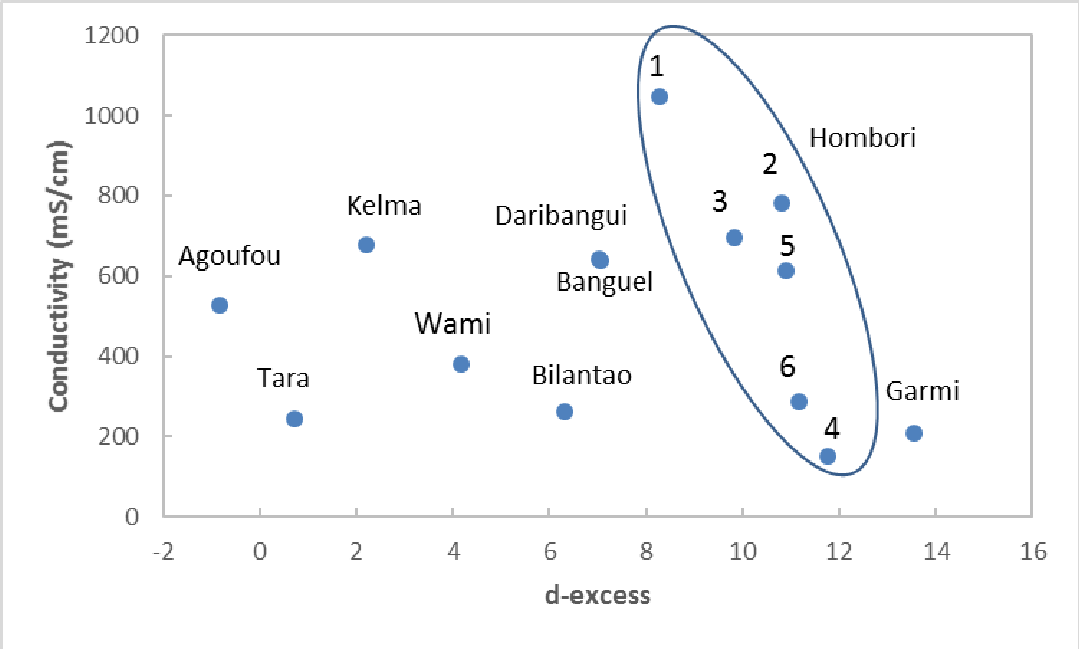

Figure 4b. Plotting of the mean d-excess values against the conductivity for the different Hombori sites.

3.4. Seasonality

Monsoon is a strong seasonal signal, alternating dry and wet seasons. The rainfall amount drastically decreases from the seaside like in Conakry (3760 mm/y), to Kankan (1480 mm/y) and to the Sahel proper zone at Hombori (376 mm/y). The wet period also shorter along this gradient from 6-7 months to 3-4 months, with a strong inter-annual variability.

Figure 5a shows the temporal variation of the $\delta^{18}O$ signal of the surface and groundwater for the area of Kankan. The figure cumulates the 2015 and 2016 samplings. It can be seen that the arrival of the monsoon depleted the $\delta^{18}O$ signal, for the groundwater from around -3 ‰ to -5 ‰, and for the surface water from around -2 ‰ to -5 ‰.

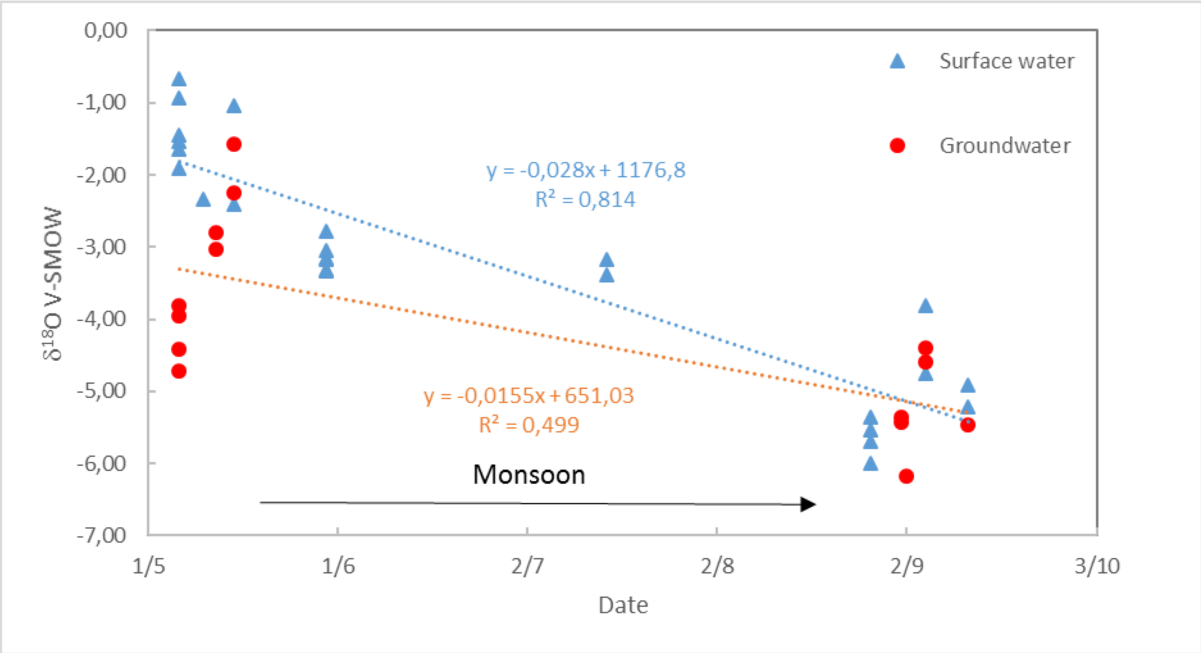

Figure 5a: Temporal evolution of the $\delta^{18}O$ values of the river Milo and ponds (blue triangle) and of the groundwater (red circle) in the area of Kankan.

Figure 5b shows the temporal variation of the $\delta^{18}O$ signal for wells in the area of Hombori with full time datasets available. The two rectangles materialize the monsoon period between June 2015 and November 2016. In general, the $\delta^{18}O$ signal becomes more depleted during the monsoon rainfall, but a refill delay is also observed for Bilantao and Hombori for instance, perhaps due to a buffering effect from groundwater reservoir. The term "evaporation" with the arrow on the graphic do not mean evaporation of the deep groundwater, but more certainly late infiltration of surface evaporated water.

Figure 6c shows the temporal variation of the piezometric level in same wells. Here the influence of the rainfall amount with the water level in the wells is more direct. At Garmi, as it is a very deep well (water table between 45 to 65 m), it was not possible to follow monthly variation.

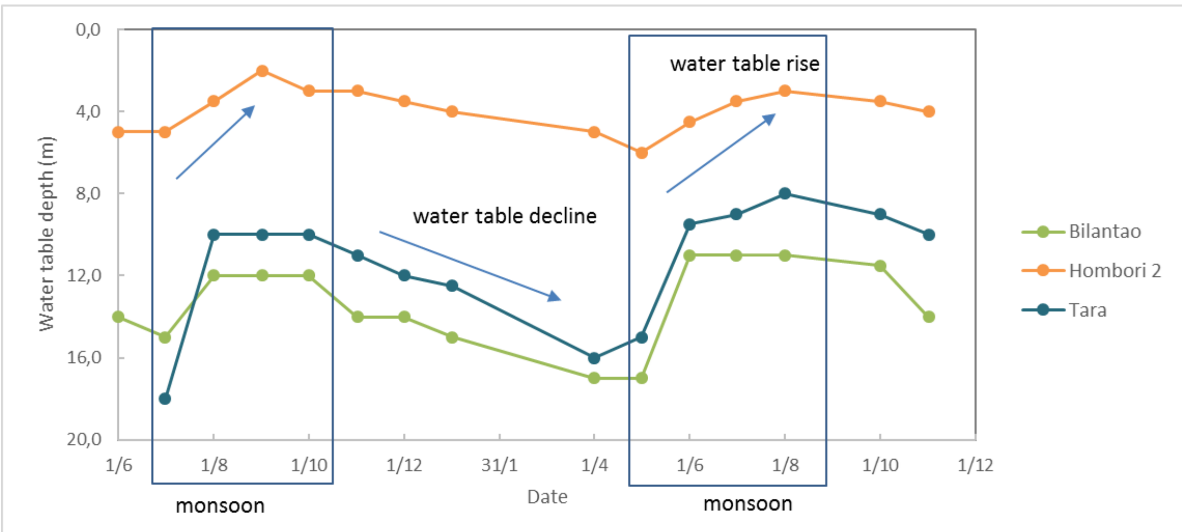

Figure 5c: Evolution of the groundwater depth of Hombori sampling sites with full datasets from June 2015 to November 2016.

4. Discussion

First, the West African monsoon, even if coming from Guinea Gulf Sea presents, continental characteristics. Effectively the depleted isotopic values found for the rainfall and the groundwater from the islands, like the Kassa and Rooma islands located in front of Conakry, the $\delta^{18}O$ values are closed to -5 ‰, and these values are found again 1500 km inland at the site of Hombori. Tropical rainfall are normally very less depleted in heavy isotopes due to the proximity of the ocean (d value close to 0 ‰) and the equilibrium with the sea moisture. In general, tropical rainfall and groundwater range from -2 to -3 ‰ as on small island as in the Caribbean Sea and in Indian Ocean [20], and [21], or along tropical coasts as in Guyana and in India [22]. In fact the depleted signal of around -5 ‰ is more similar to North-East winter monsoon of India [23], [24]; which is due to its long travel over Tibet and India [25]. One could imagine that the influence of central African on the West African monsoon is strong, but what is surprising is that coastal station located more east as Cotonou in Benin and Douala in Cameroun exhibit less depleted $\delta^{18}O$ values around -3 ‰ (GNIP database).

4.1 Seasonal variability and evaporation process different

There is strong long-term behavior in rainfall between Kankan and Hombori. The Kankan site faces a continuously decreasing rainfall amount since the fifties with seasonal variation, and many wells dry out now during the dry season. On the contrary, the area of Hombori is less influenced by this rainfall long-term lost, with shorter dry period, but has to face increasing air temperatures. Moreover, surface water has generally increased over the Sahel, including in the Gourma region and in the Agoufou pond, after the major drought of the 70-80 and this despite the decrease in rainfall over the same period [9] (Gal et al 2016).

Alter these rainfall considerations, there is also a difference between the hydrologic functioning of both sites. The Kankan area and its upper sub-area in direction of Kérouané is a savannah located in a fluvial plain of the Milo River, one of the upstream tributary of the Niger River. Both rivers are nearly in the axis of the monsoon with no orographic interference after the coastal Simandu range as Mount Nimba or latter lower hills as Mont Djidbé. In opposition, the area of Hombori is a Sahelian plateau from the Gourma region located about 200 km south of the Northern incursion of Niger River. After the Mopti range, the Hombori peaks are the last orographic interference before Sahara. The sharped sandstone peaks of Mounts Hombori, generate quite important local rainfall discrepancy, the rainfall amount in Garmi can be twice the one measured in Agoufou only 40 km away. The Hombori area is an endorheic system starting from the rainfall intercept par the peaks with either direct infiltration into the groundwater, either pouring ephemeral rivers and ponds in a global North East direction. The groundwater level range from 10 to 60 meters deep, and is only more shallow at the Hombori village. The area of Agoufou is a distinct endorheic system poured by another upstream basin, with important evaporation effect.

4.2 Comparison with surrounding IAEA GNIP dataset (w $\delta^{18}O$ and w d-excess)

The similarity of the isotopic composition found along the 1500 km transect with a mean $\delta^{18}O$ values around -5 ‰ show an homogeneity at a large scale of the West African monsoon. Thus, the continental effect along this North-south direction (latitude effect), the elevation orographic and the amount effect seems to be low.

This can be extended when compared with the available surrounding GNIP stations of West Africa as given in Table 2. The Bamako station in Mali is interesting as it gives temporal series over a long time period (1962 to 2014), even if some years are missing, and is located between the sites of Kankan and Hombori. The values of Bamako ($\delta^{18}O$ = -4.6- ‰ and d-excess = +7.8) are closed to the mean of Hombori site, even if Bamako receives about 3 times more rainfall amount than Hombori, respectively 948 and 330 mm per year). And the station of Louga in Senegal, shows oxygen18 value similar to the ones found for Kankan: $\delta^{18}O$ = -5.1- ‰ but with lower d-excess value of +5.8.

Table 2: comparison of the mean isotopic values ($\delta^{18}O$ and d-excess) for the studied sites and the surrounding GNIP stations

Site	Country	Position	Years	Rainfall	Mean d18O	mean d-excess	n	Origin
Conakry	Guinea	9°28'N 13°40'W	2016	3760	-4.9 ± 0.5	12.2 ± 3.4	3	This work
Nzérékoré	Guinea	7°51'N 9°22'W	2018	1932	-5.2 ± 0.7	11.3 ± 3.7	10	This work
Djidbé	Guinea	9°24'N 8°52'W	2017	1376	-5.1 ± 0.5	9.6 ± 3.0	6	This work
Kankan	Guinea	10°35'N 9°17'W	2015-2016	1480	-5.2 ± 0.6	13.5 ± 0.6	26	This work
Hombori	Mali	15°23'N 1°42'W	2014-2016	330	-4.4 ± 0.4	9.7 ± 3.0	141	This work
Bamako	Mali	12°43'N 7°56'W	1962-2014	948	-4.6 ± 1.7	7.8 ± 4.4	145	GNIP data
Dakar	Senegal	14°52'N 17°22'W	2013-2016	373	-4.0 ± 0.5	4.2 ± 2.0	48	GNIP data
Louga	Senegal	15°44'N 16°06'W	2013-2016	373	-5.1 ± 0.5	5.8 ± 1.7	48	GNIP data
Niamey	Niger	13°29'N 2°18'E	2009-2016	526	-3.5 ± 0.7	9.8 ± 1.0	50	GNIP data
Kandi	Benin	11°16'N 3°04'E	2014-2016	746	-3.5 ± 0.3	12.9 ± 1.6	31	GNIP data
Ouadagoudou	Burkina-Faso	12°22'N 1°28'W	2004-2018	816	-4.1 ± 1.0	10.6 ± 2.9	96	GNIP data
Bobo Dioulosso	Burkina-Faso	11°17'N 4°13'W	2010-2016	1060	-4.0 ± 1.3	8.9 ± 1.5	145	GNIP data

5. Conclusions

Few changes in the isotopic composition along the studied gradient with approximatively follows the West African monsoon and the Niger River flow. The African monsoon airflow seems to be little affected by the coastal relief between Guinea, Sierra Leone and Liberia. If there no isotopic latitude effect, a longitude isotopic effect of around 1 delta unit per 10° of longitude is observed.

Outside these general trends, there is strong seasonal and inter-annual variability with different long-term trends depending on the geographical position.

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References

1) Vitousek, P. M., Aber, J. D., Howarth, R. W., Likens, G. E., Matson, P. A., Schindler, D. W., & Tilman, D. G. (1997). Human alteration of the global nitrogen cycle : sources and consequences. *Ecological applications*, *7*(3), 737-750.
2) Netzer, H., Lira, P., Trakhtenbrot, B., Shemmer, O., & Cury, I. (2007). Black hole mass and growth rate at high redshift. *The Astrophysical Journal*, *671*(2), 1256.
3) Baijjali, W., Clark, I. D., & Fritz, P. (1997). The artesian thermal groundwaters of northern Jordan: insights into their recharge history and age. *Journal of hydrology*, *192*(1-4), 355-382.
4) Risi, C., Bony, S., Vimeux, F., Descroix, L., Ibrahim, B., Lebreton, E., ... & Sultan, B. (2008). What controls the isotopic composition of the African monsoon precipitation? Insights from event-based precipitation collected during the 2006 AMMA field campaign. *Geophysical Research Letters*, *35*(24).
5) Scanlon, B.R., Keese, K.E., Flint, A.L., Flint, L.E., Gaye, C.G., Edmunds, M., & Simmers, I. (2006). Global synthesis of groundwater recharge in semiarid and arid regions. *Hydrological Processes,* **20**, 335-3370.
6) Cuthbert, M.O., Taylor, R.G., Favreau, G. *et al.* Observed controls on resilience of groundwater to climate variability in sub-Saharan Africa. *Nature* **572,** 230–234 (2019). https://doi.org/10.1038/s41586-019-1441-7
7) Descroix, Luc, Guichard, Françoise, Grippa, Manuela, Lambert, Laurent, Panthou, Gérémy, Mahé, Gil, Gal, Laetitia, Dardel, Cécile, Quantin, Guillaume, Kergoat, Laurent, Bouaïta, Yasmin, Hiernaux, Pierre, Vischel, Théo, Pellarin, Thierry, Faty, Bakary, Wilcox, Catherine, Malam Abdou, Moussa, Mamadou, Ibrahim, Vandervaere, Jean-Pierre, Diongue-Niang, Aïda, Ndiaye, Ousmane, Sané, Youssouph, Dacosta, Honoré, Gosset, Marielle, Cassé, Claire, Sultan, Benjamin, Barry, Aliou, Amogu, Okechukwu, Nka Nnomo, Bernadette, Barry, Alseny & Paturel, Jean-Emmanuel, 2018. Evolution of Surface Hydrology in the Sahelo-Sudanian Strip: An Updated Review. *Water*, 10 (6), 748
8) Gardelle, J., P. Hiernaux, L. Kergoat, and M. Grippa. 2010. Less rain, more water in ponds : a remote sensing study of the dynamics of surface waters from 1950 to present in pastoral Sahel (Gourma region, Mali). Hydrol. Earth Syst. Sci. 14(2): 309–324. doi: 10.5194/hess-14-309-2010.
9) Gal, L., Grippa, M., Hiernaux, P., Peugeot, C., Mougin, E., Kergoat. L., (2016). Changes in lakes water volume and runoff over ungauged Sahelian watersheds. *Journal of Hydrology,* **540**, 1176-1188, doi: 10.1016/j.jhydrol.2016.07.035.
10) Favreau, G., B. Cappelaere, S. Massuel, M. Leblanc, M. Boucher, N. Boulain, and C. Leduc. 2009. Land clearing, climate variability, and water resources increase in semiarid southwest Niger: a review. Water Resour. Res. 45(7): W00A16. doi: 10.1029/2007WR006785.
11) Leblanc, M.J., G. Favreau, S. Massuel, S.O. Tweed, M. Loireau, and B. Cappelaere. 2008. Land clearance and hydrological change in the Sahel: SW Niger. Glob. Planet. Change 61(3–4): 135–150. doi: 10.1016/j.gloplacha.2007.08.011.
12) Gal, L., M. Grippa, P. Hiernaux, L. Pons, and L. Kergoat. 2017. The paradoxical evolution of runoff in the pastoral Sahelvanalysis of the hydrological changes over the Agoufou watershed (Mali) using the KINEROS-2 model. Hydrol. Earth Syst. Sci. 21(9): 4591–4613. doi: 10.5194/hess-21-4591-2017.

13) Panthou, G., Lebel, T., Vischel, T., Quantin, G., Sane, Y., Ba, A., Ndiaye, O., Diongue Niang, A. & Diokpane, M., 2018. Rainfall intensification in tropical semi-arid regions: the Sahelian case. *Environmental Research Letters*
14) Vuille, M. (2018). Current state and future challenges in stable isotope applications of the tropical hydrologic cycle. *Hydrological Processes*, **32**, 1313-1317. DOI: 10.1002/hyp.11490
15) Gangneron, F., Becerra S., & Dia A. H. (2010). L'étonnante diversité des ressources en eau à Hombori : Entre contrastes environnementaux, pratiques locales et technologies extérieures. *Revue Tiers Monde*, 4(204), 109-128, doi: 10.3917/rtm.204.0109.
16) Mougin, E., Hiernaux, P., Kergoat, L., Grippa, M., P. de Rosnay, F. Timouk, V. Le Dantec, V. Demarez, F. Lavenu, M. Arjounin,T. Lebel, N. Soumaguel, E. Ceschia, B. Mougenot, F. Baup, F. Frappart, P.L. Frison, J. Gardelle, C. Gruhier, L. Jarlan, S. Mangiarotti, B. Sanou, Y. Tracol, F. Guichard, V. Trichon, L. Diarra, A. Soumaré, M. Koité, F. Dembélé, C. Lloyd, N.P. Hanan, C. Damesin, C. Delon, D. Serça, C. Galy-Lacaux, J. Seghieri, S. Becerra, H. Dia, F. Gangneron, & P. Mazzega (2009). The AMMA Gourma observatory site in Mali: Relating climatic variations to changes in vegetation, surface hydrology, fluxes and natural resources. *Journal of Hydrology*, AMMA CATCH special issue, **375**(1-2), 14-33, doi: 10.1016/j.jhydrol.2009.06.045.
17) Craig, H. (1961). Isotopic variations in meteoric waters. *Science*, **133**, 1702-1703.
18) Coplen, T.B. (2011). Guidelines and recommended terms for expression of stable-isotope-ratio and gas-ratio measurement results. *Rapid Communications in Mass Spectrometry*, **25**, 2538-2560.
19) Dansgaard, W. (1964). Stable isotopes in precipitation. *Tellus* **16**, 436-468.
20) Lambs, L., Bompy, F., Imbert, D., Corenblit, D., & Dulormne, M. (2015). Seawater and freshwater circulations through coastal forested wetlands on a Caribbean island. *Water, 7*(8), 4108-4128.
21) Lamb, J. B., Wenger, A. S., Devlin, M. J., Ceccarelli, D. M., Williamson, D. H., & Willis, B. L. (2016). Reserves as tools for alleviating impacts of marine disease. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1689), 20150210.
22) Lambs, L., Bompy, F., & Dulormne, M. (2018). Using an “isotopic spike” from a tropical storm to understand water exchange on a large scale: case study of Hurricane Rafael in the Lesser Antilles archipelago, October 2012. *Rapid Communications in Mass Spectrometry*, *32*(6), 457-468.
23) Tliba, O., Deshpande, D., Chen, H., Van Besien, C., Kannan, M., Panettieri Jr, R. A., & Amrani, Y. (2003). IL-13 enhances agonist-evoked calcium signals and contractile responses in airway smooth muscle. *British journal of pharmacology*, *140*(7), 1159-1162.
24) Tripti, M., Lambs, L., Moussa, I., & Corenblit, D. (2019). Evidence of elevation effect on stable isotopes of water along highlands of a humid tropical mountain belt (Western Ghats, India) experiencing monsoonal climate. *Journal of Hydrology*, **573**, 469-485.
25) Gonfiantini, R., Roche, M.A., Olivry, J.C., Fontes, J.C., & Zuppi, G.M. (2001). The altitude effect on the isotopic composition of tropical rains. *Chemical Geology*, **181**, 147-167.