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ISOTOPIC PROPERTIES OF RAINFALL AND GROUNDWATER RESOURCES IN THE IULLEMEDEN BASIN, WEST AFRICA

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The isotopic composition of rainfall sampled at Niamey, Niger, between 1992 and 1999 reveals a close correlation with the climatic variables of relative humidity and mean monthly air temperature. The isotopic signature of rainfall indicates the impact of climatic variability in the Iullemeden basin. The isotopic variation of precipitation over that basin confirms the rainfall quantity effect as well as the continental effect. Lighter precipitation over the Iullemeden basin displays a more enriched isotopic composition whereas more depleted isotope values are observed in heavier precipitation. The variation can be related to evaporation at the time of rainfall. The variation of the annual weighted mean of $\delta^{18}O$ *in 1992 and 1999 rainfall points out the unusual role of both altitude and quantity effects. The continental effect which normally leads to a depletion of heavy isotopes in rainfall owing to lower temperatures of condensation is also observed. The isotopic characteristic of groundwater of the Sokoto basin, a subbasin of the Iullemeden basin, shows a good relation between* $\delta^{18}O$ *and* $\delta^{2}H$*. This relation suggests the same origin of vapor and the same processes of condensation. The low slope and the position of data points below the GMWL shows the influence of evaporation. The rather depleted values of* $\delta^{18}O$ *and* $\delta^{2}H$ *for the groundwater taken from Goronyo, Taloka, and Amahali boreholes tapping the Wurno Formation of Cretaceous age reflects paleogroundwater recharged during the cooler climate of the Pleistocene era.*

INTRODUCTION

The Iullemeden Basin covers the northwestern corner of Nigeria and extends southwards and southeastwards from the Nigeria-Niger border towards the north central parts of Nigeria. It lies within latitude 10.00 to 13 North and longitude 3.45 to 8.00 East and encompasses the whole of Sokoto State, Kebbi State, Zamfara State and parts of Katsina and Niger States, covering a total land area of approximately 131,600 square kilometers (Figure 1). The Iullemeden basin extends over 500,000 km^2, of which 434,000 km^2 are in Niger. About 65% of the total 15 million people living in the basin are from Niger.

The Sokoto basin, part of the Iullemeden basin, is located in Nigeria and is highly important to Nigeria from several different aspects:

- Religious, with the seat of the Kalifat;

- Economic, representing the food basket of northwest Nigeria;

- Population density, with high concentrations of people in cities and towns in the States of Sokoto, Kebbi and Zamfara with a population of approximately 6 million with close to 4 million in the Iullemeden Basin.

The Sokoto and Rima Rivers drain this part of the country to the Niger River. Also, the basin covers a zone that has been affected by the drought in the last several years and has a strong exploitation of the groundwater resources. The study area has an annual mean rainfall varying between 150 and 400 mm for three rainy months; the annual mean evapotranspiration exceeds 2500 mm. The Niger River and its tributaries drain the basin. The hydrogeological setting is essentially Continental Intercalaire and Continental Terminal of the Iullemeden Basin.

Climate and Hydrology

The Iullemeden basin is part of the arid and semiarid west African zones. The main rainfalls are caused by squall line processes. From north to south in the basin, the mean annual precipitation is lower than 150 mm in the Saharan belt, between 150 mm to 300 mm in the nomadic Sahelian belt, between 300 mm to 600 mm in the sedentary Sahelian belt, and between 600 mm to 800 mm in the Sahelian Sudan belt, with a maximum rainfall over 1000 mm (Anon, 1999).

The Niger River represents the main drainage network. At the Niamey station, the mean annual value of runoff is 2000 m^3/sec during the high water period (December to February) and 38 m^3/s in the low water period (May to June). In July 1974, the runoff was 0.4 m^3/sec and zero on June 12, 1985 for few days (Anon, 1999).

Geological and Hydrogeological Setting

The Iullemeden basin is bounded by the Pan African mobile belt (northern Touareg, southern Nigerian complex) and the West African stable crystalline basement (western Man shield) (Bellion, 1987; Dodo, 1992). The basin shows a sandstone saturated thickness of more than 1000 m (Figure 2) representing the continental Intercalaire of Continental aquifer (Tertiary) (Greigert, 1966; Dikouma et al., 1993). These two major aquifers are separated by marine limestone (upper Cretaceous) and the Paleocene deposits (Greigert, 1978; Dodo, 1992).

The Iullemeden basin is affected by the Pan African fault which characterizes the collision between the Pan African mobile belt and the West African stable crystalline basement (Greigert, 1978; Bellion, 1987; Kogbe, 1991). This major fault bounds the intercalaire Continental aquifer in the western part of the basin. Its downthrow is at least 1000 meters (Greigert, 1978; Dodo, 1992).

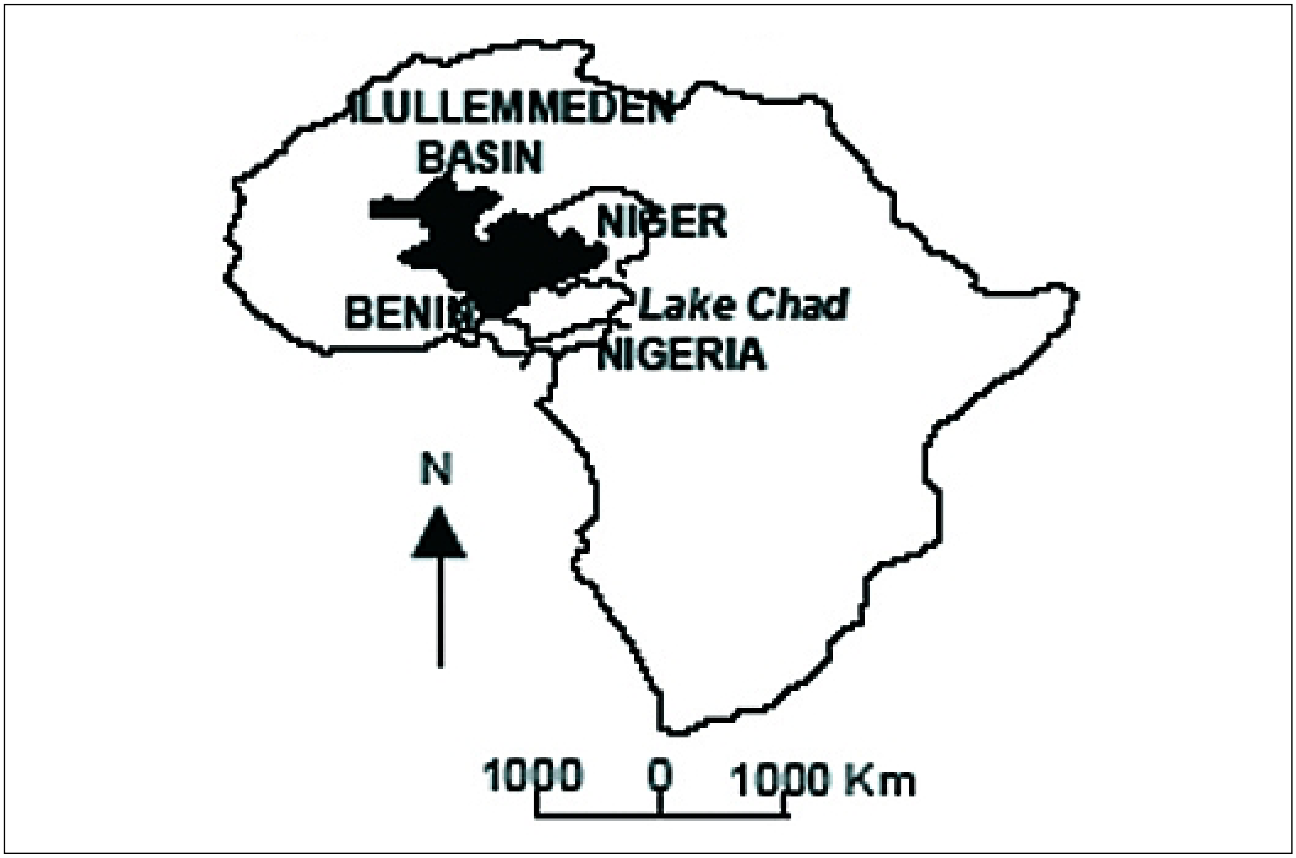

Figure 1. Location map of the Iullemeden Basin.

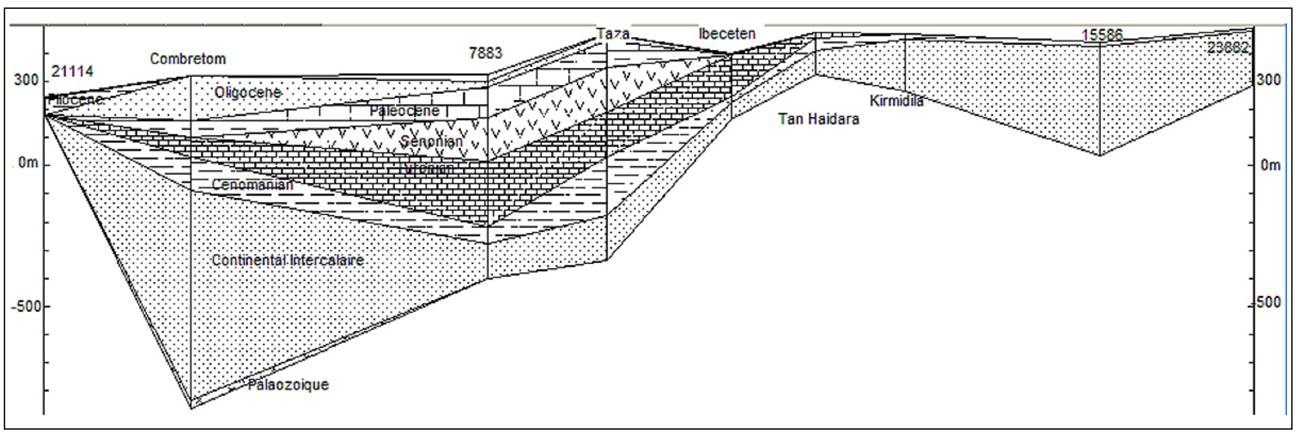

Figure 2. Geologic cross section along Iullemeden Basin.

RESULTS AND DISCUSSION

Altitude and Quantity Effects on Mali Precipitation

The $\delta^{18}O$ value is negatively correlated with the quantity or amount of rainfall in Niamey. The term ‘amount effect’ is ambiguous as it depends on the size of the vapor reservoir and on the condensation process as well as on the amount of rainfall. Total condensation of a small atmospheric vapor reservoir can result in a heavier isotopic composition than condensation of the last portion of a large reservoir, and yet produce the same amount of rainfall. Figure 3 shows that the correlation between $\delta^{18}O$ and the amount of rainfall in Niamey is in the range of 0 to -2‰ per 100 mm of rainfall. This is comparable to the study carried out by the IAEA-WMO network (IAEA, 1992) with a coefficient of determination that exceeds 65%, which is fairly good. On the local

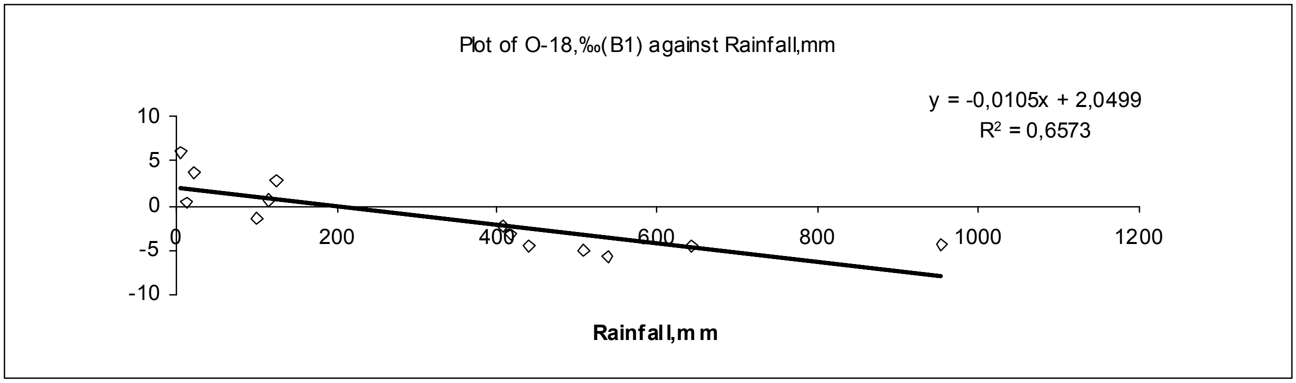

Figure 3. Quantity effect on Mali precipitation.

scale of Niamey precipitation, the lowest $\delta^{18}O$ content is found for the wettest months. The least–squares fit to these data is:

$$\delta^{18}O = (-0.011)P + 2.05 \ (r^2 = 0.66) \tag{1}$$

The altitude effect in Niamey rainfall can best be illustrated by the inspection of Figure 4 where $\delta^{18}O$ values of precipitation at higher altitude generally will be more negative. The gradient in $\delta^{18}O$ is around 1‰ per 100m. The least–squares fit to these data is:

$$\delta^{18}O = (0.015) \text{ altitude in m } -9.96 \tag{2}$$

with coefficient of determination $r^2 = 0.50$.

Temperature Effect

Figure 5 shows that there is no clear dependence of $\delta^{18}O$ in Niamey rainfall on ground temperature. This decoupling of heavy isotope content of rain from ground temperature is clearly evident in this figure and conforms with the findings near the equator and in humid regions with monsoonal climates (Yurtsever et al., 1981).

Niamey Rainfall and Gobal Warming

Niamey rainfall shows that the increase in atmospheric temperature during the years 1993 and 1997 has a corresponding increase in the isotopic contents of $\delta^{18}O$ (Figures 6a and b). Further inspection of the figures shows the isotopic imprint of the observed global warming.

It is evident from Figures 6a and b that the stable isotopic enrichment that occurred during the years 1993 and 1997 is due to the evaporation effect resulting from global warming. Further

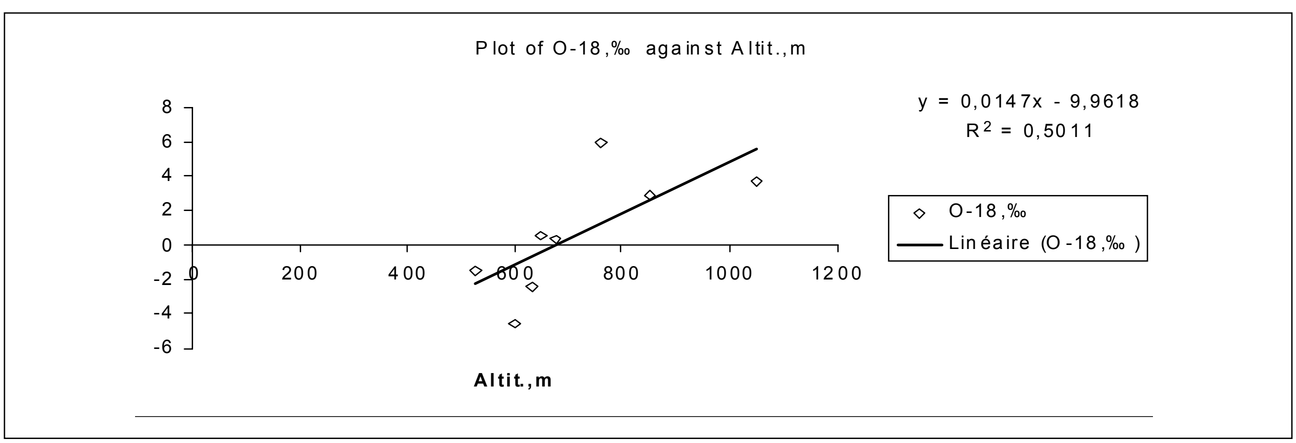

Figure 4. Altitude effect on Niamey rainfall.

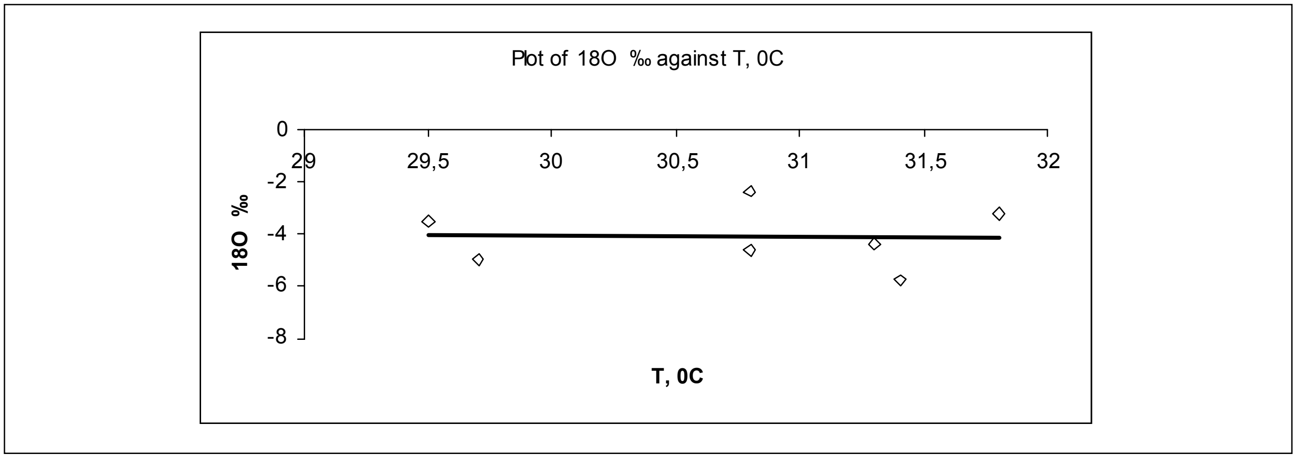

Figure 5. Temperature effect on Niamey rainfall.

inspection of this figure reveals that the rise in ground temperature (2 degrees Celsius) that started in 1995 and ended in 1997 has impacted the enrichment of $\delta^{18}O$ from -5‰ in 1995 to -3‰ in 1997. This situation has been reflected in the isotopic composition of the recharge pulses that occurred during that period.

Isotopic Characteristics of Groundwaters in the Iullemeden Basin

The Iullemeden basin has been subjected to drought in the last years. This situation has led to the excessive use of groundwater.

The isotopic data for the groundwater (JICA, 2000) as well as the surface water and irrigation water from the Sokoto Basin in the northwestern part of Nigeria, which is part of the Iullemeden basin, are shown in Figure 7.

The relationship between $\delta^{18}O$ and $\delta^{2}H$ shows that the Rima River is recharging part of the

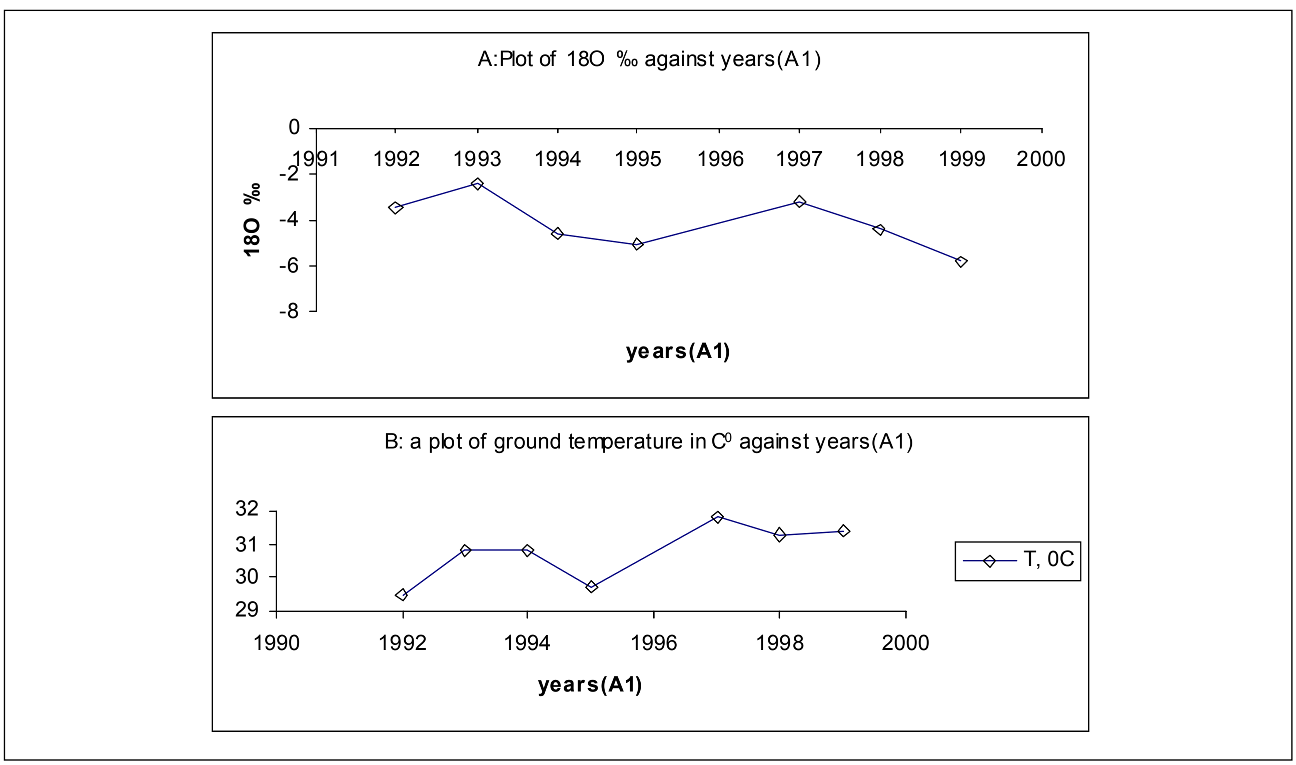

Figure 6. Variation of mean annual $\delta^{18}O$ (A) and mean ground temperature (B).

alluvial aquifer in the Sokoto Basin, while the portion of paleowater related to the Continental Intercalaire receives no recharge. Further inspection of this figure shows that the isotopic variation in the groundwater of the Sokoto Basin may also be controlled by the 'mass effect'. Groundwater originating from lighter precipitation displays a more enriched isotopic composition. The figure also reflects the similarity between irrigation water and both types of modern and paleowater, i.e. the same isotopic signature as the drainage water. The regression line fitting all groundwater samples from the Sokoto Basin in Nigeria is given by the following equation:

$$\delta^2H = (4.78)\delta^{18}O - 9.8 \qquad (r^2 = 0.85 , n =24)$$

This equation defines the local meteoric water line for the Sokoto Basin. It has a slope of 4.7 that is totally different from the slope of 8 of the global meteoric water line estimated by Craig (1961). It agrees with the local line developed by Gallaire et al. (1994) for the Aïr massif rainfall in Niger:

$$\delta^2H = (4.63)\delta^{18}O - 8.19$$

The low slopes (4.7, 4.6) suggest the influence of evaporation on the majority of groundwater resources in the Sokoto Basin.

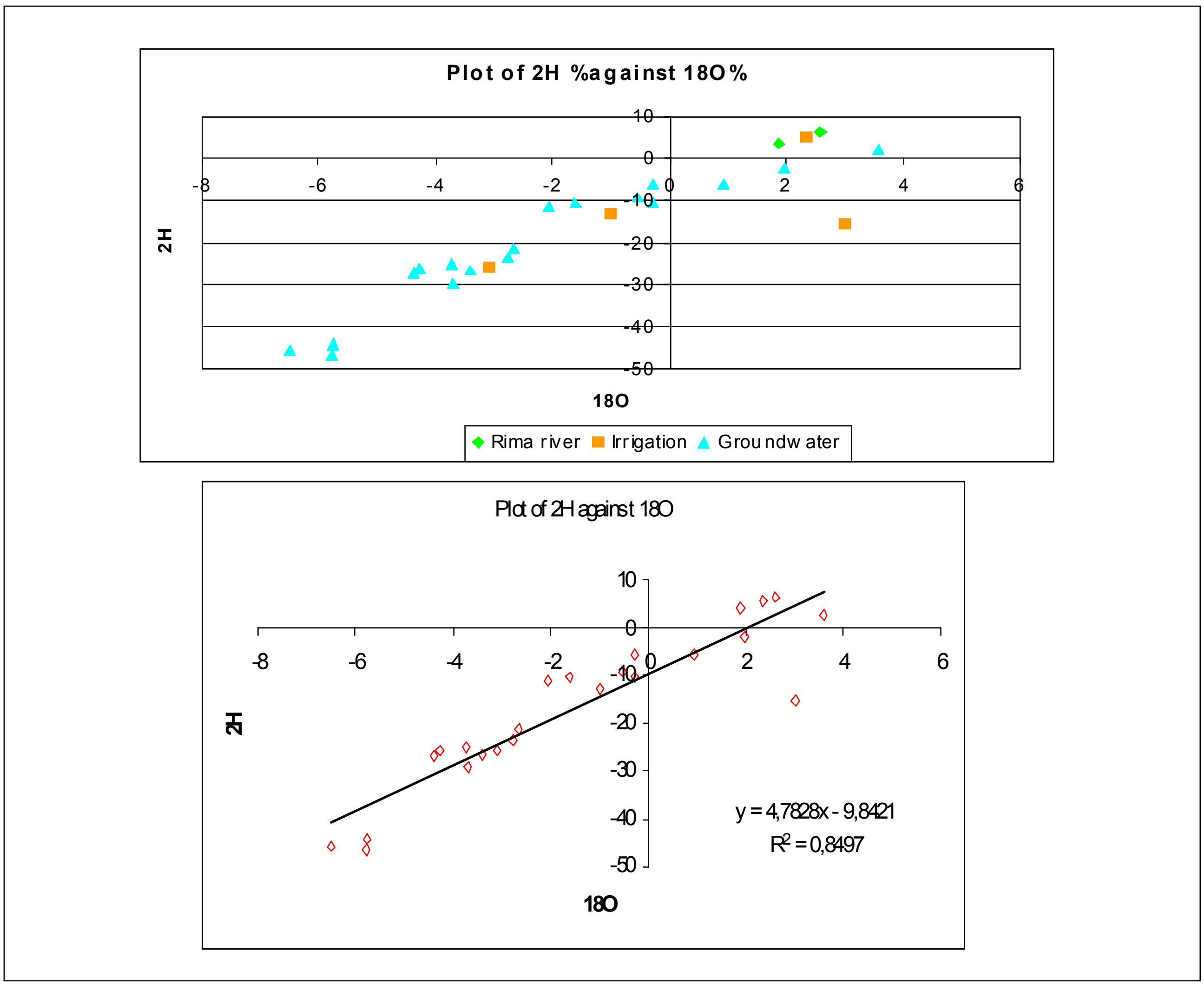

Figure 7. Cross plot of δ^2H versus $\delta^{18}O$ for groundwater, surface water and drainage water in the Sokoto Basin (Iullemeden basin).

CONCLUSIONS

In Niamey rainfall, the isotopic variation of precipitation over the Iullemeden basin has confirmed the effect of rainfall quantity or the "amount effect" as well as the "continental effect". The isotopic signature of the rainfall shows signs of global warming. This is confirmed by the relationship between ground temperature and rainfall isotopic composition. The groundwater of the Iullemeden Basin has shown two major poles; the modern water of Quaternary age and the paleowaters of the Continental Intercalaire and Complex Terminal of Paleocene age. The shallow aquifers in the Iullemeden Basin receive a considerable recharge from the surface water bodies represented by the Rima and Sokoto rivers which discharge to the Niger River.

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