GROUNDWATER VULNERABILITY AND RECHARGE OR PALAEORECHARGE IN THE SOUTHEASTERN CHAD BASIN, CHARI BAGUIRMI AQUIFER

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Abstract

Stable isotopes and major chemical elements have been used to investigate present or ancient groundwater renewal in the multilayered aquifer of the Chari-Baguirmi plain, South of Lake Chad. On the Western side, recharge mainly occurs from the Chari River during the flood period.. Within the Ndjamena area, the rise of the piezometric level in the contaminated subsurface zone provokes an increase in nitrate concentrations. Rainfall recharge is mainly located close to the outcropping basement, *i.e.* on the Eastern side of the area and does not occurs in the central part of the plain where groundwater also presents a stronger evaporative signature. This support the hypothesis attributing a major role to evaporation processes in the formation of piezometric depressions in the Sahel zone. There is no evidence of present day or ancient water recharge from Lake Chad.

1. INTRODUCTION

The aim of the Chari Baguirmi study was, using chemical and isotopic tools, to investigate present or fossil groundwater renewal, and to relate these results with environmental changes in the Southeastern Chad Basin.

A large variety of recharge mechanisms may be involved :

- directly by the rainfall through the soil and the unsaturated zone. In such a case, the recharge is largely influenced by rainfall and evaporation characteristics (quantity, distribution, intensity, etc...), and by the depth of the piezometric level ;
- local recharge of surface runoff, ponds, or through the Chari river-bed;
- recharge by the way of lake or palaeolake, especially in Chad.

The study of these mechanisms can also be of great importance to evaluate the aquifer vulnerability, mainly around the urban centers like N'Djamena.

Two specific zones are concerned :

1. near N'Djamena, for studying the relationships between the Chari River and the shallow groundwater, as well as the implications of the recharge in groundwater pollution ;
2. North and East N'Djamena, across the Chari Baguirmi piezometric depression (Figure 1). The objective is to characterize the recharge and to evaluate the role of the palaeolake related to the recent river water or rain recharge ; the results are also to be used to verify the theory of recharge deficit and evaporative process in the genesis of piezometric depressions.

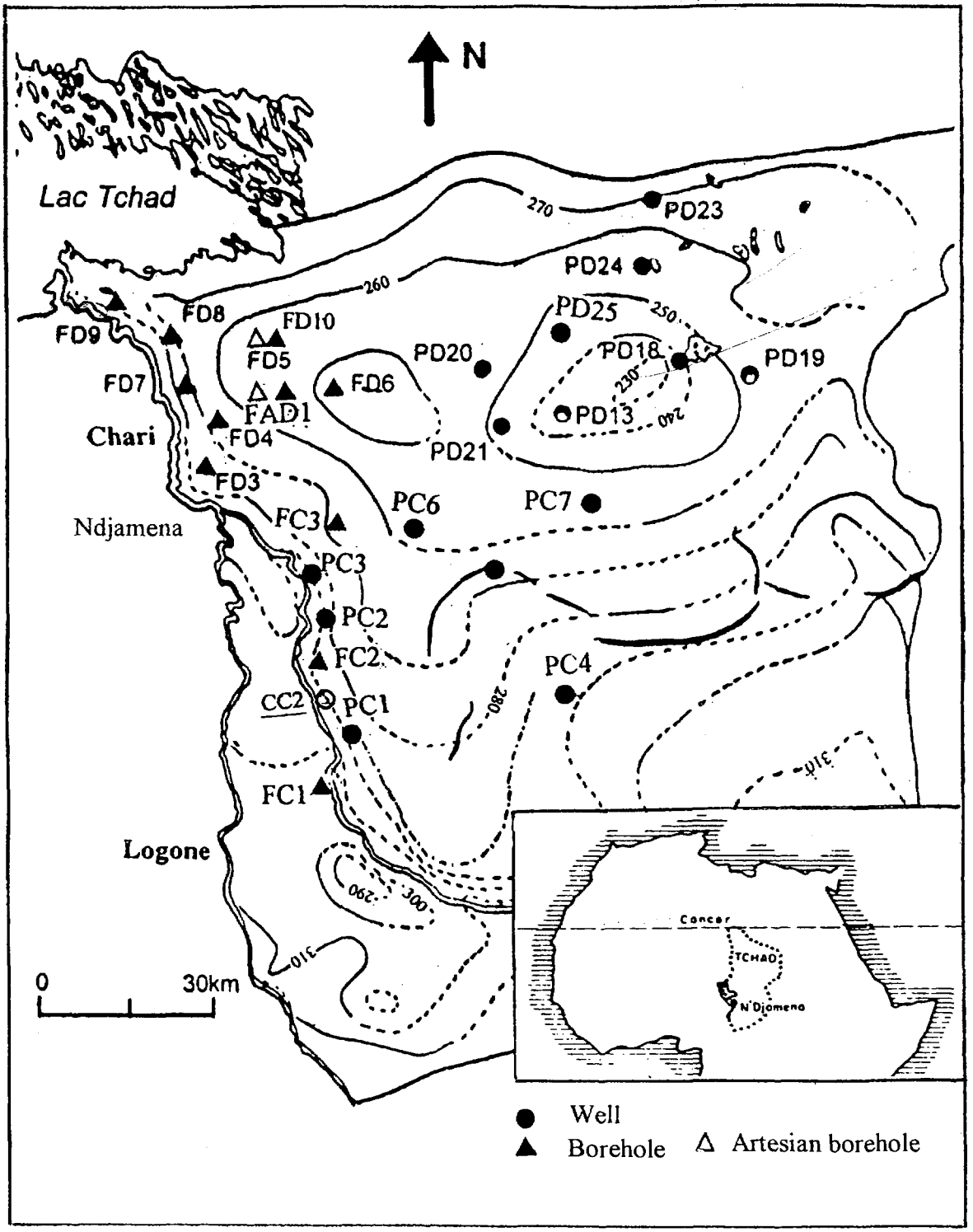

Figure 1 – Sampling sites and piezometric map in the Chari Baguirmi plain

2. METHODS OF INVESTIGATIONS

Hydrogeological and geochemical studies have included stable isotope analysis of rainfall as the input signal to the hydrogeological system. Within the project area, each event was sampled at the airport station of N'Djamena, during the rainy season 1995.

The results have been compared to the isotopic rainfall data obtained from the IAEA Network (IAEA/WMO/GNIP Network, 1998 ; stations of N'Djamena, Kano, Khartoum, Geneina). Hydrochemistry and isotope hydrology have been used to establish the geochemical evolution of groundwater, and relative ages in order to characterize the interconnections between the unconfined groundwater, Chari River, Lake Chad and rainfall. Samples of modern or old shallow groundwater were obtained from traditional wells or boreholes. The sampling campaigns have been carried out every month during a complete hydrological cycle (April 1995 to April 1996). Groundwater samples were taken from traditional wells and boreholes : 12 wells and 2 boreholes in N'Djamena ; 7 wells and 8 boreholes in the Chari Baguirmi plain. Filtered samples were collected ; the sample for anion analysis (250 cm3) was unacidified and that for cation analysis was acidified with nitric acid. Major cations and anions (including bromide) were determined respectively by atomic absorption spectrometry and ionic chromatography at the Avignon laboratory.

At every step of the sampling, *in-situ* measurements of pH, Alkalinity, Electric Conductivity and Temperature were carried out.

3. HYDROLOGICAL AND HYDROGEOLOGICAL SETTINGS

The Chari Baguirmi Basin is limited to the Northwest and to the South by basement rocks, to the West by the Chari River, and to the North by Lake Chad. This basin forms the Southwestern part of the Chad Basin which is filled by continental sediments of Continental Terminal (CT) to Quaternary.

Quaternary deposits consist of clays and sandy loam alluvial deposits, and lacustrine or deltaïc sediments. The thickness varies from 10 to 50 m.

Deep groundwater occurs mainly in the sediments of CT and Lower Pliocene. The CT, composed of clays and sandy clays, has a low permeability compared to that of the Lower Pliocene formation. The latter is confined under 300 m of low permeability sediments (Pliocene) and artesian discharge can occur in the boreholes in the Western part of the basin.

Unconfined and semi-confined groundwater occurs mainly in Quaternary sediments which may form multilayered aquifers and present piezometric depression. This aquifer system presents a great variability in lithology, and as a consequence, transmissivity shows values ranging from 10^{-3} to 10^{-8} m^2s^{-1} (Table 1)

Table 1 Hydrodynamic parameters of the Chari Baguirmi upper aquifer system (From : Artis and Garin, 1991 ; BRGM, 1987 ; Schneider, 1967)

	Discharge $m^3.h^{-1}$	Specific discharge $m^3.h^{-1}.m^{-1}$	Permeability $m^2.s^{-1}$	Transmissivity $m^2.s^{-1}$	Storage coefficient
Old boreholes	0,7 to 108	0,07 to 8,7	1,5 10-3 to 4,7 10-4	$3\ 10^{-4}$ to $7\ 10^{-3}$	$3\ 10^{-3}$ to $5\ 10^{-2}$
Recent boreholes	3,02 to 11,80	0,7 to 14,6		$1,2\ 10^{-3}$ to $2,8\ 10^{-8}$	

It seems that there is a coupling between the hydrogeological systems of the confined and unconfined aquifers, the phreatic shallow aquifer being sustained by the deeper aquifer. The low recharge rate existing since the beginning of the Holocene period has caused the water table to attain depth up to 50 m, and present-day measurements of the piezometric level recorded since 1963 show a continuous decrease. This decline of the piezometric surface represents the depletion from water storage from a wetter climatic period.

All the hydrogeological data have been recently compiled by Schneider and Wolff (1992). In the Northeast part of the lake, there is evidence of very low recent recharge : isotopic data have been interpreted as a mixing between old evaporated lacustrine water and modern recharge (Fontes *et al.*, 1970). Considering the structure and the depth of piezometric levels, present-day and old recharge could preferentially occurred to the East of the area where the basement outcrops, to the West from the Chari River, and to the North from the lake.

During Holocene humid spells, the levels of Lake Chad were probably some 40 m higher than today. During the wettest periods (around 8 000 and 6 000 yr B.P. ; Servant, 1983), Lake Chad or flooding systems covered the main part of the Chari Baguirmi plain and could have constituted an important source for aquifer recharge

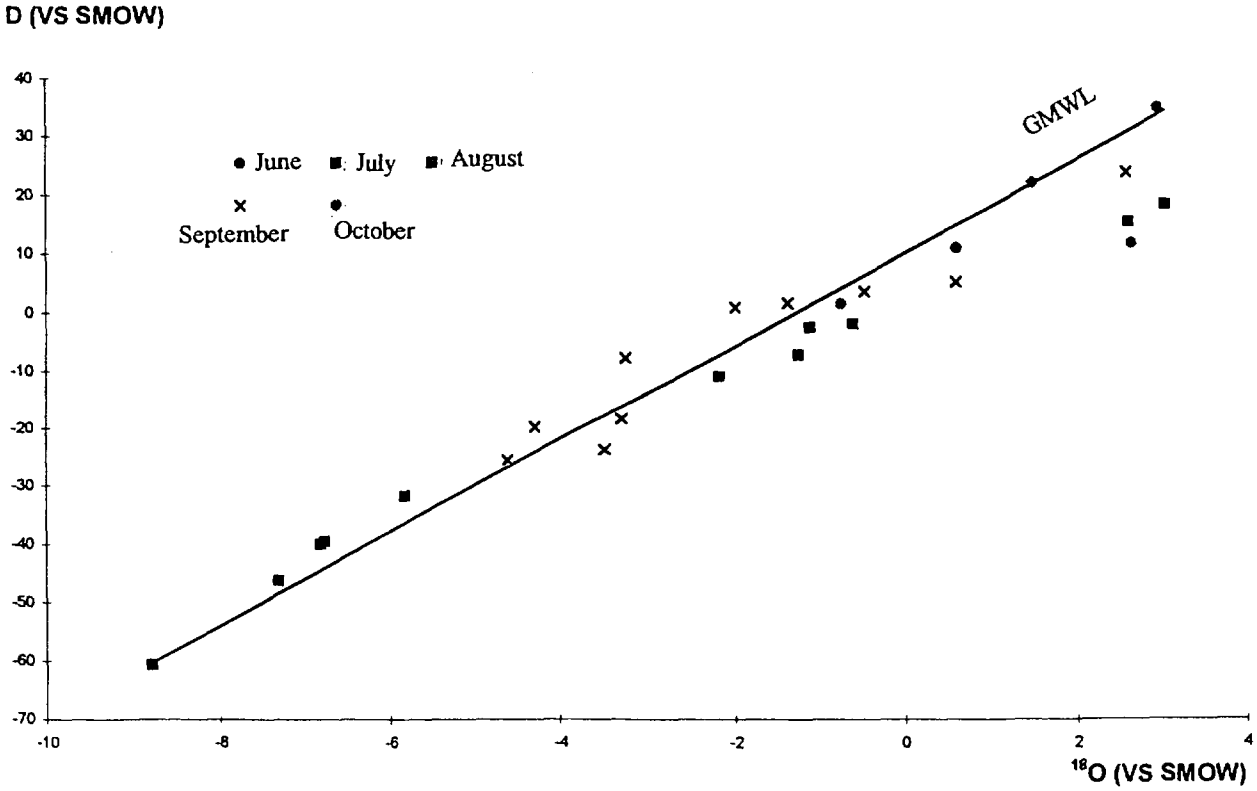

Figure 2 - Relation between ^{18}O and ^{2}H of the rainfall (rainy season 1995)

4. RESULTS AND INTERPRETATION

Up to date, all ^{14}C analyses on groundwater are not still available. As a consequence, only provisional interpretations may be provided on the Chari Baguirmi plain. The main results can be summarize as follows :

- The rainfall signal has been well defined during the rainy season ; the isotopic composition of precipitation is well correlated with the monsoon mechanisms (Figure 2). Relative positive values are observed at the beginning of the rainy season with some evaporated waters while more depleted values occur at the end of July, during August and the beginning of September. Then, non-evaporated rain water is characterized by more positive values. Similar results have been observed in Senegal some years ago (Travi *et al.*, 1993). Considering the $\delta^{18}O$ weighted mean value and IAEA data, we can consider that the present-day rainfall signal value ranges between -5 and -6 ‰ *vs* SMOW.

- Groundwater hydrochemical data plotted on a Piper diagram show water evolving from Ca-Mg-HCO_3-dominated fresh water near the Chari River and the Eastern border, to higher alkaline $NaCO_3Cl$ or $NaCO_3$-SO_4-dominated more saline water in the Northern and central parts of the Chari-Baguirmi plain. This chemical evolution suggests a modern recharge on the two sides of the plain (East and West), whereas very few recharge is evidenced in the area of the piezometric depression zone.

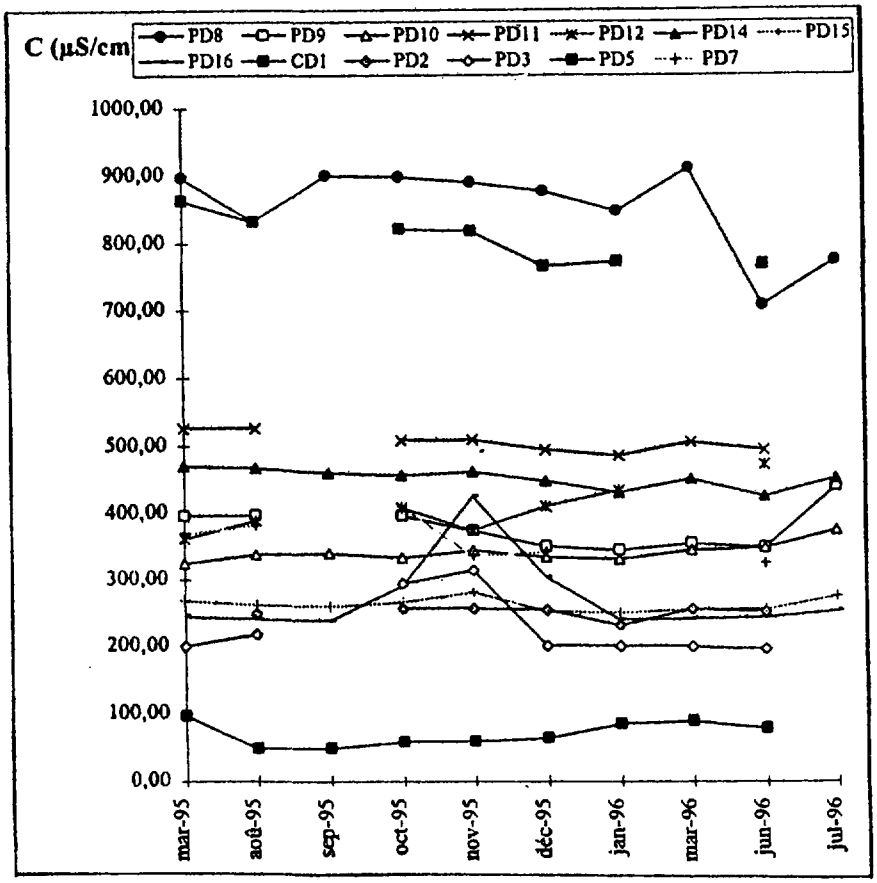

Figure 3 - Conductivity response pattern of wells and boreholes near NDjamena

- Near N'Djamena, the Electric Conductivity which was used as a general marker of groundwater hydrochemistry, coupled with ^{18}O measurements along two profiles show evidence of replenishment of the aquifer from the Chari River during flood periods (Figure 3 and 4) : conductivity is increasing with the distance from the river and $\delta^{18}O$ contents of samples taken from most of the wells correspond to the Chari River values during floods. The two peaks in conductivity observed in Figure 3 are related to nitrate contamination occurring during the flood period due to the rise of piezometric level in the contaminated subsurface zone (latrines and waste deposits). This is confirmed by the evolution of annual nitrate contents. The concentration of nitrate across the area is variable, and ranges from 5 to 150 $mg.l^{-1}$., the higher values being observed at the end of the flood period when the piezometric level reaches its maximum.

- All along the Western border of the plain, the oxygen- 18 contents close to -3 ‰ confirm the annual recharge from the Chari River during flood period (October and November).

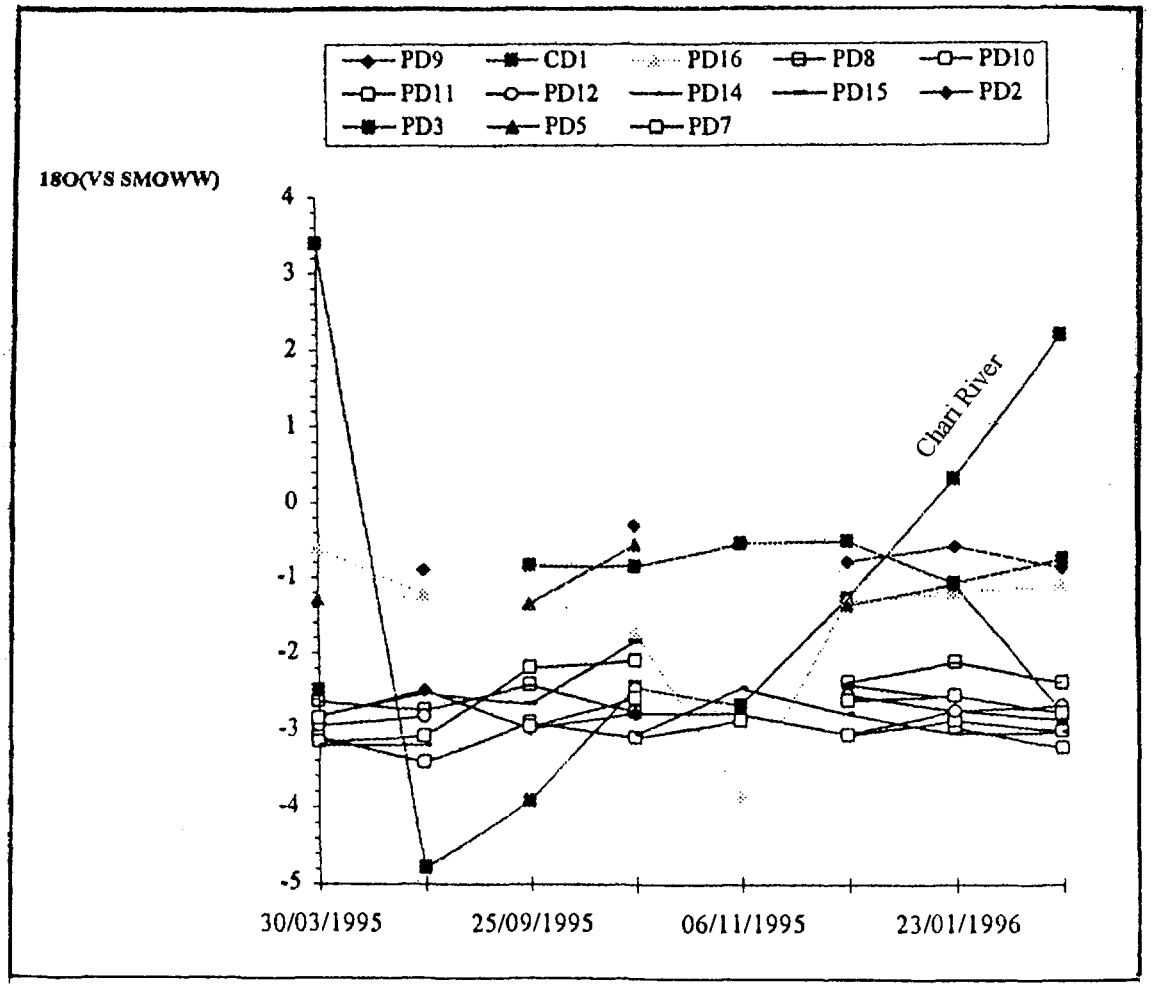

Figure 4 - Isotopic response pattern of Chari River and groundwater near NDjamena

- On a ^{2}H versus ^{18}O diagram almost all of the groundwater have isotopic composition which lies below the Global Meteoric Water Line (GMWL) (Figure 5). Recharge from rainfall occurs, to the East, near the outcropping basement ; this recharge is characterized by an evaporative line which intersects the GMWL between — 4 and – 5 ‰ vs SMOW, for ^{18}O. Samples taken from the central part of the plain near the piezometric depression (PD24, PD23,PD13,FD11) fall on an evaporation line with its origin close to more depleted values (probably older rainfall episodes in agreement with preliminary tritium results) and show a stronger evaporative signature. This could support the hypothesis attributing major importance to evaporation processes in the formation of the regional piezometric depressions in West Africa (Ndiaye *et al.*, 1993). But an age gradient between the East side and the middle of the depression has to be confirmed by expected ^{14}C values.

- There is no evidence of direct recharge in the Center part of the plain coming from rainfall or from present or ancient lake water.

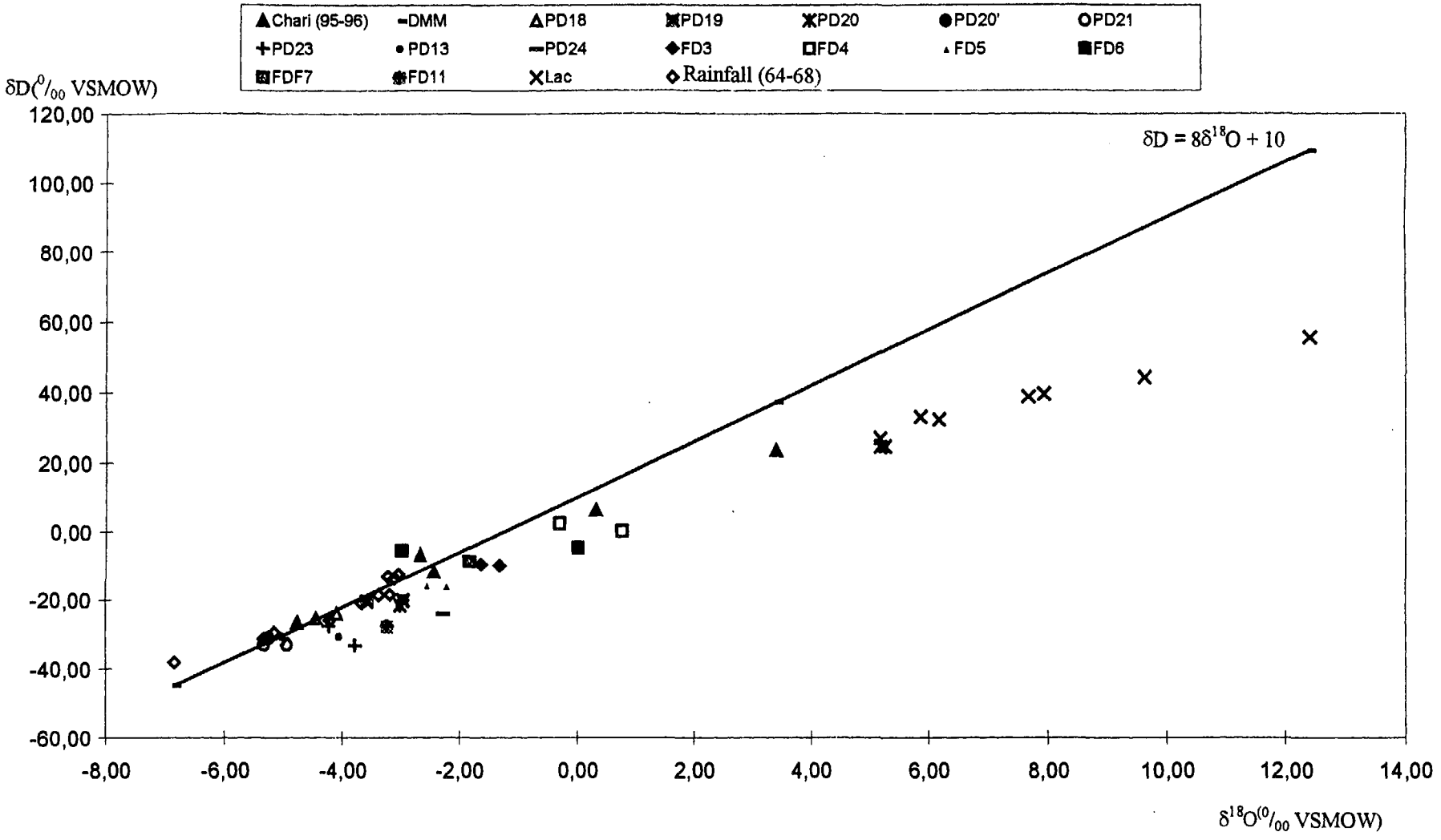

Figure 5 - Relation between ^{18}O and ^{2}H of rainfall at Ndjamena (64-71), Chari River (95-96) and Lake Chad (1967)

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