

## RECHARGE OF THE PHREATIC AQUIFER IN THE NORTHWESTERN LAKE CHAD BASIN (NIGER)

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**ABSTRACT** The phreatic aquifer of the Lake Chad basin in Niger spreads over more than 300,000 km<sup>2</sup> and constitutes a huge groundwater resource. In spite of the arid climate, it is primarily recharged by slight rainfall infiltration and from the Komadougou Yobe, the only river in the region. Smaller contributions can come from surrounding aquifers, Lake Chad and the Pliocene artesian aquifer below. According to numerical modelling of the aquifer south of the parallel 17° N, the average of effective infiltration over the whole area is less than 1 mm per year, with annual rainfall varying between 10 and 350 mm. Hydrochemical and isotopic measurements confirm the existence of poor recent infiltration.

### INTRODUCTION

The Chad basin extends over a huge area (2 millions of km<sup>2</sup>), from which about a quarter is situated in Niger. The main part is centred on Lake Chad and the rest is composed by secondary endoreic basins. In Niger, the Lake Chad basin is divided into three departments (Agadez, Diffa and Zinder). Because of the Saharan climate in the northern part of the basin, the information available north of the parallel 17° N is very scarce. This paper is therefore devoted to the phreatic aquifer in the department of Diffa.

As the region is very broad, sparsely populated and distant from the capital of Niger, it does not contain much hydraulic equipment. Hydrological and hydrogeological data are rare and often poorly reliable. Early hydrogeological studies date from the 1960s and 1970s. More recent information has been collected and synthesized only in 1990 (PNUD, 1991).

Above the granite basement, outcropping in the western border, the thickness of Mesozoic and Cainozoic sediments is rapidly increasing towards the rift axis, where it reaches 10,000 m. Quaternary sand and silt, containing the phreatic aquifer, can exceed 100 m in depth (Fig. 1). They consist of alluvial, eolian and lacustrine deposits (Durand et al., 1984).

The drainage pattern is limited :

- the Komadougou Yobe, an impermanent river without any tributary in Niger and whose flow decreases downstream,
- the northern basin of Lake Chad, dried up since 1988,
- small temporary pools in topographic hollows in the southwest near Nigeria:

The phreatic aquifer, extending continuously towards Chad and Nigeria, has gentle hydraulic gradient (0.01 to 0.25 %) ; generally, groundwater flows converge on Lake Chad. A hydrogeological peculiarity is the Kadzell piezometric depression where the water table is 40 m lower in the centre than along the borders.

Mineralization in the phreatic aquifer is often low ( $100$  to  $400 \mu\text{S}\cdot\text{cm}^{-1}$ ) but can reach up to  $5000 \mu\text{S}\cdot\text{cm}^{-1}$  in areas of high evaporation (Lake Chad basin, topographic hollows with shallow water) where there is a large variability in time and space. From north to south, the hydrochemical facies is sulphate-sodium, bicarbonate-sodium and bicarbonate-calcium.

The population, of approximately 200,000 inhabitants, is concentrated in a small southern belt. North of the parallel  $14^{\circ}30' \text{N}$ , the density is  $0.06$  inhabitant/ $\text{km}^2$ .

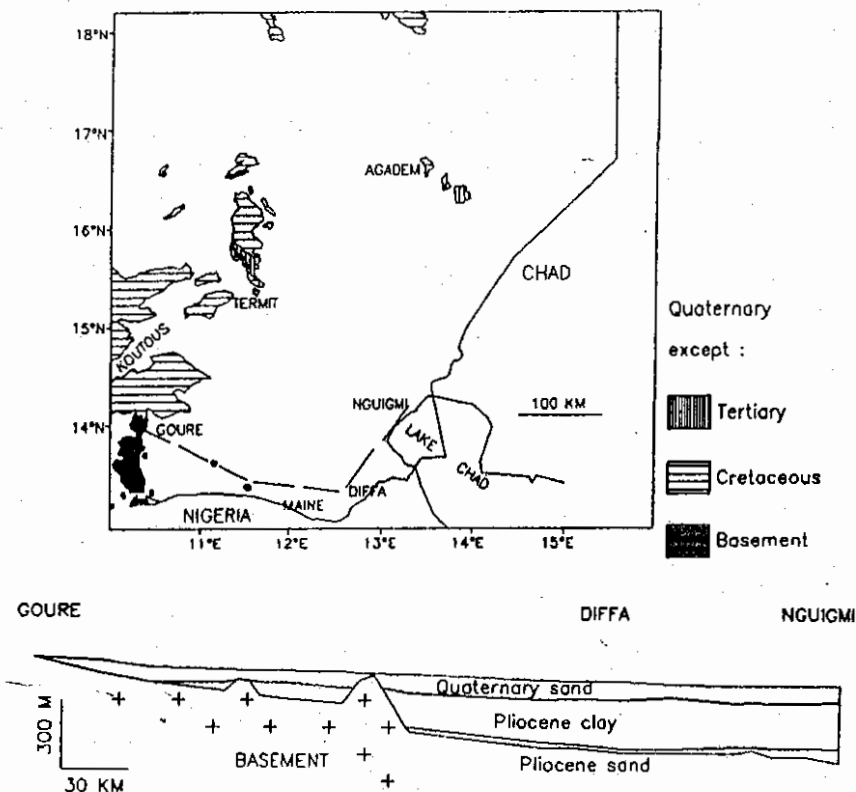


Fig. 1 Geological framework of the Lake Chad basin in Niger and section in the southern belt of the basin

## RAINFALL INFILTRATION

The Sahelian climate is characterized by a short rainy season restricted to the summer months. The annual rainfall decreases from south to north and, to a lesser extent, from west to east. The average annual rainfall from 1953-1988 varies between 10 and 350 mm. South of parallel 14° N, there were 20 to 37 rainy days per year and 6 to 12 days per year with rainfall exceeding 10 mm for the same period. In the southern belt, Nguigmi and Maïné-Soroa are representative of extreme values (Fig. 2). The 1970s and 1980s have been much drier, inducing a clear movement of isohyets southwards. Average of 1980-1988 in Figure 3 shows this aggravation.

A simple calculation is made using daily data from the five oldest meteorological stations (27 to 67 years). A storage model represents the soil as a single tank; the variations of water content are due to rain, evaporation and infiltration. It does not consider the plant transpiration and the delayed evaporation after the end of the rainy season. With a soil storage of 75 mm and a daily evapotranspiration of 6 mm, there is no infiltration at all two years out of three; the average infiltration is between 11 and 23 mm per year, i.e. about 5 % of the annual rainfall. This rough evaluation, available for the "humid" southern belt, constitutes an upper limit. The real infiltration is probably far less.

In the extreme west of Niger, a detailed survey of recharge to the phreatic aquifer indicates an infiltration of between 5 and 10 % of the annual rainfall (Leduc and Desconnets, 1994). This ratio is assessed in a Sahelian zone more propitious to infiltration (rainfall about 500 mm per year, more pronounced topography which favours the concentration of surface runoff). Infiltration across the Lake Chad basin in Niger is therefore much more limited than this evaluation suggests.

Rainfall infiltration can also be estimated from piezometric fluctuations in the phreatic aquifer. There are only two areas where the annual variation of the water level is significant: along the Komadougou Yobe (up to 2 m, see below) and west of Maïné-Soroa where groundwater is shallow in the centre of many small endoreic basins (0.5 to 1 m). Outside these regions, the piezometric stability throughout the year confirms the extreme weakness of infiltration, even in the south. However, a groundwater recharge exists: water in the aquifer is essentially old but a recent inflow is obvious in some isotopic analyses (PNUD-UNESCO-CBLT, 1972; Chouret et al., 1977; Roche, 1980).

Despite the scarcity of data, especially from the north, a numerical modelling of the phreatic aquifer up to the parallel 17° N has been carried out. The most judicious calibration implies an average infiltrating flow of about 0.3 mm per year (Leduc, 1994). This inflow is in fact the resultant of real infiltration and evapotranspiration. A similar piezometric reconstitution could be obtained with increased rain infiltration (0.5 mm per year instead of 0.3) and increased permeability (nearly twice more), larger than ground values but still acceptable. On the other hand, an effective rain recharge of 2 to 4 mm per year is completely excessive.

The Kadzell piezometric depression can only be explained by an evapotranspiration larger than infiltration and a very low permeability; vertical flows surpass horizontal circulation. The clayey soils in this region prevent infiltration during the rainy season. Even if the water table is deep, an infinitesimal evaporation can exist; the numerical modelling estimates it at about 0.1 mm per year.

Other piezometric depressions in West Africa have already been explained in a like manner (Aranyossi & Guerre, 1990).

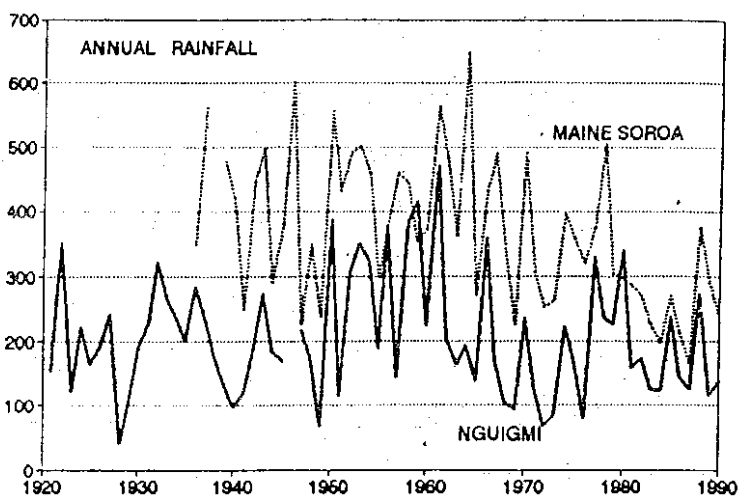


Fig. 2 Annual rainfall in Maine-Soroa and Nguigmi

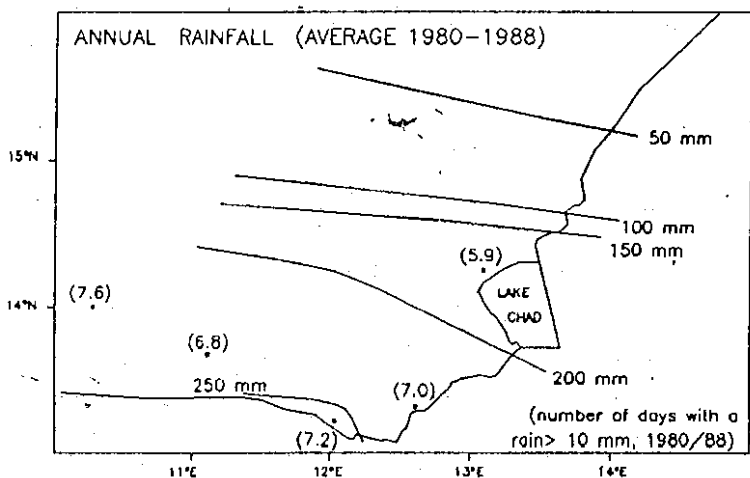


Fig. 3 Rainfall characteristics for 1980-1988

## RECHARGE FROM LAKE CHAD

Lake Chad is divided in two basins. The northern one is fed only by the Komadougou Yobe and the overflow from the southern basin. The lowering of the level in the southern lake causes the partial or total drying up of the northern basin. The northern lake had completely disappeared in 1908 ; it is permanently dried up since 1988.

The reconstituted lake level during this century has fluctuated between 278 and 284 m. It is often higher than the phreatic surface. Therefore, in spite of the probable low permeability of clay in its bed, Lake Chad plays a prominent role in regional hydrogeology. Even if more than 90 % of the lake water evaporates, the small percentage available for infiltration is very important to groundwater flow ; Carmouze (1976) estimates it at about  $4 \cdot 10^9 \text{ m}^3$  per year for a mean level of the lake.

In Niger, two zones appear on the 1991 piezometric map (Fig. 4) :

- the northern zone where the piezometric head is close to or higher than the lake level ; groundwater flows from the northwest to the lake ;
- the western zone where the piezometric head is lower than the lake level (up to 30 m in the centre of the Kadzell piezometric depression).

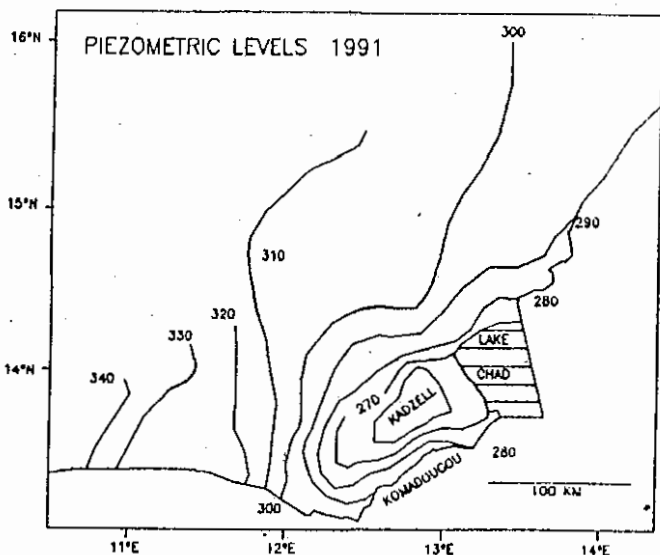


Fig. 4 Piezometric map of the phreatic aquifer



## RECHARGE FROM OTHER AQUIFERS

The Quaternary aquifer is recharged by three surrounding massifs of Cretaceous sandstone (from northwest to northeast Koutous, Tenuit and Agadem). Similarly, the aquifer of Plio-quaternary sand and gravel filling the north of the rift discharges towards the studied area. It is difficult to evaluate these contributions because there are very few wells, sometimes dried up, altitudes are approximate, hydrodynamic characteristics are unknown and no spring has ever been measured.

Except for the western border where Quaternary sediments directly overlap the granitic basement, the bottom of the phreatic aquifer in the south is a sequence of Pliocene clay (up to 200 m thick). Below this impervious layer, Pliocene sand contain an artesian aquifer. To the north, clay becomes gradually thinner until the two aquifers join together. When they are separate, the Pliocene head is always higher than the Quaternary head (up to 50 m in the centre of the Kadzell piezometric depression). In spite of such a difference and the large area of contact involved, leakage through the semi-pervious formation must be limited by the very low vertical permeability of Pliocene clay.

A second type of exchange between Pliocene and Quaternary aquifers is the free flowing of artesian boreholes which constitute permanent pools.

## WATER BALANCE

A preliminary estimate of the water balance can be proposed in spite of the numerous and large uncertainties surrounding each term. In some cases, the advanced value could be divided or multiplied by ten. Volumes are calculated using different methods when circumstances permit.

### *Estimates based on ground data*

Main inflow to the phreatic aquifer, the rain infiltration is less than 5 % of the annual rainfall, i.e. less than  $800 \cdot 10^6 \text{ m}^3$  per year over the southernmost  $140,000 \text{ km}^2$ . We have no idea of the actual value of the effective infiltration, which must be much lower than this limit.

The calculation of leakage from Pliocene is hazardous as no vertical permeability can be measured (the chosen value,  $5 \cdot 10^{-11} \text{ m.s}^{-1}$ , is very hypothetical). It is probably between 0 and  $4 \cdot 10^6 \text{ m}^3$  per year, subject to substantial uncertainty. The free flow of artesian boreholes gives between  $0.5 \cdot 10^6$  and  $10^6 \text{ m}^3$  per year to the phreatic aquifer ; this amount is reliable. Contributions from other surrounding aquifers are estimated from hydraulic gradients at less than 3 millions of  $\text{m}^3$  per year, with large uncertainty.

Recharge from Komadougou Yobe is probably between 12 and  $20 \cdot 10^6 \text{ m}^3$  per year.

Outflow is shared out between evaporation, human activities and natural groundwater flow to the phreatic aquifer in Chad. This natural flow to the aquifer in Chad, estimated from hydraulic gradients, is about  $2 \cdot 10^6 \text{ m}^3$  per year ; the accuracy of this calculation, analogous to the evaluation of recharge from surrounding aquifers, is poor.

The water demand for human activities is much more precise. It consists of :

- cattle watering ( $9 \cdot 10^6 \text{ m}^3$  per year),
- irrigation ( $4.5 \cdot 10^6 \text{ m}^3$  per year),
- village consumption ( $1.5 \cdot 10^6 \text{ m}^3$  per year).

A significant portion of this water demand, approximately one third, is met for surface water (the Komadougou Yobe and small temporary pools) during the rainy season. The rest comes from the phreatic aquifer.

The major part of the outflow is due to evapotranspiration, which has never been measured. Over most of the aquifer, the interesting term for the water balance is not the real evaporation but the effective infiltration. In the Kadzell depression and the bed of Lake Chad, evaporation is higher than infiltration. Due to the depth of the water table, evaporation in Kadzell cannot exceed 1 mm per year ( $10^7 \text{ m}^3$  per year). On the contrary, the uncertainty about evaporation in the dried up Lake Chad is very large: 1 mm to 1 m ( $3.5$  to  $3500 \cdot 10^6 \text{ m}^3$  per year).

The accuracy of these different estimates is highly variable. Unfortunately, the predominant flows (rain infiltration and evaporation) are the less well known. The water balance is therefore very imprecise.

#### *Estimates based on numerical modelling*

Numerical modelling uses these elementary evaluations to check their coherence. Given the present information, the chosen calibration seems to be reasonable, even if many values of flow used in the model are lower than the previous estimates based on ground data. They could be increased but this implies an increase of permeability when medians of transmissivity in the present calibration and in situ are very close together ( $7 \cdot 10^{-3}$  and  $5 \cdot 10^{-3} \text{ m}^2 \cdot \text{s}^{-1}$  respectively). Annual amounts detailed below are results from the numerical modelling of  $140,000 \text{ km}^2$  south of parallel  $16^\circ 30' \text{ N}$ .

Inflow into the phreatic aquifer is distributed among :

- approximately  $35 \cdot 10^6 \text{ m}^3$  per year from effective rain infiltration over the entire aquifer except in Kadzell and Lake Chad where evaporation prevails,
- $6.5 \cdot 10^6 \text{ m}^3$  per year from the Komadougou Yobe,
- $2.5 \cdot 10^6 \text{ m}^3$  per year from surrounding aquifers.

Annual outflow from the aquifer is :

- $12 \cdot 10^6 \text{ m}^3$  from human activities (man, cattle and irrigation),
- $2.5 \cdot 10^6 \text{ m}^3$  from natural flow to the phreatic aquifer in Chad,
- $1 \cdot 10^6 \text{ m}^3$  from evaporation in the Kadzell depression (i.e. 0.1 mm per year),
- $26 \cdot 10^6 \text{ m}^3$  for evaporation in the Lake Chad bed (i.e. 7.3 mm per year).

In fact, input and output flows of a grid cell could be modified simultaneously without changing their sum. The groundwater balance based on the model is therefore to be considered globally. For example, the value in the centre of Kadzell is the resultant of three very weak phenomena : evaporation, leakage from Pliocene and rain infiltration. Out of them, none can be measured directly. Similarly, the estimate of effective rain infiltration in the model does not reveal the real values of evaporation and infiltration.



### *Comparison of withdrawal and resources*

Whatever the calculation, the total effective inflow seems to be less than 100 millions of m<sup>3</sup> per year. The groundwater resources available in the southernmost 140,000 km<sup>2</sup> can be approximated at 500 billions of m<sup>3</sup> with average values of porosity (10 %) and saturated height (35 m). Even with so many uncertainties in the calculations, the effective recharge is very limited compared to the huge resources.

For the groundwater management, the extreme weakness of replenishment is not problematic with regards to the slight pumpings. The water demand will therefore be satisfied for many decades. Nevertheless, attention must be paid to the sound use of Komadougou Yobe, which significantly supplies the southern part of the phreatic aquifer.

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