POOLS AND RECHARGE OF THE CONTINENTAL TERMINAL PHREATIC AQUIFER NEAR NIAMEY, NIGER

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ABSTRACT In the study area, representative of the Sahelian environment near Niamey (Niger), small endoreic pools play a major role in the aquifer recharge. Three sites are chosen to illustrate the heterogeneity of pool-groundwater relationships. Infiltration (up to 300,000 m^3 per day in the largest pool) is primarily controlled by the pedological nature of the pool bottom. Evaporation is much lower than infiltration. Most of the water accumulated in the temporary pools contributes to the recharge of Continental Terminal. The rapid response of the phreatic aquifer can exceed several metres. Its amplitude depends on local hydrodynamic characteristics, inflow and the distance from the pool. It can also vary with the moisture content of the unsaturated zone.

BACKGROUND

Estimates of groundwater recharge in the Sahel vary greatly depending on authors, methods and regions. Based on a regular monitoring of 60 pools and 250 wells, our three year survey focuses on the evaluation of the rain infiltration towards the Continental Terminal phreatic aquifer near Niamey, Niger.

The study area of Hapex-Sahel (Hydrologic Atmospheric Pilot Experiment in the Sahel) is limited by the parallels 13°N and 14°N and the meridians 2°E and 3°E. Our survey has been restricted to the part north of River Niger, i.e. about 8000 km^2.

Surface

In a flat landscape of more or less eroded lateritic plateaux, the recent geodynamic evolution has degraded the old drainage network into numerous small endoreic systems. During the short rainy season (June to September), surface runoff concentrates in temporary pools.

According to geomorphologic and hydrological criteria, pools of the Hapex-Sahel area are classified into three groups : pools on lateritic plateaux, pools in valley bottoms closed by dunes and pools of fossil river beds (Desconnets et al., 1993).

The obvious correlation between variations in the pool and aquifer levels indicates a massive infiltration under the pools. This is the primary process of aquifer recharge. The three pools detailed below (Samadey, Wankama and Banizoumbou) illustrate a part of the variability of recharge processes.

The three sites are close together (10 km between Samadey and Banizoumbou or Wankama). The pools are located in valley bottoms. Therefore, they represent only a part of the variability of pools and aquifer in the region surrounding Niamey. Observations relative to lateritic plateaux are detailed elsewhere (Desconnets et al., 1993).

The maxima of rainfall in August coincide with the largest volumes in the pools.

Groundwater

Continental Terminal is an accumulation of late Tertiary tabular detrital sediments, mainly composed of sand and silt with lateritic layers. On the western border of the study area, Continental Terminal is thin and directly overlaps the granitic basement. Eastwards, Continental Terminal becomes thicker and two or three different aquifers can be differentiated ; its bottom is older continental deposits.

Inside the Hapex Sahel degree square, two regions can be identified in the phreatic aquifer. In a small northwestern portion, the piezometric level is highly variable in time and space ; the mineralization also changes across very short distances, which indicates possible leakage with a deeper aquifer. The rest of the study area is more homogeneous : hydraulic gradients are weak even when piezometric mound and depression exist ; electrical conductivity of the water is low (median less than 100 $\mu S.cm^{-1}$).

The highest levels in the phreatic aquifer near the pools are observed in August, i.e. when pools reach their maximum volumes. Maxima in the aquifer farther away from the pools are variable (August until December). With the exception of areas very close to the pools, the phreatic surface has low natural fluctuations throughout the year : the median is about 60 cm in 1992 for the entire Hapex Sahel degree square. Very close to the pools, it can sometimes reach several metres, up to 9 m (Leduc and Lenoir, 1994).

The three sites are situated in a very uniform area, one of the lowest piezometric zones of the phreatic aquifer. The hydraulic gradient is less than $4\ 10^{-4}$. The median fluctuation of the water level is 40 cm in 1992.

Periods of interest

The three pools have been studied on different scales depending on the rapidity of infiltration processes : two days for Samadey (19-20/7/93), a significant part of the rainy season (1993 in Wankama) and almost the whole year for Banizoumbou (1992).

BANIZOUMBOU

The pool

Banizoumbou is one of the numerous temporary pools appearing in the rainy season in the meanders of the "kori" (river) of Dantiandou, a fossil valley partially filled with eolian sands. This kori is still active only for short periods and small lengths. The drainage basin has an area of 0.6 km^2 and the pool extends over several thousands of square metres. A heterogeneous deposit of impervious clay lies at the bottom of the pool and holds water several months after the rains stop (fig. 1).

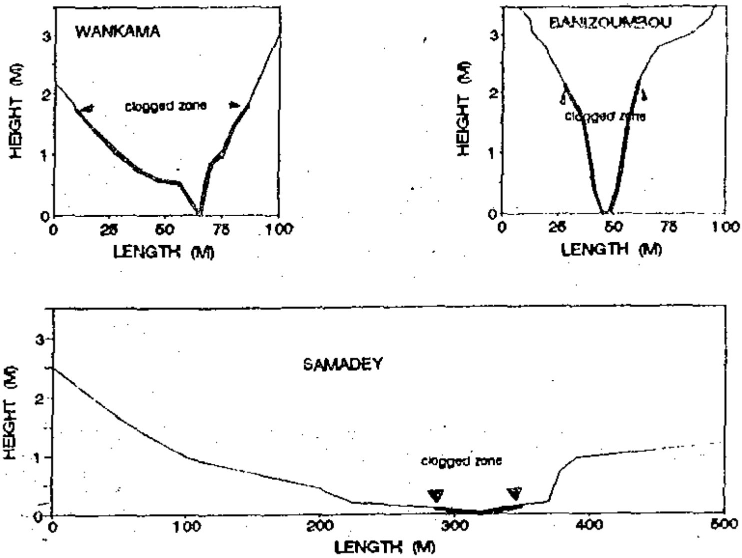

Fig. 1 NE-SW cross sections of the pools

The aquifer

The piezometric network is composed of two wells in the village and two piezometers close to the pool. The distance from the pool is 750 and 550 m for the two wells and 120 and 50 m for the two piezometers. The four points are approximately aligned.

The farther well has been monitored monthly since 1987 ; the other one has been surveyed about 8 times a year in 1992 and 1993. The farther piezometer has an automatic level recorder providing data every 15 minutes since October 1990 ; the closer was bored in June 1993 and has been irregularly observed. The pool floods have been measured once or twice a week in 1992 and almost daily in 1993. In 1994, the variations in the pool and the two piezometers will be registered automatically.

The interannual regular rise of the groundwater level is 10 cm per year in the village. After filtering this long-term evolution and perturbations due to pumpings, annual amplitude disappears. The impact of the recharge is then indiscernible 500 m away from the pool.

Results

As piezometric variations in the two wells of the village are not significant, recharge can be studied with the only piezometer available in 1992 (Fig. 2). Before the middle of July, the aquifer level decreases regularly ; the first small flood in June has no influence at all. Floods in the end of July and the beginning of August have very limited impact : until 30/8, the increase is about 10

The piezometric network consists of three piezometers close to the monitored pool (30, 80 and 180 m) and two wells near a second pool (5 and 500 m). The two wells have been monitored weekly during 1993. Automatic recorders test the groundwater levels of the two piezometers close to the pool and of the pool itself. Soil humidity has also been surveyed in the rainy season. For 1993, the annual piezometric fluctuation is 3.1 and 1.5 m in the two wells (3.4 and 2.7 respectively in 1992) and 5.4, 4.4 and 2.8 m in the three piezometers.

The electrical conductivity of groundwater varies between 600 and 900 $\mu S.cm^{-1}$ in the well closer to the pool and 320 in the other one. For surface water, it is less than 100 $\mu S.cm^{-1}$ in the first pool and between 200 and 1000 in the second one. The high mineralization in the second pool and its close well is due to the artificial contamination from CT1. The variation of electrical conductivity throughout the rainy season depends on the relative inflows from the artesian borehole and from the surface runoff.

Results

In 1993, the aquifer level in the three piezometers and in the two wells has been unchanged until 21/7. The first floods of the pool (14/6 and 16/6) had no effect on groundwater (Fig. 3). The following floods were barely perceptible (less than 10 cm per flood) until 13/8/93 when the groundwater level rose significantly (45 cm on 14/8, 3.2 m on 22/8, 2.5 m on 3/9).

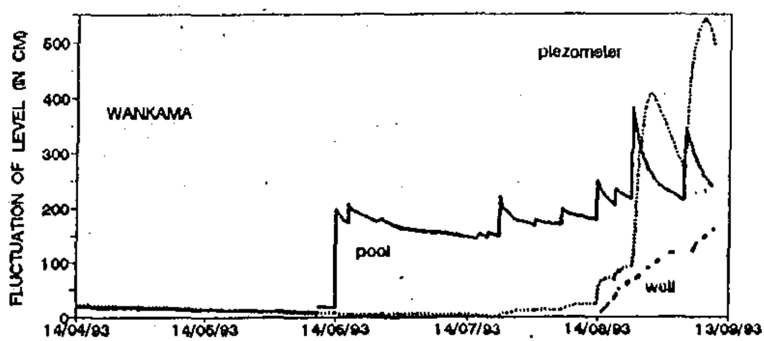

Fig. 3 Fluctuation of the water level in Wankama (pool and aquifer)

This process has already been observed in 1992 : there was no change of the water level until the end of July.

The temporal delay between the beginning of the pool flood and the groundwater reaction is short : 4 to 6 hours for the first piezometer before 13/8/93, 1 to 2 hours after and almost twice more for the second piezometer.

S. Galle (personal communication) has calculated the average movement of the wetting front to be about 20 cm per day in the zone 0-3 m. This can be compared with the width of the unsaturated zone right under the pool (about 15 m) and the two month delay between the first flood (13/6/93) and the change in response of the aquifer (13/8/93).

For an entire year, the estimated inflow from CT1 is about 10^5 m^3 per year, i.e. approximately the same amount as the recharge from the first pool (1.44 10^5 m^3 in 1992). Other pools of the kori increase the total rain infiltration in the Wankama zone.

SAMADEY

The pool

Samadey is an old thalweg head, part of a drainage basin extending over about 20 km^2. More recently, sandy deposits have isolated this upstream zone (6 km^2). The pool can cover up to 2 10^5 m^2. Its morphological and pedological framework differs from Wankama and Banizoumbou. For example, valley sides are much smoother (Fig. 1). There is no clear clayey sediment on the bottom of the pool, but in a very small area covered by an organic silt. The induced reduction of permeability is much more limited than the impact of clogging in Wankama and Samadey.

The water in the pool completely disappears a few hours or days after a flood with large bubbles at the surface of certain zones. Therefore, the pool is often dried up in the rainy season.

The aquifer

The depth to the water table is 45 m. The only observation point is an old hand-dug well where an automatic recorder has sometimes provided data with unexplained interferences. Hydrodynamic characteristics of the well are poor. The apparent geological homogeneity observed on the side of the well is not confirmed in other parts of the basin.

Results

The flood of July, 19th is detailed on Figure 4. The level of the pool rose from 0 to 45 cm in 80 minutes, the drying up took about 30 hours. The aquifer reaction started 3 hours after the beginning of the flood and the maximum was reached 24 hours later ; the piezometric level had an increase of 27 cm.

Such a rapid impact through 45 m of unsaturated zone implies preferential paths. Different explanations exist as active galleries, due to termites or roots, and small fossil tubes, which can be seen everywhere in Continental Terminal deposits. This recharge process is unique in the region because of its rapidity and scale.

This is a small flood : the estimated infiltration is less than 10,000 m^3 per day whereas it has once reached 300,000 m^3 per day. As usual, the daily water loss is linearly correlated with the width of water in the pool.

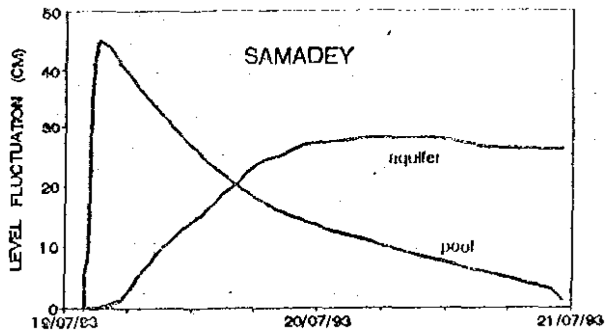

Fig. 4 Fluctuation of the water level in Samadey (pool and aquifer)

DISCUSSION

In the three cases, the water budget of the pool has been worked out with the basic assumption that outflow from the pool is distributed among evaporation and infiltration because the other losses can be neglected. Desconnets and Taupin (1993) have compared various methods for estimating the evaporation of a plateau pool in the Hapex Sahel zone. The results are similar. The simplest method is therefore chosen for extrapolation in our three sites. It is based on daily measurements of evaporation from the class A pan of the Niamey airport corrected by an exponential formula.

The main characteristics of the three periods are in the table below. Water remaining in the pool of Wankama at the end of the study period (22,000 m^3) will infiltrate or evaporate later ; the ratio infiltration/rainfall is not definitive.

	basin area km^2	duration days	total rain mm	surface runoff mm	runoff /rain %	evapor. loss m^3	infil. loss m^3	infil. /rain %
Samadey	6.3	2	26.0	1.90	7.1	185	11594	7.0
Wankama	2.0	69	395.5	34.60	8.7	3399	43629	5.5
Banizoum	0.6	168	424.0	57.25	13.5	3592	27718	11.9

Figure 5 shows the distribution of the water losses among infiltration and evaporation depending on the width of water in the pool. In the case of Samadey, the difference between these two processes is independent from the water level : evaporation is extremely slight (between 0.5 and 5 % of infiltration). On the contrary, both pools in the kori of Dantiandou have a smaller difference which sharply decreases beneath 1.75 m. This limit must be linked with the clogged zone. In all cases, water losses due to evaporation are weak even for long periods including the dry season (Fig. 6). The losses by infiltration are not uniform as well for a flood time as for an entire year ; they can be very large for short periods.

The pedological nature of the interface pool-soil controls infiltration. When the bottom of the pool is made of sandy permeable sediments, as in Samadey, the emptying of the pool is very rapid and can reach up to 300,000 m^3 per day. In the other cases of Wankama and Banizoumbou, the clogging of the lower part of the pool creates a double system : infiltration is easy and rapid (up to 20,000 m^3 per day) through the sandy upper sides of the pool whereas clayey deposits in the lower area strongly limit infiltration (less than 100 m^3 per day) and keep water in the pool a long time after the end of the rainy season. The transition between the clogged bottom and the permeable bank is sharp.

The water budget in partially clogged pools is primarily determined by the temporal distribution of floods and their volume : a long succession of regular and moderate rainfall will induce a much more limited aquifer recharge than with a few large floods. The comparison of the aquifer reaction in 1992 and 1993 illustrates this phenomenon: the rain distribution during 1993 has been more uniform and the water table has had lower increases (0.4 instead of 0.6 m in Banizoumbou, 130 m away from the pool and 1.5 instead of 2.7 m in Wankama, 500 m away from the pool).

Preferential paths, which are demonstrated by the rapidity of infiltration processes in Samadey, can exist in other places but to a much lesser extent.

Even though recharge processes are rather similar in both sites, Banizoumbou shows some differences compared to Wankama :
- the aquifer response is smaller (about ten times less close to the pool),
- the impact of the recharge is very localized,
- the date of the first significant rise of the aquifer is highly variable,
- the space between the pool and the mean level of the water table remains probably unsaturated in Banizoumbou.

This can be explained by larger infiltrated volumes in Wankama and different hydrodynamic characteristics in both sites. The 1994 survey will improve our knowledge of the recharge processes.

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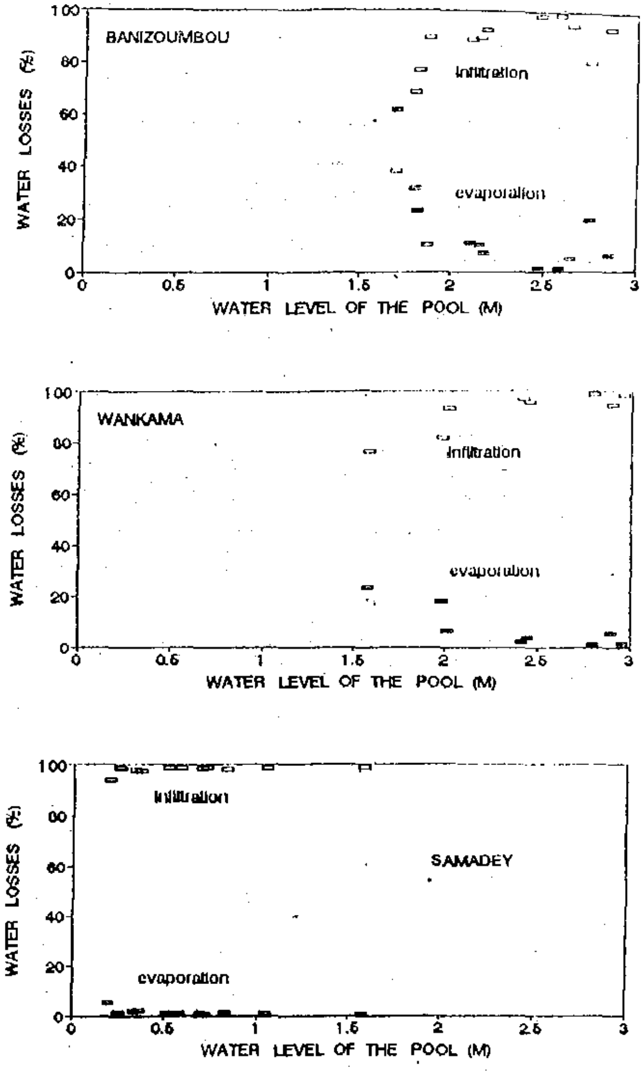

Fig. 5 Relative importance of evaporation and infiltration depending on the water level in the pool

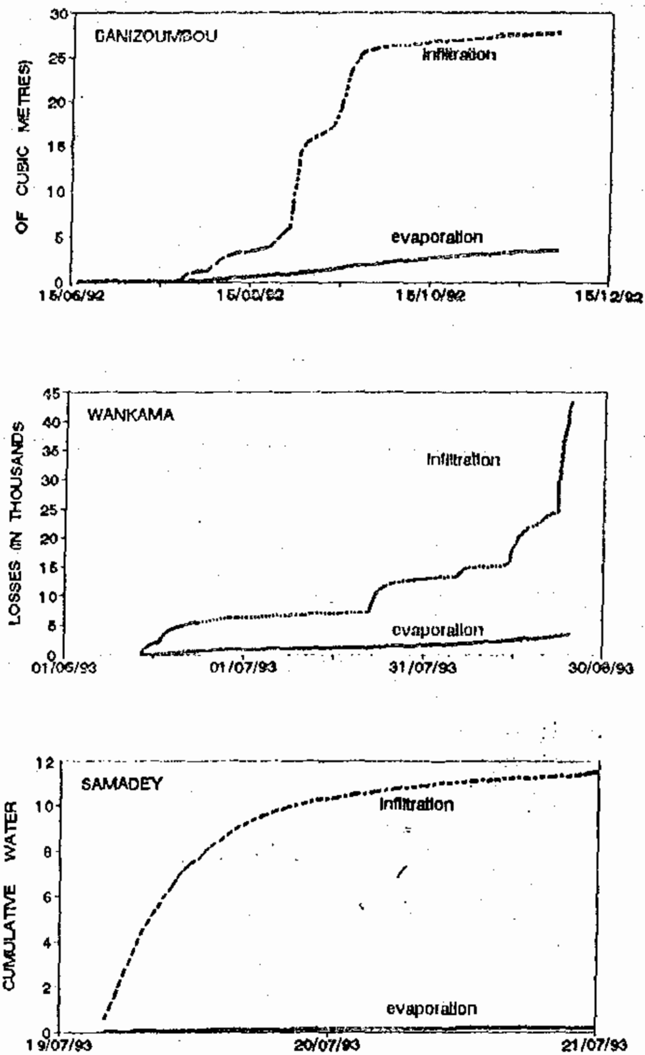

Fig. 6 Cumulative losses by evaporation and infiltration

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