Journal of Hydrology 424–425 (2012) 1–15

Contents lists available at SciVerse ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Experimental evidence of deep infiltration under sandy flats and gullies in the Sahel

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ARTICLE INFO

Article history:
Received 24 September 2009
Received in revised form 28 April 2011
Accepted 9 November 2011
Available online 18 November 2011
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Harald Kunstmann, Associate Editor

Keywords:
Endorheic area
Sandy soil
Runoff
Deep infiltration
Niger

SUMMARY

Despite the strong reduction in rainfall observed after 1968, the water table of some endorheic areas in the Sahel has been found to be rising over the last several decades. It has been previously demonstrated that this is due to land use changes which have led to a severe increase in runoff and erosion. In such areas, the excess in runoff causes a strong increase in the number of ponds, their sizes and thus, their duration. Ponds have been identified as the main zones of deep infiltration of water. The aim of this study was to investigate whether other areas of the Sahelian region could also be defined as deep infiltration ones as well, and then, whether they were contributing to aquifer recharge.

Soil water content was surveyed for five consecutive years (2004–2008) by implementing a set of measurement devices at different depths. The hydrologic water balance was monitored at stream flow gauge stations located upstream and downstream of two small endorheic catchments.

The observed replacement of bush vegetation by crops and fallow areas led to the appearance of extended bare soil areas due to both aeolian and hydric erosion, triggering a strong reduction in soil infiltrability under millet fields and fallow lands as well as in the soil water holding capacity. It also resulted in the formation of a great number of gullies and sand sediment deposits in the endorheic areas.

Measurements showed that sandy deposits correspond in fact to large areas of deep infiltration: tens of thousands of cubic meters of water infiltrated catchments of less than 1 km^2. Runoff decreased by up to 50% in the sandy deposit areas, while infiltration (close to 1300 mm h^{-1}) was observed up to depths of 10 m. These factors would raise the water table and significantly modify the surface and sub-surface components of the water cycle.

1. Introduction

For 40 years, the Sahel and most of West Africa has experienced substantial drought (Le Barbé and Lebel, 1997) and significant land use changes (Leduc and Loireau, 1997) leading to a strong increase in the runoff coefficients and stream flows in most Sahelian areas (Albergel, 1987). This phenomenon has been named "The Sahelian Paradox" (Descroix et al., 2009). The HAPEX–Sahel (Hydrological and Atmospheric Pilot Experiment) program, (*see J. Hydrol., Special Issue, Vol. 188–189, 1997*) provided, among many comprehensive results, valuable measurements dealing with the Sahelian soil water content and its spatial and temporal variability (Cuenca et al., 1997), as well as on the infiltration of water through deep soil layers of the vadose zone (Bromley et al., 1997; Leduc et al., 1997).

In certain endorheic areas in the Sahel, the water table level has been found to be rising over the last several decades despite the strong reduction in rainfall observed after 1968. This phenomenon has been previously defined as the "Niamey Paradox" (Leduc et al., 2001; Favreau et al., 2002): the excess in runoff has significantly increased the number of ponds. Such ponds being the main zones of deep infiltration (Leduc et al., 2001; Massuel et al., 2006), their increase explains the rise of the water table level (Leblanc et al., 2008). While this mechanism is typical of the hydrology within the Sahelian endorheic zones, the existence of exorheic areas in the Sudano–Sahelian region leads to another type of hydrologic

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doi:10.1016/j.jhydrol.2011.11.019

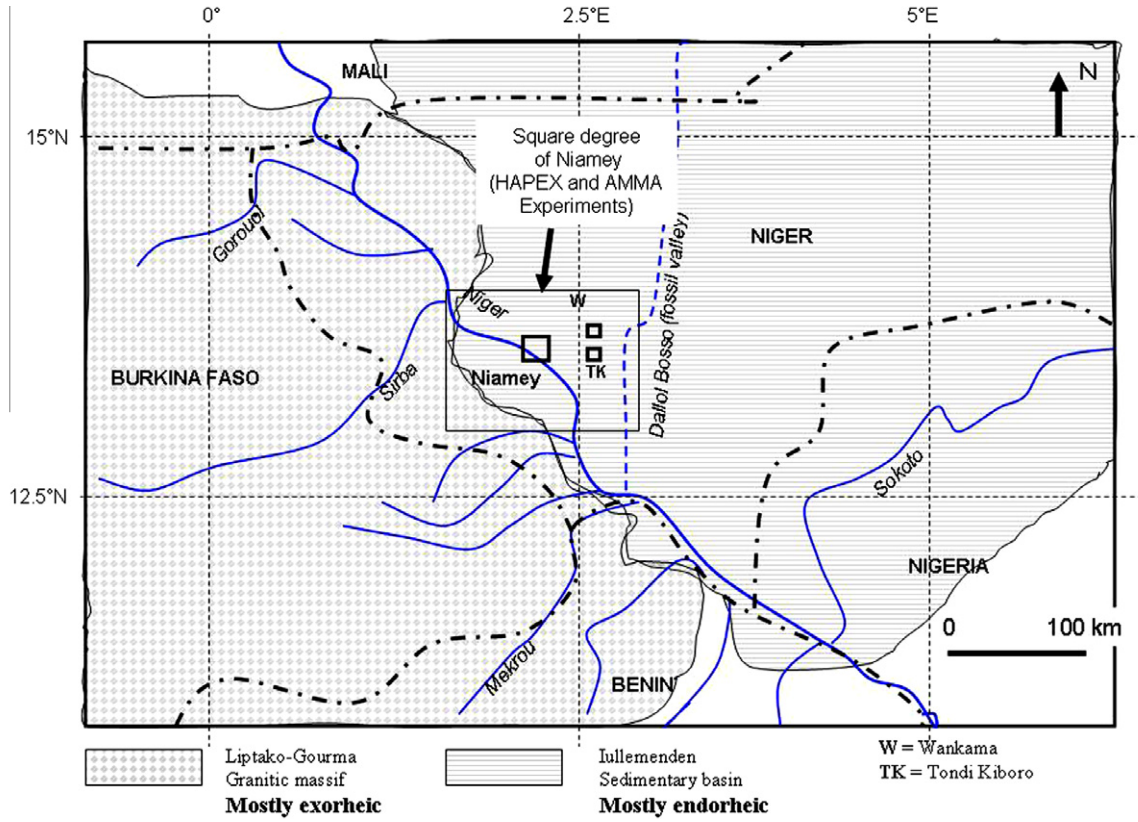

Fig. 1. Location of the two experimental catchments within the Western Niger; Niger River approximately separating the exorheic plutonic (westward) from the endorheic sedimentary areas (eastward).

functioning (see boundary limits in Fig. 1) (Descroix et al., 2009). As a matter of fact, the current active erosion processes are leading to the appearance of many new gullies and new spreading areas where sediments extracted by aeolian and hydric erosion and then transported in the gullies, are deposited (Chinen, 1999; Leblanc et al., 2008; Le Breton, 2012). The gully beds are currently characterized by sand deposits ranging from 2 to 4 m wide, several tens of centimeters deep (up to 1–2 m) and hundreds of meters long. Spreading areas are formed by these newly created streams when they reach gentler slopes, because their transport capacity becomes suddenly insufficient to carry such significant volumes of sand. They form sandy deposits of the order of hundreds of square meters, up to several hectares, and, in some cases, tens of centimeters deep. As an example, Fig. 2 shows the strong spatial extension of gullies and spreading areas since 1950 as observed by Le Breton (2012) for the Wankama catchment. This is also consistent with observations made by Leblanc et al. (2008), who showed that the length of the gullies increased by a factor of about 2.5 over the same period.

The goal of this study was twofold: (i) to get further insight into the role played by gully beds and spreading areas on the process of deep infiltration into endorheic zones, (ii) to compare the spatio-temporal evolution of wetting front according to different devices.

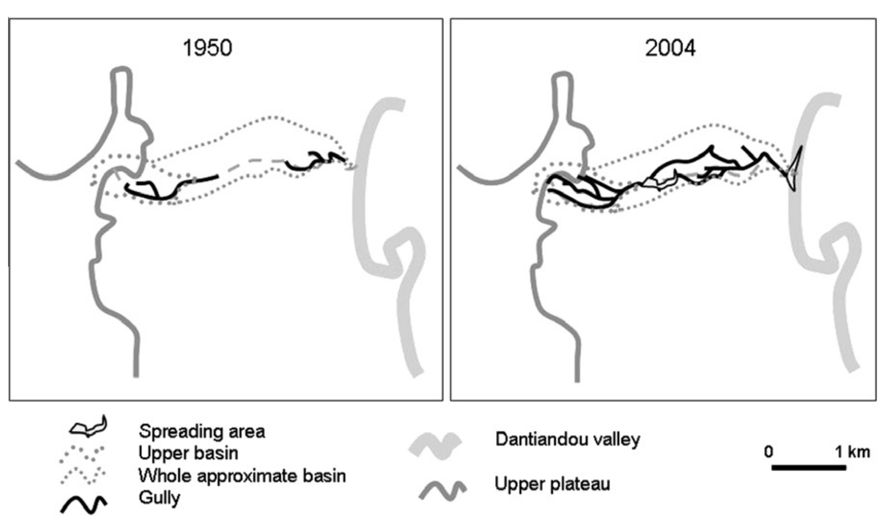

Fig. 2. Maps of the Wankama catchment showing the evolution of gullies and spreading areas between 1950 and 2004 (from Le Breton, 2012). The Dantiandou valley is the main, fossil, tributary valley.