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Rapid evolution of water resources in the Senegal delta

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ABSTRACT

In recent decades major water developments have led to an agricultural transformation of the Senegal delta both in Senegal and Mauritania. This otherwise, semi-arid region of the Sahel band now has an abundant supply of freshwater all year round mostly used for irrigation and urban water supply, including for the capital cities of the two countries. Archives from the Landsat satellites and in-situ hydrographs were used in this paper to retrace and analyse the hydrological changes that have taken place in the region since the middle of the 20th century. The satellite archives indicate that the area covered by irrigation increased by one order of magnitude from 73 km^2 in 1973 to ~770 km^2 in 2010. The observed hydrological changes are complex, multi-faceted and often of great magnitude. If the water cycle was representative of natural conditions in the early 1980s, it is now representative of a heavily modified system controlled and impacted by human activities. The first hydraulic infrastructure was installed in 1947 to enable the Lake of Guiers to become the main water supply for Dakar. Two large dams were built on the Senegal River in the mid-1980s that modified the hydrological regime of the river by 1) preventing seawater intrusion, 2) raising the stage of the river and of Lake of Guiers and 3) moderating floods. Another recent hydrological change in the delta was the opening of river mouth in 2003, which has led to a reduction of the average water level while increasing the semi-diurnal tidal wave between the river mouth and Diama. Each phase of these river regime changes and each step of the irrigation expansion are expressed in localised changes in the physical groundwater system. Increasingly, the retroaction from the shallow aquifer systems is observed as a rise of the saline water table. This poses a threat to the environmental and agricultural value of the region, and the salinization of the soils. Mitigating actions for this threat are currently being envisaged by the authorities.

1. Introduction

The hydrologic cycle is exposed to multiple environmental stressors, such as changes in land cover (e.g. Scanlon et al., 2005, 2007; Favreau et al., 2009), surface water diversion schemes (Leblanc et al., 2012) and climate variability (e.g. Leblanc et al., 2009; Tweed et al., 2009). They all potentially lead to important shifts in the hydrologic cycle by modifying the nature and intensity of the hydrological processes. These impacts on the hydrological cycle vary in magnitude, extent, and timing and feedback mechanisms are also often observed.

Globally, the hydrological impacts from environment changes are particularly visible in semi-arid regions where water resources are limited, natural variability is high and ecosystems resilience is low (e.g. Ragab and Prudhomme, 2002). Many semi-arid regions have also experienced a sharp increase in water demand from high population growth and farming expansion in the 20th century. A severe drought has also affected many the Sahelian countries in the 1970s and 1980s (e.g. Mahé and Paturel, 2009). In the Senegal Basin, the response to this drought and the increase in the precariousness of water resources and agriculture (e.g. Taïbi et al., 2009) led to the construction of a series of dams on the Senegal River initiated by the OMVS (Organisation pour la Mise en Valeur du fleuve Sénégal). The regulation of the river led to many environmental and socio-economic changes. The most important is probably the agricultural transformation of the region with the introduction of irrigation on a broad scale.

This study is based on two main research questions:

i) What changes in the Senegal River and irrigated agriculture were observed?

ii) What were the surface water and groundwater responses to these hydro-agricultural developments?

To respond to these questions, this paper presents an integrated analysis of hydrological changes since the second half of the 20th Century using observations from multi-disciplinary datasets. It concerns only the left bank of the Senegal River, which is situated in Senegal. Though the hydrology of the Basin is relatively well documented under natural

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conditions (e.g. Rochette et al., 1974), recent hydrological changes under the increasing anthropogenic pressures are important and have, to date, received limited attention (Bader and Cauchy, 2013). In this study, surface water and groundwater resources are studied conjunctively. Important interactions between these two major compartments of the water cycle were reported in the region (Saos and Zante, 1985). Accounting for surface water and groundwater interaction is therefore required to grasp the full complexity of the response of the connected hydrosystem to environmental changes. Surface water and groundwater hydrographs provide direct observations of changes in 1) the river hydrological regime, 2) groundwater and surface water interactions and 3) groundwater recharge and storage in irrigated and non-irrigated areas. This information was complemented by a time series of Landsat scenes that allowed us to map the rapid expansion of irrigation across the Senegal delta region and facilitated the interpretation of the hydrograph data.

2. Study area

The Senegal delta, is a vast flat floodplain of meandering channels downstream of Dagana that regroup in a single estuary when reaching the Atlantic Ocean (Fig. 1). The Senegal River is the junction of the Bafing and Bakoye Rivers, whose headwaters are located in the Republic of Guinea, and then traverses 1800 km to the mouth located south of Saint Louis in Senegal. The mean slope of the river is about 0.02‰ over its last 900 km. The river feeds several streams, canals, and lakes in the delta region, including Lake R'Kiz in Mauritania and Lake of Guiers in Senegal, which is the principal source of fresh water supply for Dakar. The Senegal River crosses three climate zones, Guinean, Soudanean and Sahelian (i.e. annual average rainfall varying from ~2000 mm to 200 mm). Within the Senegal delta, annual rainfall is influenced by the northern Sahelian tropical climate, which is characterized by a long dry season (October to June) and a short rainy season (July to September) (Fig. 2a). The average annual temperature is around 27 °C, with a minimum of 23 °C in January and a maximum of 30 °C in September. The relative humidity is high during the rainy season with a monthly average of about 80%. The inter-annual variations of rainfall are presented for Saint-Louis and Podor in Fig. 2b, and highlight the rainfall deficit during the drought that began in 1969 and peaked in the early1980s.

In response to this drought and to support the irrigation development two dams were constructed on the Senegal River by the middle of the 1980s (Diama and Manantali). The introduction of this infrastructure, in particular the Diama dam, induced significant environmental, socio-economic and cultural changes in the Senegal delta by allowing the intensification and expansion of irrigated agriculture. During the initial stages of irrigated agricultural development in the delta, large areas of land were managed by government (SAED: Société nationale d'Aménagements et d'Exploitation des terres du Delta). Subsequently, most of the irrigated land has been handed to groups or individual farmers (PIV: Individual Perimeters).

The Senegal delta is part of the Senegalese-Mauritanian sedimentary basin dated Mesozoic-Cenozoic. The oldest formation is the Maastrichtian, which is mainly comprised of sand and sandstone (Sall, 2006). This is overlain by the discontinuous Eocene marine clay, marl and limestone, and the continuous layer of sandy clay detrital sediments that form the Continental Terminal formation, which outcrops at Dagana (Rochette et al., 1974). During the Quaternary, sea level transgression and regression cycles were accompanied by fluvial erosion and alluvial deposits (Le Brusq, 1980; Van Lavieren and Van Wetten, 1988; Loyer, 1989). During the marine transgression, the Inchirian I (sandy clay sediments with low permeability) and Inchirian II

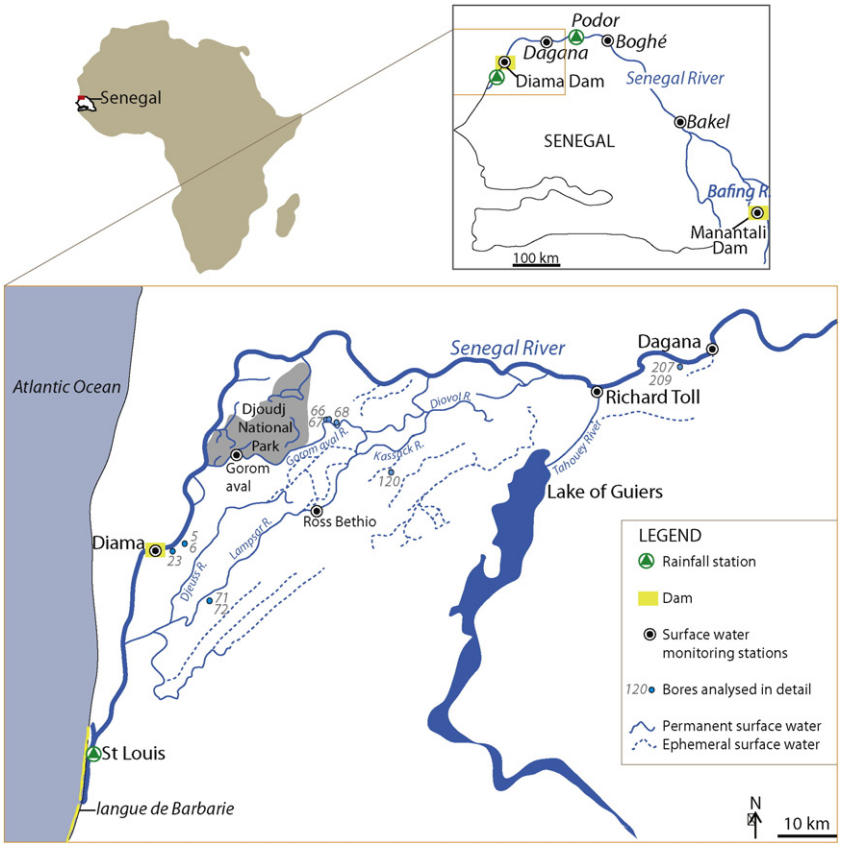

Fig. 1. Location of Senegal in northwestern Africa, Senegal River, other permanent and ephemeral surface waters, the Diama and Manantali dams, surface water and rainfall monitoring stations, and the locations of groundwater bores analysed in detail in this study. Only the Senegal part of the delta is presented in this figure.