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Hydrodynamic and salinity evolution of groundwaters during artificial recharge within semi-arid coastal aquifers: A case study of El Khairat aquifer system in Enfidha (Tunisian Sahel)

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ABSTRACT

In common with most coastal aquifers, the El Khairat aquifer suffers the imbalance between recharge and intense exploitation and the extent of agricultural activity. As it is part of the Tunisian Sahel, the Enfidha region has a semiarid climate with very irregular rainfall which makes the groundwater resources quite fragile. This region has major difficulties in managing its water resources which are in decline, especially since, for the last decades, their renewal by rainwater has no longer been sufficient to re-establish the equilibrium.

In such a case, the artificial recharge of aquifers by water from dams is a credible alternative to preserve the water resources against marine intrusion and pronounced fall in the piezometric level.

The present investigation, based on available data, is aimed to monitoring the piezometry of the El Khairat aquifer during artificial recharge operations (2002–2005) by water from the dam and to identify the impact of the artificial recharge on groundwater quality.

The results of this monitoring have shown that the artificial recharge realized between 2002 and 2005, had for effect an increase of the piezometric level of the phreatic aquifer of +0.4 to +2.63 m, especially in the "Ain Garci" zone. The piezometric level of the deep aquifer has also recorded an important increase reaching +3.82 m. After artificial recharge of the aquifer, the spatial distribution of the salinity shows quite low salinity values (lower than 2 g/l) in the western and north-eastern parts of the aquifer, the zone of artificial recharge, whereas the highest ones are found especially in the coastal zones and at the boundaries of the Sebkha where they exceeded 3 g/l.

Moreover, we note a slight salinity reduction toward a central zone of the aquifer. Indeed, the zone characterized by salinity lower than 2 g/l and situated near the recharge site becomes more extensive.

1. Introduction

As groundwater is often the only reliable source of fresh water and it is the only renewable water resource in arid and semi-arid regions, this is due to sporadic rainfall; groundwater recharge is limited to infiltration of the flood water through beds of ephemeral streams (wadis) (Al-Ahmadi and El-Fiky, 2009). The streams carry large volumes of water during a flood. In the absence of dams, a large proportion of flood waters may disappear into salts marshes (Sebkha) (Zammouri and Feki, 2005). With the increasing use of groundwater for agricultural, municipal and industrial needs, the annual extraction of groundwater is far in excess of net average recharge from natural resources. Consequently, a large number of aquifers in coastal zones are being increasingly exploited and affected by a constantly growing human impact (Fedrigoni et al., 2001; De Marsily, 2003; Bouwer and Pyne, 2005). There is an urgent need for artificial recharge of groundwater by augmenting the natural infiltration of precipitation into subsurface formation by some suitable method of recharge. In order to improve the natural regime of the aquifer, artificial recharge of groundwater together with dam construction, has become increasingly important in many industrialized under development countries located in semi-arid regions, such case of Tunisia, where the natural replenishment of groundwater is slow compared to the exploitation of groundwater (Greskowiak et al., 2005; Abderrahman et al., 2007). The artificial recharge is a process consisting of introducing water in a permeable formation, as to be reused in different

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conditions. Therefore, it is a temporary storage of the surface waters in an underground reservoir (Bize et al., 1972). Artificial recharge is one method of modifying the hydrological cycle and thereby providing groundwater in excess of that available by process. With a constantly increasing demand in water from one side, and limited resources from another side, Tunisia adopted reasoned management strategies, to stock water of rises in underground reservoirs, initially dispersed annually for lack of recuperation, by the artificial recharge process (Nazoumou, 2002).

In Tunisia, artificial recharge of aquifers started at the beginning of the 1970s and from 2000 it has aimed at underground storage of the equivalent of 100 million meter cubes of surface water in aquifers at a dozen recharge sites (METD, 1998). One of the chosen sites is Enfidha (governorate of Sousse), because of the water resource problems and the prevailing geological and hydrogeological conditions. In this region of, a dam has been constructed in 1999 on the wadi El Khairat. It contributed to the natural recharge of the aquifers to which they are associated. Since the setting in water of the dam, it has been noticed a continuous decrease of the piezometric levels of the aquiferous system of El Khairat, and simultaneously an increase of the exploitation by boring and wells. To remedy to this unbalance, an artificial recharge has been undertaken from 2002.

Therefore, the aim of the present work is the monitoring of the hydrodynamic and hydrochemical parameters of the El Khairat aquifer during artificial recharge operations by water from the El Khairat dam.

2. Geology and hydrogeology

The watershed of El Khairat is situated on the oriental flank of the Tunisian Dorsal, in the extension, toward the East, of the synclinal of Saouef (Fig. 1). As it is part of the Tunisian Sahel, the region of survey has a semiarid climate with very irregular rainfall which makes the groundwater resources quite fragile. The daily average temperatures vary between 11 °C in winter (January) to 28 °C in summer (August). The annual average precipitation is 353 mm/year. The study site is located on an alluvial plain whose geology is dominated by Tertiary and Quaternary deposits. Stratigraphic layers range from the Oligocene to the Halocene (Fig. 1). The wadi El Khairat takes birth in Djebel Khalifa, in the governorate of Zaghouan, and crosses the alluvial plain of El Khairat which surface is of 63 km^2, and contains an important aquiferous system that is subdivided, in Satour Bou Larga-fedjet El Hamma (Fig. 2), by a hydraulic sill (sill of Ain Garci) in two distinct zones: Ain Garci (upstream) and of Enfidha-city (downstream) (Manaa et al., 1996).

The zone of Ain Garci corresponds to an underflow aquifer lodged in an alluvial matrix (pebbles, gravels, sands) more or less detritic and clayey of a thickness reaching the 100 m. Laterally, the extension of these alluviums is often limited by the presence of the argilloarenaceous formations of the Mio-Pliocene. The substratum of the alluvial aquifer corresponds in the upstream, to the marls of the Vindobonian, but in downstream, it is generally characterized by clays and sandstones of Mio-Pliocene presence. The median zone presents a weak thickness of the aquifer (0–25 m), corresponding to the ascent of the marly substratum.

In the zone of Enfidha-city, the geometry of the reservoir presents three communicating aquiferous horizons (Chadly, 2002):

- Sandy or argilloarenaceous phreatic horizon, lodged in the superficial formations.
- Semi-deep horizon captured by boring, whose lithology consists of sands, pebbles and gravels.
- Deep horizon contained in sands and gravels. The substratum of this horizon is constituted by the marls of the Vindobonian.

The El Khairat aquifer is characterized by a transmissivity varied between 2×10^{-3} and 7×10^{-3} m^2/s in the zone of Ain Garci, and between 1×10^{-3} and 4×10^{-3} m^2/s in the zone of Enfidha-city. Manaa et al. (1996) fixed a storage coefficient of 10% and potential resources in the order of 7×10^6 m^3/year.

The infiltration of flood water through the beds of wadi "El Khairat" constitutes major source of aquifer recharge (El Batti, 1974). The infiltration of the pluvial waters and the recharge from the piedmonts of the South part constituted by the overflow of the waters of the Mio-Pliocene, participate incidentally in the aquifer recharge (Manaa, 1991). Waters mobilized in the dam of El Khairat built in 1999 contributed to the natural recharge of the aquifers to which they are associated. Discharge occurs of this aquifer are the Mediterranean Sea and the areas of evaporation (Sebkha). The general flow direction is north-west to south-east (Fig. 3). This

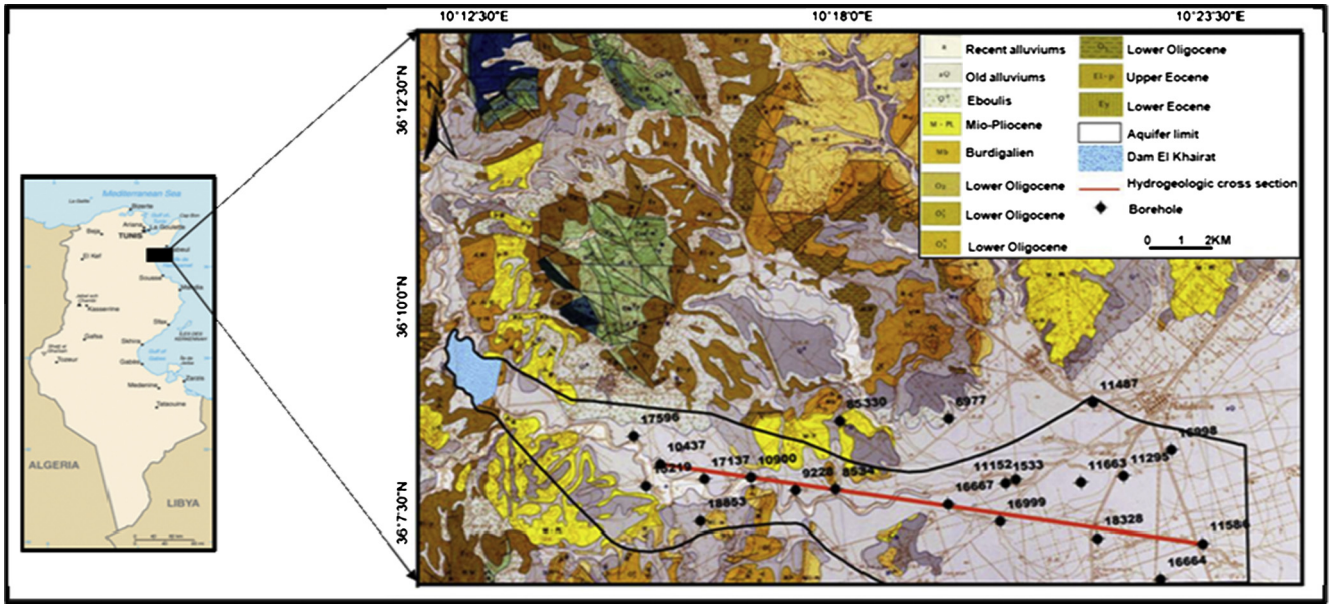

Fig. 1. Localization and geological map of the study area (extracted from the geological map of Enfidha at 1/50,000).