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Groundwater management options in an arid environment: The Nubian Sandstone Aquifer System, Eastern Sahara

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ABSTRACT

Groundwater is the only water resource across the "hyper" arid Eastern Sahara. Management of this resource is imperative for the sustainable development approaches. A 3D GIS-based groundwater flow model for the Nubian Sandstone Aquifer System (NSAS) was developed to simulate the groundwater management options for the different development areas/oases within the aquifer, and to predict the environmental impact of the present and future groundwater extraction schemes on the whole system. Based on the actual and planned extraction rates of the NSAS, five extraction scenarios were suggested to investigate the most feasible groundwater management option in terms of the economic lifting depth until year 2100. The model was calibrated and validated under the transient conditions. The calibrated model was then used for the prediction simulations. The results of simulating the present extraction rates of the NSAS until 2100 showed that the free flowing phenomenon will disappear all over the modeled area. At this simulation time, a groundwater volume of 354 km^3 will be extracted from the aquifer storage. Scenario 3 was found to be the optimal groundwater management option that meets the development ambitions and at the same time keeps the safe economic lifting depth as well.

1. Introduction

The area of the Nubian Sandstone Aquifer System (Fig. 1) is composed of one huge, unbroken tract of true desert area which is characterized by extreme aridity and rainfall scarcity. The only slight exceptions are the narrow littoral zone extending along the Mediterranean Sea and the most southern margins of the area that receive scanty amounts of rainfall. Islands of life in the interior of this desert are represented by the oases regions, which are located in a series of depressions in the desert plateau and owe their existence exclusively to the groundwater resources (Williams and Faure, 1980; White, 1983; Cloudsley-Thompson, 1984).

The climate of the Sahara has undergone noticeable variations between wet and dry over the last few tens of thousands of years. The groundwater within the NSAS aquifer is very old, however, the last wet period occurred 4000–8000 years BP as discussed by many authors (Pachur et al., 1987; Heinl and Brinkmann, 1989; Pachur et al., 1990; Pachur, 1999; Kröpelin, 1999; El-Baz et al., 2000; Kröpelin, 2001; Sadek et al., 2001; Thorweihe and Heinl, 2002; Sturchio et al., 2004; Gossel et al., 2006, 2010b; Voss and Soliman, 2014).

As stated in several modern publications (i.e. CEDARE, 2001, 2002; Ebraheem et al., 2002, Ebraheem, 2003; Ebraheem et al., 2003, 2004; Ghoneim and El-Baz, 2007; Gossel et al., 2004, 2006, 2008; Sefelnasr, 2002, 2007, 2008; Sefelnasr et al., 2006a,b; Sefelnasr et al., 2014; Voss and Soliman, 2014) the water of the (shared) Nubian Sandstone Aquifer is non-renewable and shared among Egypt, Libya, Sudan, and Chad (Fig. 1). Most of the present water extracted from the NSAS is used for agriculture, either for large development projects in Libya or for farms located in old traditional oases in Egypt (New Valley). The area occupied by the aquifer system is about 2.35 million km^2.

The aquifer is of significant importance because it is the only water resource for this arid area. The increasing demographic growth and the lack of renewable fresh water resources in this arid region have resulted in an increasing attention to the groundwater potential represented by the NSAS. Many attempts were made by Egypt and Libya to develop and utilize this aquifer system during the last three decades, this in turn affects directly the groundwater resources of the aquifer and results in developing huge drawdown depressions around the well fields in the corresponding areas.

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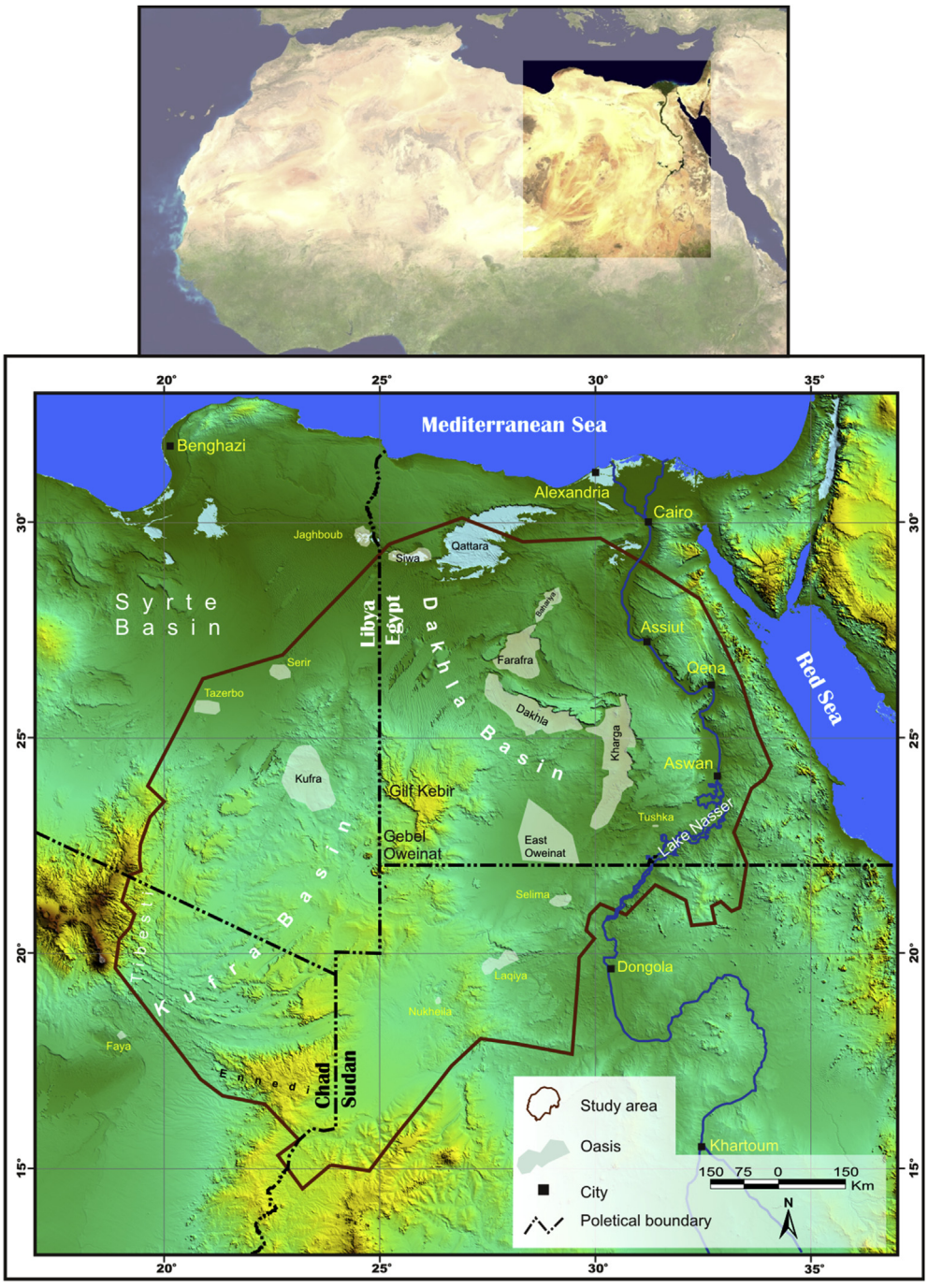

Fig. 1. A DEM of the Eastern Sahara including the study area of the Nubian Sandstone Aquifer System and the development areas. Sources: USGS (2004) and NASA (2005, 2006).

Through the aridity and the non-renewability of the area, the groundwater exploitation from the NSAS has to be managed on basis of groundwater demand, availability and socio-economic aspects. This work is an attempt to simulate different groundwater management schemes based on the given groundwater extraction values for both actual and planned extraction rates.

The data framework for NSAS composed of large aggregations of spatial datasets and records in assorted formats. The powerful tools of ArcGIS were utilized to construct and develop a coherent Geodatabase for the NSAS that allowed for compiling those datasets in a unique structure and defining the topological and temporal relationships. Working with and leveraging the capabilities of the Geodatabase platform made it easier to accomplish the relevant spatial analysis and manipulation, prepare the data as an input for different modeling systems as well as to update the data.

Geodatabase is used and incorporated to establish a conceptual framework to model the real hydrogeologic system, which is an essential step before the development of a numerical groundwater flow model. This includes different assumptions which lead to the estimation or quantification of the different components of the aquifer system, including hydraulic conductivities, storativities, etc. The period 1960–2005 was chosen as a calibration period based on the availability and temporal distribution of the data. Different steps were carried out to simulate the different groundwater