Ain Shams Engineering Journal (2015) 6, 1–15

Ain Shams University

Ain Shams Engineering Journal

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www.sciencedirect.com

CIVIL ENGINEERING

An overview of integrated remote sensing and GIS for groundwater mapping in Egypt

Salwa Farouk Elbeih *,[1]

Engineering Applications and Water Division, National Authority for Remote Sensing and Space Sciences, 23 Joseph Tito st., El-Nozha El-Gedida, Cairo, Egypt

Received 9 March 2014; revised 17 August 2014; accepted 24 August 2014
Available online 8 October 2014

KEYWORDS

Groundwater;
Mapping;
Remote sensing;
GIS;
Egypt;
Decision support

Abstract Groundwater is considered the major portion of the world's freshwater resources. One of the main challenges facing the sustainable development of Egypt is the need for better management of its limited fresh water resources. Groundwater exists in the Nile Valley, Nile Delta, Western Desert Oases, and Sinai Peninsula. Hydrogeological mapping of groundwater resources is one of the main tools for the controlled development of groundwater resources. Remotely sensed surface indicators of groundwater provide useful data where practical classical alternatives are not available. Integrated remote sensing and GIS are widely used in groundwater mapping. Locating potential groundwater targets is becoming more convenient, cost effective than invasive methods and efficient with the advent of a number of satellite imagery. The nature of remote sensing-based groundwater exploration is to delineate all possible features connected with localization of groundwater. Data,

Abbreviations: ALOS, Advanced Land Observing Satellite; ASTER, Advanced Spaceborne Thermal Emission and Reflection Radiometer; IWACO, Consultants for Water and Environment; DEM, Digital Elevation Model; FAO, Food and Agricultural Organization; GIS, Geographic Information Systems; GRACE, Gravity Recovery and Climate Experiment; GPR, Ground Penetration Radar; IRS, Indian Remote Sensing; JICA, Japan International Cooperation Agency; LST, Land Surface Temperature; msl, meters above sea level; NARSS, National Authority for Remote Sensing and Space Sciences; PALSAR, Phased Array type L-band Synthetic Aperture Radar; RS, remote sensing; RIGW, Research Institute for Groundwater; SIR-C, Spaceborne Imaging Radar C band; SAR, Synthetic Aperture Radar; UNDP, United Nations Development Program; VES, Vertical Electric Sounding

* Mobile: +002 01003377582.
E-mail address: saelbeih@narss.sci.eg.
[1] Associate Professor.

Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2014.08.008

driven out of remote sensing, support decisions related to sustainable development and groundwater management.

1. Introduction

In one of their most recent reports, the United Nations Population Division projects stated that the Egyptian population is expected to reach 100,909 million by the year 2025 and 123,452 million in 2050 [1]. Most of the Egyptian population (97%) lives in the Nile Valley and Delta, which represent about 4% of the territory [2].

Groundwater accounts for 26% of global renewable fresh water resources [3]. Salt water (mainly in oceans) represents about 97.2% of the global water resources with only 2.8% available as fresh water. Surface water represents about 2.2% out of the 2.8% and 0.6% as groundwater. The problem is not only to locate the groundwater, as it is often imagined, but the engineer's problem usually is to find water at such a depth, in such quantities, and of such quality that can be economically utilized. Groundwater is a term used to denote all the waters found beneath the ground surface [4]. Groundwater aquifers are not just a source of water supply, but also a vast storage facility providing great management flexibility at relatively affordable costs.

One of the main challenges facing the sustainable development in Egypt is the need for better development and management of its limited fresh water resources. Some of the most important groundwater problems in Egypt are: over-exploitation and lowering of its levels in some areas; saltwater intrusion into freshwater aquifers in some of the Nile Delta governorates; waterlogging and/or salinization.

With the advance in space technology, it is now possible to employ remote sensing techniques for estimating surface and subsurface water over large areas. These methods are very useful for rapid groundwater mapping of large and inaccessible areas. The necessity of remote sensing based groundwater exploration is to demarcate and delineate all possible features connected with localization of groundwater. These features are extracted from the appropriate satellite data products and integrated with the thematic details obtained from topographic sheets of the desired scale. The use of conventional techniques, (e.g., geophysical, statistical or geostatistical techniques, numerical modeling, etc.) for groundwater management, is often severely limited by the lack of adequate data. Frequent and long-term monitoring of groundwater and vadose zone systems by these conventional methods is expensive, laborious, time-consuming and destructive [5]. Innovative technologies, as remote sensing (RS) and Geographic Information Systems (GIS), have an immense role to play [5].

2. Water resources in Egypt

Egypt lies in the northeastern corner of the African Continent and has a total area of about 1 million km^2. The Egyptian terrain consists of a vast desert plateau dissected by the Nile Valley and its Delta, which occupy about 4% of the total country area. Since ancient times the Nile has been the main source of fresh water to the country covering all water needs for Egypt's population, which inhabited the Nile Valley and the Delta. Human activities in the remaining 97% desert land remained confined to a few localities, where deep groundwater was available through springs and seepage zones (valleys, oases, and depressions) [6]. Under the 1959 Nile Waters Agreement between Egypt and Sudan, Egypt's share of the Nile flow is 55.5 billion m^3/year. Egypt is a water scarce country, with less than 1000 m^3 of available freshwater/year/capita. The rate of water usage in Egypt is approximately 190 L/person/day. On the other hand, water needs for typical Middle Eastern-North African diet is 294 L/person/day. The annual average rainfall is 51 mm [7].

Table 1 shows the water budget of Egypt in 2010; as given in the 2050 water strategy of the Ministry of Water Resources and Irrigation [7,8].

From this water budget, it is clear that Egypt's water demand for irrigation, industry, and domestic consumption already exceeds the supply of the Nile. This is substituted by recycling fresh water more than once, which imply that there is shortage in the fresh water resources, and also reflects the high efficiency of the system as well as the sensitivity of the system to deterioration in water quality problems that may arise [7].

Groundwater exists in the fringes of the Nile Valley, Nile Delta, Western Desert, and Sinai Peninsula. Groundwater is the only available resource for interdisciplinary development in the areas around the Nile Valley, because of insufficient rainfall. Groundwater in the Nile aquifer system and desert fringes is not a resource in itself as it is replenished from the river Nile by seepage from canals and deep percolation from irrigation application [9]. Groundwater in the Western Desert is deep seated. Recent studies have indicated that this is not a renewable resource and use of this fossil water depends on the cost of pumping and potential economic return over a fixed time period [10].

On the other hand, in the coastal zones, groundwater reservoirs are recharged from local rainfall [2]. The largest groundwater deposit is the giant Nubian sandstone aquifer underneath the eastern part of the African Sahara, and is shared between Egypt and four other countries [11]. The hydrogeological framework of Egypt comprises six aquifer systems [12,2,13,10,14,6,9], as shown in Fig. 1:

(1) *The Nile aquifer system*, assigned to the Quaternary and Late Tertiary, occupies the Nile flood plain and desert fringes. The aquifer consists of a thick layer of graded sand and gravel covered by a clay layer in its major part. The aquifer thickness varies from 300 m (at Sohag) to only a few meters (at Cairo and Aswan) North of Cairo. The aquifer system is renewable and the main recharge source is the infiltration from the excess water application for agriculture and seepage from the irrigation water distribution system.

(2) *The Nubian Sandstone aquifer system*, assigned to the Paleozoic–Mesozoic, occupies a large area in the Western Desert, and parts of the Eastern Desert and