

Development of New Water Resources in Egypt with Earth Observation data: Opportunities and Challenges

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Abstract

The work presented here shows some preliminary results from an on-going U.S. – Egypt collaborative project that deals with the assessment of natural resources in an area located west of the Nile Valley near Aswan and Kom Ombo in the Western Desert of Egypt. The exploration and assessment of new untapped groundwater resources may enable the gradual expansion of urban and agricultural areas away from the Nile Valley into the desert. In the Western Desert of Egypt these additional water resources are mainly found in the Nubian aquifer systems where large quantities of groundwater accumulated during previous pluvial times. Present recharge of the Nubian aquifer is limited to areas near mountains or permanent water bodies (such as the River Nile and Lake Nasser), where occasional rainfall events and excess water from rivers and lakes may recharge the aquifer. Often this recharge occurs along open and well-connected fractures, which act as preferential water conduits. However, in desert areas (such as the Western Desert of Egypt) these fracture zones are often difficult to locate because they are covered by windblown sand deposits. Ground penetrating radar together with a new generation of satellite borne radar images are revolutionizing the way we map and identify these hidden structures. Some of the fracture systems revealed by radar technology seem to be particularly promising in terms of bringing groundwater from the Nubian aquifer and possibly excess water from the River Nile or Lake Nasser into the study area. Detecting and mapping these potential water conduits will ultimately lead to a better understanding of the geo-structural framework of the underlying aquifer, and its potential to support agriculture and other land development plans in a sustainable way. In addition, optical satellite sensors (such as Landsat) provide useful information for monitoring and assessing the rate of land use change along the Nile River and its tributaries.

Keywords: *water resources, arid lands, remote sensing, ground penetrating radar*

1. Introduction

Ensuring food security and sustainable growth are among the top priorities of the Egyptian government. Therefore, major programs have been undertaken in the last decades to relieve population pressure along the narrow Nile Valley, increase Egypt's arable land and generate new employment

opportunities especially for young people. One significant step toward accomplishing these goals is the selection of suitable sites for urban and agricultural development. Decision makers require timely and updated information on land and water

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resources in order to carry out land planning and development tasks.

Agriculture is the principal consumer of global fresh water resources and Egypt is no exception to this rule. Currently more than half of its groundwater resources are being used for irrigation especially in inland areas. This has triggered a series of problems, such as the lowering of the groundwater table, which can ultimately lead to the depletion of the aquifer, soil and water salinization due to poor irrigation practices, as well as vegetation stress which leads to a decline in crop productivity. Consequently, improved land and water resources exploration and management methods are needed in order to identify suitable areas for agricultural expansion and implementing better land and water conservation measures.

At the same time new untapped groundwater resources need to be identified and explored. In the Western Desert of Egypt these additional water resources are mainly found in the Nubian aquifer systems where large quantities of groundwater accumulated during previous pluvial times. Present recharge of the Nubian aquifer is limited to areas near mountains or permanent water bodies (such as the River Nile and Lake Nasser), where occasional rainfall events and excess water from rivers and lakes may recharge the aquifer. Often this recharge occurs along open and well-connected fractures, which act as preferential water conduits. However, in desert areas (such as the Western Desert of Egypt) these fracture zones are often difficult to

locate because they are covered by windblown sand deposits.

Remote sensing technology has made timely and spatially explicit information gathering possible with a wide variety of sensors (operating in the optical and microwave region of the solar spectrum) and constantly improving sensing capabilities. In arid environments, satellite remote sensing sensors are particularly useful because they have the capability of providing detailed and updated information over vast areas which is essential for many applications, including the exploration of new land and water resources, monitoring of agricultural and urban land expansion and its impact on the natural environment. However, regardless of the level of sophistication these sensors may have, field information (for surface and subsurface observation, calibration and validation) is a required component of any remote sensing study.

In this paper, we present preliminary research results from an ongoing U.S. – Egypt project which deals with the assessment of natural resources in an area located west of the Nile Valley near Aswan and Kom Ombo in the Western Desert of Egypt (Figure 1). This area constitutes the Aswan sector of a development corridor proposed by El-Baz (2007) where a pilot study is being carried out using satellite remote sensing assisted by field survey techniques, including ground penetrating radar.

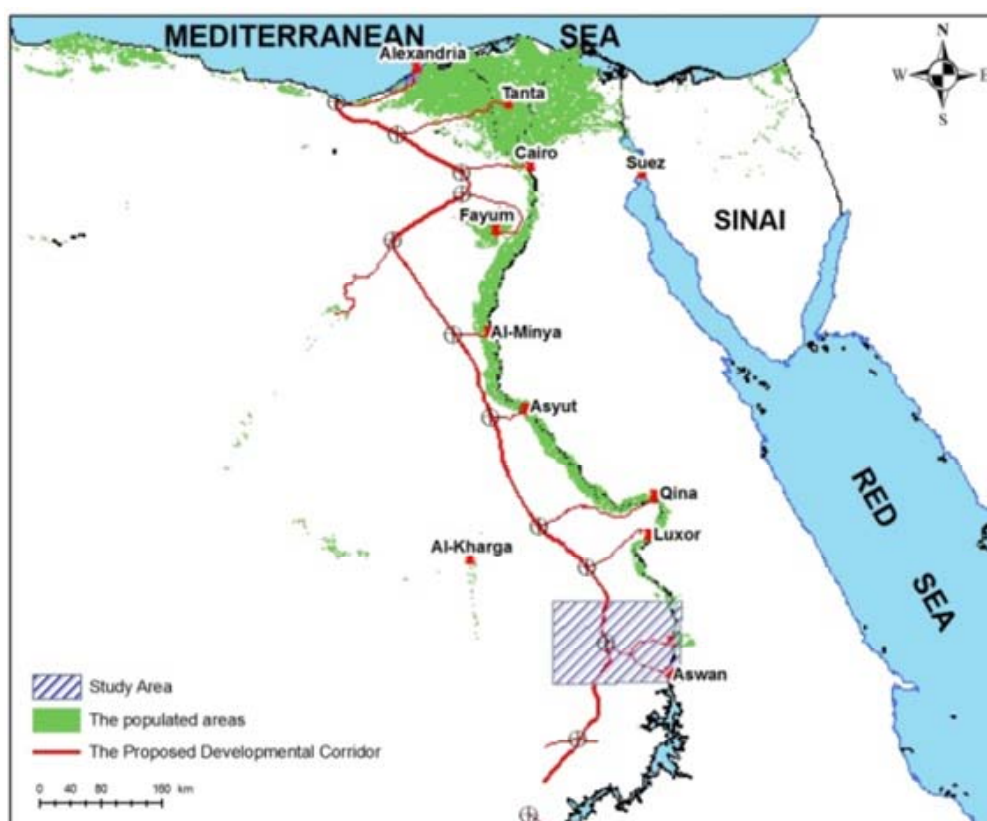


Figure 1: Location of the study area northwest of Aswan

2. Geological Characteristics of the Study Area

The study area is located west of Aswan city, in the Western Desert between latitude 24° to 25° N and longitude $31^{\circ} 30'$ to 33° E, and comprises the El-Gallaba Plain, the western part of the Kom Ombo basin, and Wadi El-Kubanyia (Figure 2). It is characterized by an arid climate with desert-like conditions. Although rainfall is not significant throughout the year, some rare and irregular storms take place over scattered localities during the winter season.

Geologically, the study area is situated within the African Platform with its Pre-Cambrian folded basement, thus its tectonic framework is related to the Last African Orogenic belt (Said, 1962; Abd El-Razik and Razavaliaev, 1972). The entire Nile Valley in Egypt is controlled by wrench faults that are generally parallel either to the Gulf of Suez or the Gulf of Aqaba directions (Youssef, 1968). The

stratigraphic sequence of the study area ranges in age from Pre-Cambrian to Quaternary. The Pre-Cambrian rocks consist mainly of igneous and metamorphic rocks. The sedimentary section overlying the basement complex ranges in age from Palaeozoic to Recent. Thus, the study area has been affected by the same structural deformation processes that generated the Nile Valley and shaped the Kom Ombo basin located east of the Nile River (Figure 3). The study area lies in a relatively large basin (western extension of the Kom Ombo basin) which occasionally receives a significant amount of surface runoff during the rainy season from the eastern Red Sea mountain range. Recently, two productive oil fields have been discovered in this area, which are of great importance for future land development plans. In spite of this recent discovery, the hydrological setting of this area is still not well understood, and therefore, its groundwater potential remains largely unknown.

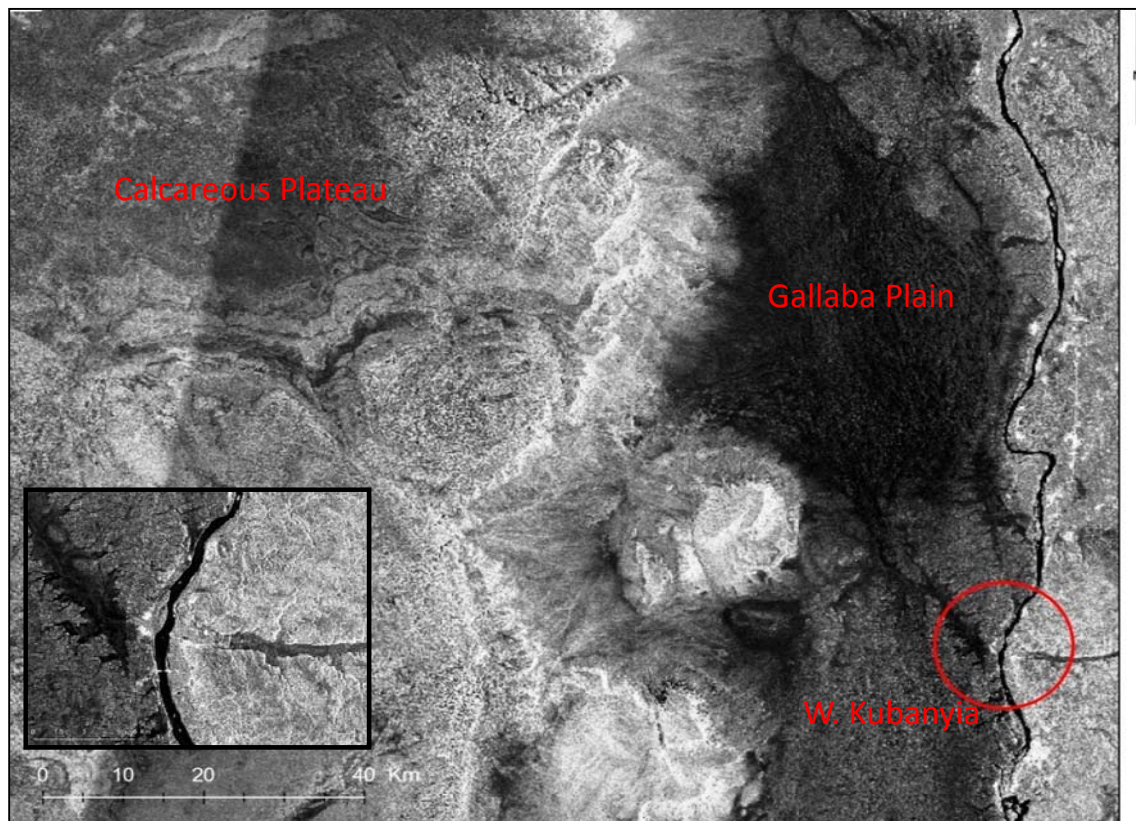


Figure 2: Radarsat-1 image showing Wadi El-Kubanyia and its ancient fan systems west of Aswan.

3. Geo-structural Mapping with Radar

Preliminary work in the study area included field visits in mid-2009 and early 2010 to assess the geomorphological, geological and hydrogeological setting of Wadi El-Kubanyia and the El-Gallaba Plain lying north of it. Satellite radar images (Radarsat-1) revealed an important alluvial fan in this plain that is believed to be the ancient alluvial fan system of Wadi El-Kubanyia (Figure 2). According to Thurmond et al. (2004) Wadi El-Kubanyia was the western continuation of Wadi Abu Subeira (east of the Nile) before the drainage system was fundamentally reorganized in Middle Pleistocene time, reversing its flow direction. Nowadays Wadi El-Kubanyia flows SE into the

Nile; however, in late-Pliocene and early-Pleistocene time this drainage system may have been flowing into the opposite direction causing a large alluvial fan which is now buried under a vast flat plain (El-Gallaba Plain). Optical images (Figure 4a) do not reveal any channels beneath the plain but radar images (from recent high resolution and multipolarized radar sensors such as ALOS PALSAR) do reveal the buried extension of the old Wadi El-Kubanyia channel (Figure 4b). This finding has significant implications in terms of the potential water resources in this area. The old drainage system may have carried large quantities of water from the Eastern Desert into the Gallaba gravel plain (Hinz et al., 2003).

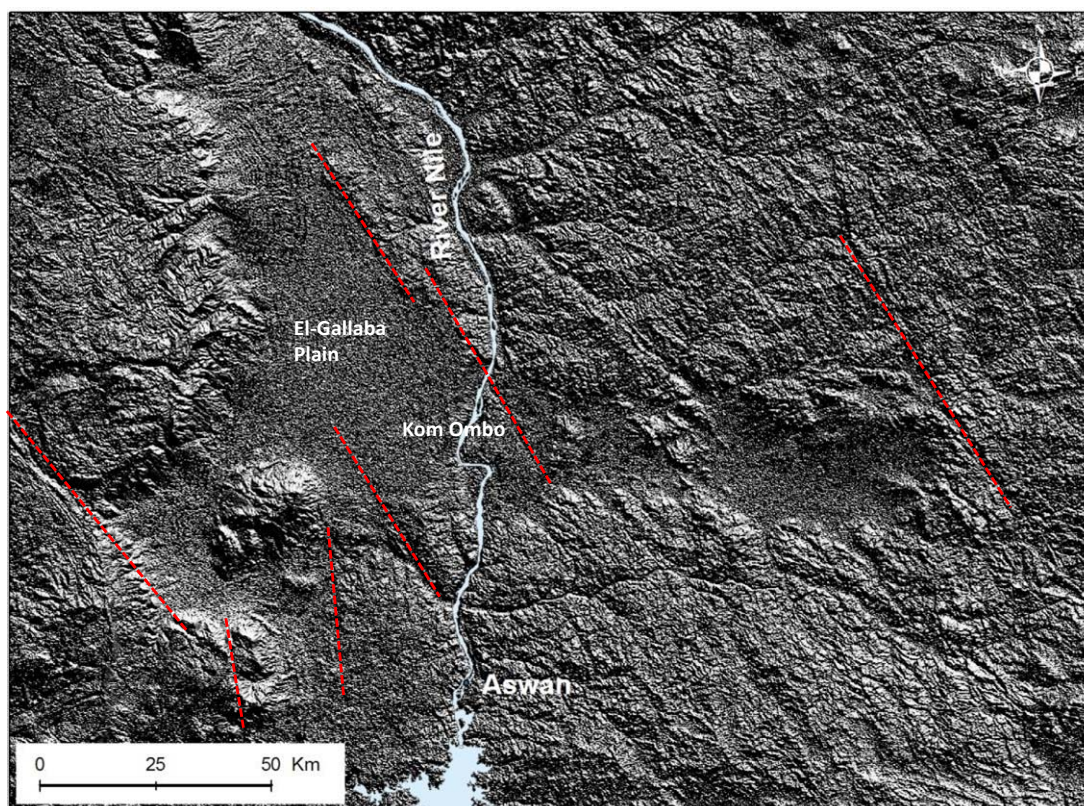


Figure 3: Shaded relief map (SRTM DEM) of the study area with main fault trends (NW-SE and N-S) possibly controlling groundwater flow in El-Gallaba Plain (fault trends are inferred)

In addition, deep seated fractures trending in NW-SE, N-S and E-W directions seem to control much of the Kom Ombo graben structure. These fracture sets have been investigated in detailed in the Kom Ombo graben east of the Nile (El Bastawesy et al., 2010) but not in its western extension, which is our area of interest. From our preliminary work in the western extension of the graben we infer (based on satellite imagery) a set of prominent structures mainly striking in NW-SE and N-S direction (Figures 3 and 4). N-S structures are generally shorter and less pronounced. Our initial work (Gaber et al., 2011) focused on an area where we believed that the old Wadi El-Kubanyiah channel must be buried under the El-Gallaba Plain sand dunes (Figure 4). Satellite radar images supported by field based radar investigation revealed indeed a high concentration of fracture clusters mostly striking in NW-SE direction following the main direction of the Wadi El-Kubanyia channel into the plain. Furthermore, ground penetrating radar (GPR) provided cross sections of the ground, revealing the succession and depth of sedimentary layers. Figure 5 shows an example of a GPR

survey that was conducted in one of the test sites in the El-Gallaba Plain. The GPR profile shows a relatively thin layer of sand sheet deposits lying on top of the older consolidated surface deposits (Figure 5 b). The offsets along the horizontal layers are caused by faults. Most of these structures are not visible on optical satellite images but are detectable by radar. Where the thickness of the windblown sands covering the El-Gallaba Plain increases, fewer structures are detected by the radar sensor. However, a substantially higher number of fractures than previously known were discovered using radar images (Gaber et al., 2011).

The reason for the increased number of faults detectable by radar is that the dry sand of the Western Desert of Egypt provides very good conditions for the low frequency synthetic aperture radar (SAR) sensors (L-band) to penetrate relatively deep. This means that most of the modern sand sheets in the Western Desert are transparent to L-band radar enabling the detection of subsurface features that provide very valuable information related to past fluvial activities

(McCauley, F., et. al., 1982 and Schaber, G., et. al., 1997). Our research has shown that the ALOS/PALSAR L-band (1.27 GHz, 24 cm) sensor is able to penetrate and image buried structures in low electrical loss materials such as the dry sands of the El-Gallaba Plain, and together with its quadrature polarization mode (HH, HV, VH and

VV) has the ability to collect and measure information on polarimetric scattering properties of these buried structures (Gaber, et. al., 2011). Therefore, radar mapping is a promising tool for obtaining a better understanding of the subsurface structures that possibly control groundwater flow in the aquifers found in the study area.

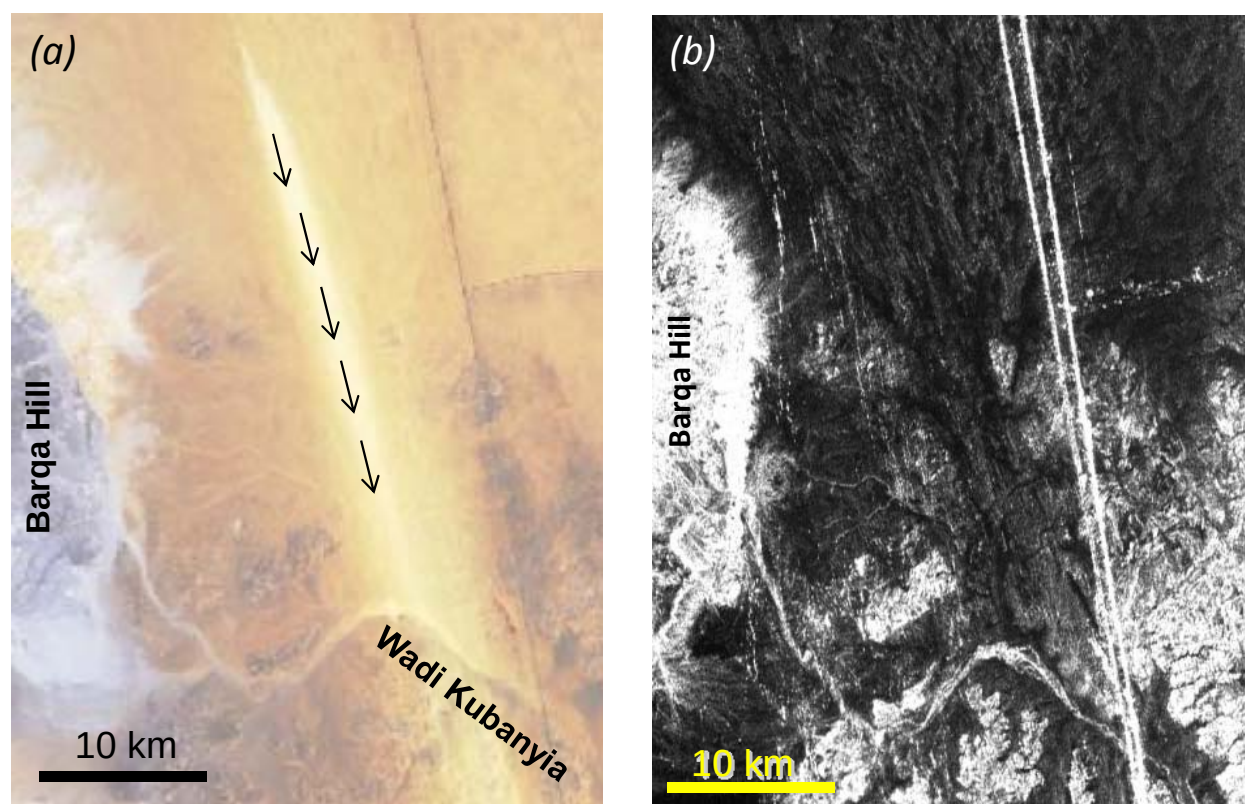


Figure 4: (a) optical satellite image showing moving sands; (b) satellite radar image revealing faults under the sand

4. Hydrogeological Implications of Radar Faults

The geo-structural and hydrological setting of the western Kom Ombo basin where the El-Gallaba Plain lies is not well known. Most hydrogeological studies in this region of the Western Desert have been conducted either to the north or south of the study area. Specifically the western margin of the Lake Nasser has been investigated in order to understand the role that subsurface basement structures play in supplying water from the lake to the adjacent Nubian aquifers. Detailed geophysical survey methods combined with borehole data have

revealed the geological and tectonic setting of this region and allowed a first insight into the geometry of the aquifers SW of Aswan near Lake Nasser (Evans, 1991; Metwaly et al., 2006; Rabe et al., 2009). These studies have shown that the aquifer system is not homogenous but consist of several horizontal layers that are crisscrossed by deep seated structures (reactivated basement structures) causing in some cases uplifting or subsidence of aquifer sections. Some of these structures are also responsible for seepage from Lake Nasser into the aquifers as well as across aquifer layers separated by aquaclude horizons. The predominant fracture

orientations are NW-SE, N-S, and NE-SW, the latter one being primarily responsible for recharging the aquifers west of Lake Nasser (Rabe et al., 2009).

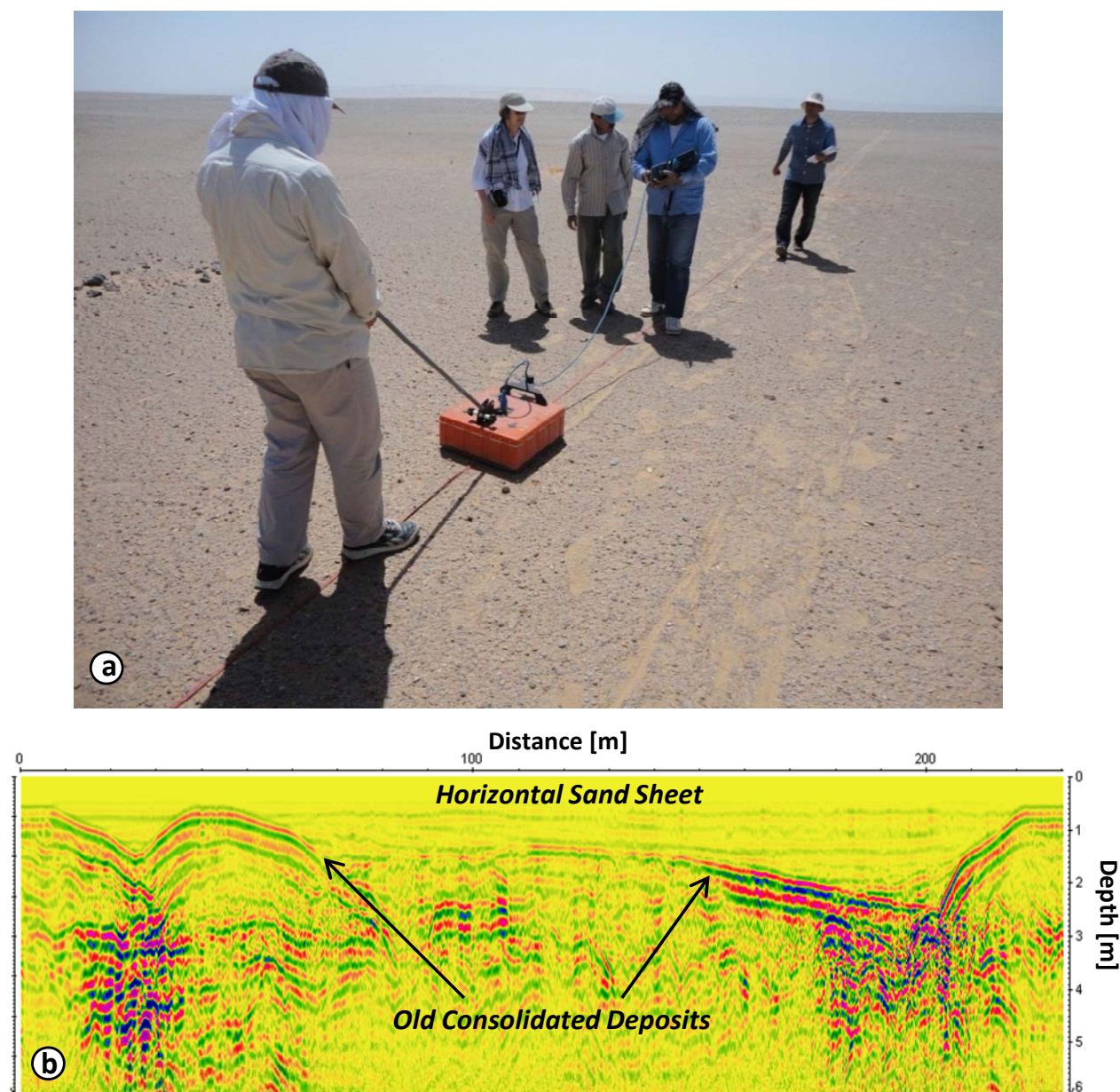


Figure 5: (a) field measurements of subsurface conditions using a GPR; (b) GPR profile

The northern extension of these deep seated fracture systems into the study area northwest of Aswan is presently not known because they are possibly hidden under the windblown sand deposits of the El-Gallaba Plain. However, further south of the study area where the bedrock outcrops at Lake Nasser near the Aswan High Dam, Landsat images clearly reveal a network of fractures deeply

incised in the rock. The fracture network is especially visible on Landsat TM images acquired when the water level in the lake was low (Figure 6). However, as the bedrock becomes covered by Aeolian sands further to the north, the geo-structural information is more difficult to discern from optical images. This is one of the reasons why the aquifer geometry is largely unknown in

the study area. The other reason is the lack of borehole data which makes it difficult to estimate aquifer parameters. Some new boreholes have been located by our initial study in the northern part of the El-Gallaba Plain and water samples have been

collected for chemical analysis. The results suggest that some mixing with water from the Nile is occurring but the mechanism (via fractures or seepage) is not clear.

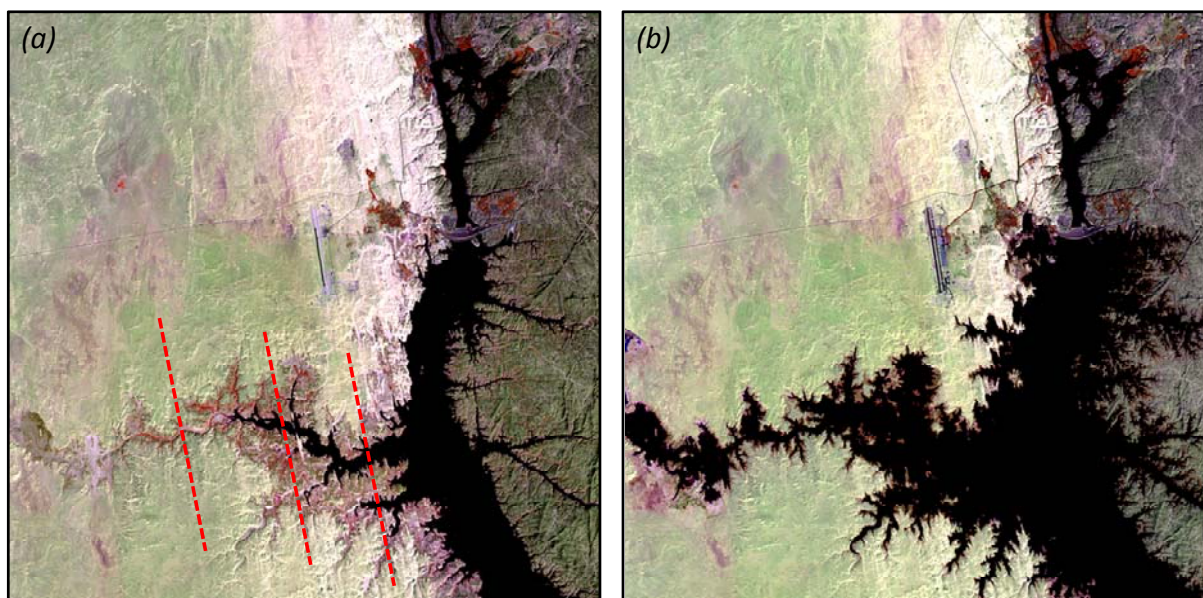


Figure 6: (a) 29 January 1988; (b) 30 January 2009
Landsat TM images of Aswan Dam and Lake Nasser

There is a clear need for investigating the role that these deep seated (and reactivated) fracture zones play in connecting the El-Gallaba Plain aquifer system with the Nubian Sandstone aquifer in the south as well as with the Nile River and Lake Nasser in the east/southeast. The same applies to possible recharge from the adjacent Tertiary limestone plateau (Figure 2) in the west via fractures and/or occasional flashfloods. These are all important questions that need to be addressed prior to any land development activities. Optical as well as radar satellite sensors have the capability of providing geospatial information needed for a systematic land evaluation and for the exploration of alternative (untapped) water resources.

5. Mapping Agriculture Expansion with Optical Images

Agricultural land in the study area is mainly found in the Nile Valley where the soils are most fertile due to the nutrient-rich sediments deposited by the seasonal Nile floods. Most of the agricultural expansion in the study area occurs in the eastern side of the Nile Valley, in Kom Ombo and Idfu regions where Nile tributaries (wadis) provide the best conditions for arable soil and water access. However, the hilly terrain in the Eastern Desert limits the expansion of agricultural land.

In order to determine how agricultural activities have developed over the past 20 years in the Aswan sector, a Landsat TM time series was used to obtain maps showing major land cover/use changes over time (Figure 7). Three Landsat TM images were selected with similar anniversary dates and with intervals of 10 to 12 years. Their main characteristics are listed in Table 1.

Table 1

Landsat image characteristics

Sensor	Month	Day	Year	Path	Row
Landsat 4 TM	January	29	1988	174	043
Landsat 5 TM	February	23	2000	174	043
Landsat 5 TM	January	30	2009	174	043

An unsupervised classification approach (K-means) was selected to obtain an initial number of 50 classes that were subsequently merged to only eight main classes. The class merging and labeling was done based on visual inspection of high resolution images (Google Earth images of 2002 and 2009), a geological map (Conoco, 1987), spectral information and field knowledge. A classification accuracy assessment was performed with 500 random points selected for each image. A kappa coefficient of 0.67, 0.64 and 0.71 was obtained for the 1988, 2000, and 2009 images, respectively.

The time series of Landsat classifications indicates that the expansion of irrigated agriculture is mostly occurring east of Kom Ombo, in a low lying area caused by a tectonic graben structure. The hill shaded relief map in Figure 3 shows the east-west trending graben structure flanked by NW-SE striking fault systems. On the other hand, the western expansion of agricultural land in the El-

Gallaba Plain is very small and limited by lack of surface water and sand encroachment. The Landsat images clearly differentiate two types of sand accumulations in the plain area, namely a thin layer of moving sand (sand veneer) and a thick layer of sand deposits (sand dunes). In order to develop this area for agriculture, a detailed map of surface sediments and soils is needed. Multispectral satellite images can provide this type of information, especially those obtained with a sensor that has many spectral bands covering a wide range of the solar spectrum (e.g. hyperspectral sensors such as Hyperion). It is foreseen that future Earth observation satellite missions will carry improved optical sensors that will greatly facilitate spectral soil mapping from space. Nevertheless, older satellite mission such as Landsat are irreplaceable because of the enormous image archive they produced over the past 40 years.

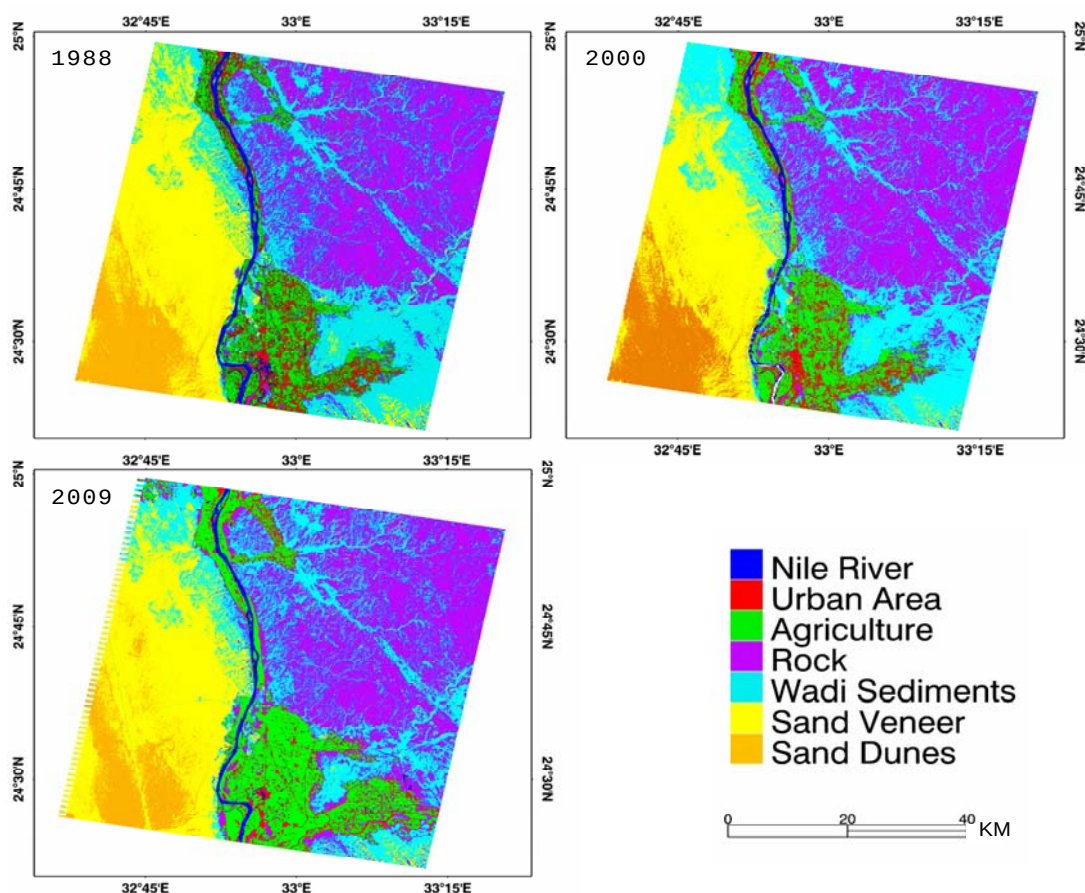


Figure 7: Time series of classified Landsat TM images showing major land cover types

6. Conclusion

Soil and water resources are indispensable natural resources for any land development plans in arid lands, especially for agricultural development. This is the situation in the El-Gallaba Plain of the Western Desert near Aswan, where an old alluvial plain (ancient delta) bounded by the Nile River to the east and the Tertiary limestone plateau to the west has the potential to carry significant amounts of groundwater and provide good soils. This region is currently being investigated by the authors of this article with the goal to understand the geo-structural framework of the El-Gallaba Plain aquifer system. Through the use of satellite optical and radar images assisted by ground penetrating radar (GPR) they were able to map numerous fracture systems currently hidden under the alluvial fan of the El-Gallaba Plain (Gaber et al., 2011). One such fracture system seems to be particularly promising in terms of bringing groundwater from the Nubian aquifer and possibly excess water from

the River Nile or Lake Nasser into the study area. Much of this fault zone is concealed under a linear sand dune field (visible as a bright linear feature in Figure 4a). However, where the sand dunes intersect a wadi system (Wadi Kubanyia), a deflection of its course occurs probably controlled by the hidden structure which may serve as a preferential pathway for groundwater flow. Such areas constitute good potential drilling sites for groundwater abstraction.

Acknowledgements

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