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USE OF SATELLITE IMAGES IN ECONOMIC DEVELOPMENT: THE CASE OF WATER RESOURCES IN THE ARAB WORLD

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USE OF SATELLITE IMAGES IN ECONOMIC DEVELOPMENT: THE CASE OF WATER RESOURCES IN THE ARAB WORLD

by

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Abstract

The slow pace of economic development in countries of Southwest Asia and North Africa increased poverty and exasperated efforts to catch up with the rest of the world. One path to remedy the problem is to utilize space-age methods and techniques to find and properly use natural resources. Because of the dry climate in most of these countries, water is a rare albeit essential ingredient of socio-economic development.

During the past three decades, images were obtained from space platforms with increasing clarity of detail. These images provide a valuable tool to study the environment and monitor its changes in space and time. They are also ideal for understanding of the natural processes of collection, transportation and storage of water in the ground. Use of these images allows the reduction of both the time and the cost of securing additional resources. It also allows the application of unconventional approaches to groundwater exploration.

In this contribution illustrations are given regarding three of these approaches that were tested after the analysis of satellite images, including: (1) considering that sand is produced by the breakup of rock and the transportation of the particulate matter by rivers and streams to inland topographic depressions, it follows that areas with large accumulation of sand (dune seas) lie above much groundwater from seepage of the surface water into the substrate; (2) realizing that fractures in solid rock constitute areas of increased porosity, they form zones for the accumulation of groundwater, even when they occur in non-porous rock; and (3) identifying the courses of former rivers and streams by radar images from space reveals the passageway of surface water in the past, therefore, the location of groundwater at present.

From these examples it is concluded that satellite images must be utilized in the strategic planning for water resources in the Arab World. These data are available to any user, and their utilization far outweighs the cost of their acquisition, enhancement and analysis. Securing strategic water resources for the future allows the planning for proper economic development.

Introduction

The Earth has been the object of intensive exploration from space during the last 30 years. It was realized that photographs from space are particularly useful in the identification of natural resources in remote areas. They are also ideal for monitoring the changes to the environment in space and time, by comparing images of a region to others obtained at a later time. Views from space allowed the evaluation of changes due to both natural processes and activities of mankind. They also allowed the study of global phenomena as well as local features.

In particular, these factors were most important in the study of the origin and evaluation of arid landforms of the Earth (El-Baz, 1988). The reason being that deserts remained the least understood of all the features of the earth because of three reasons:

a) The Earth sciences began in Europe, which is the only continent on Earth that does not have a desert. Therefore, the pioneers of geology did not write about arid landforms, and those who came after them followed suit.

b) The desert is vast and harsh, therefore, few researchers venture into it because of the immensity of scale and the dangers of desert travel.

c) Conventional geologists seek solid rock *in situ*, in place, to sample for later study. However, most desert surfaces are covered by transported mixtures of rock fragments, soil and sand.

Images from space presented a unique tool to study the deserts and monitor their environment (El-Baz, 1988). This is particularly true because arid regions are usually free of clouds and are easy to photograph from above; a space photograph covers a large area and allows the recognition of regional patterns; and due to the lack or scarcity of vegetation cover, a space photograph can be considered a map of the chemical composition of the exposed rocks, soils and sands.

This contribution illustrates some applications of space images to studying and monitoring the arid lands of the Earth. Emphasis is placed on examples of work by the author in the Arab region, which represents the largest desert belt in the world, particularly for ground-water exploration.

Space Imaging

Greater detail in photographs from space resulted from advancements in the technology of remote sensing during the past four decades. Remote sensing is simply defined as investigating an object or a phenomenon from a distance, such as by imaging the surface of the Earth from a spacecraft or probing its subsurface with radar waves.

Imaging of the Earth from space began with the manned Gemini, Apollo, Skylab, Apollo-Soyuz, and Space Shuttle missions (El-Baz, 1998). Photographs on these missions were mostly obtained by cameras aimed by astronauts at important features or significant phenomena. In addition, the unmanned Landsat program introduced in 1972 digital imaging from space (Short et al., 1976). In this case, the image data are transmitted to ground receiving stations for processing and distribution.

For data acquisition from Earth orbit, unmanned and manned spacecraft are planned to fly in high, medium, or low orbits. The highest orbits are left to the unmanned weather satellites, such as Meteosat of the European Space Agency (ESA). These are propelled to a height of 36,000 kilometers above the Earth. At this altitude, their motion is equivalent in speed to the rotation of the Earth about its axis. Such satellites are termed geostationary, and they remain above the same point on the Earth to acquire and transmit repetitive images as frequently as hourly (El-Baz, 1998).

At the lowest orbits, most manned missions are placed below 350 kilometers, to a minimum of 150 kilometers above the Earth. For example, the Space Shuttle operational altitude is about 250 kilometers. From this altitude, images show greater detail such as those of the Large Format Camera which produced images with 10 meter resolution (El-Baz, 1998).

Intermediate orbits, from 700 to 1000 kilometers above the Earth, are left to most unmanned imaging satellites. For example, the polar-orbiting satellites of the National Oceanic and Atmospheric Administration (NOAA) fly at altitudes of 835 to 870 kilometers; the near-polar orbits of Landsat reach a maximum altitude of 920 kilometers above the Earth; and the French digital imaging satellites, *Systeme Pour l'Observation de la Terre* (SPOT) operate from an altitude of 830 kilometers or less. Images collected from these altitudes provide greater local detail than is possible from the high-altitude satellites (Lillisand and Keifer, 1994).

Sand and Wind in the Sahara

The relationship between wind and water processes in the Great Sahara of North Africa is revealed by the interpretation of satellite images. These include the regional views from the Advanced Very High Resolution Radiometer (AVHRR) instruments onboard the National Oceanic and Atmospheric Administration (NOAA) satellites. Further details are provided by photographs obtained by astronauts on manned missions, images of the Landsat Multi-Spectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM), as well as radar data from NASA's Spaceborne Imaging Radar (SIR) and Radarsat. These data provide unique perspectives that allow the recognition of regional influences on wind action and surface features, which result in ground-water concentration (El-Baz, 2000).

The Great Sahara includes some of the driest regions on the Earth. In its eastern part, the received solar radiation is capable of evaporating over 200 times the amount of rainfall. In this desert, precipitation is extremely variable and unpredictable; in some regions it rains only once in 20 to 50 years. This condition necessitates a complete dependence on ground-water resources for human consumption and agricultural activities, taking into account the high evaporation rates and the windy environment.

Space views of the Great Sahara show that surface winds trend in an arcuate pattern that emanates from the direction of the Mediterranean Sea. This is based on the fact that dune lines indicate the direction of the prevailing wind. AVHRR data show that this pattern changes from southward in the northern part of the desert to westward along the borders with the Sahel, a belt of North Africa just south of the Sahara.

This pattern was first suggested for the region of the eastern Sahara based on field mapping by Bagnold (1941). It was also mapped in the rest of the Sahara based on Meteosat data. Wind-produced erosional scars throughout the desert suggest that this regime was effective during much of the last million years. Sand dune chains in the Western Desert of Egypt prove the consistency of this regime at least during the past 5,000 years (El-Baz, 2000).

In the Western Desert of Egypt, sand-carrying wind moves toward the south during most of the year. However, the direction may be slightly affected by local topographic prominences. The rate of motion of dunes in the Kharga depression of the Western Desert of Egypt varies from 20 meters per year for the large barchan (crescent-shaped) dunes to 100 meters per year for the smallest (1 m high) barchan dunes. Seasonal winds from the south do occur, particularly in mid-Spring, but these are not significant transporters of sand (El-Baz, 1988).

As shown by global topographic data and orbital photographs, sand accumulations of the Sahara occur within topographic depressions. This must be explained in any theory regarding the origin of sand and the evolution of dune forms in space and time. Also, the dune sand is composed mostly of well-rounded quartz grains (El-Baz and Warner, 1979). The exposed rocks to the north of the sand seas are mostly limestones, which could not have been the source of the vast amounts of quartz sand.

The two facts cannot support the conventional view of the origin of the sand by wind erosion and its transportation from the north. The majority of the sand appears to have formed by fluvial erosion of sandstone rocks exposed in the southern part of the Sahara. Because areas presently covered by dune sand are topographically low, they must have formed inland basins that received sediments from northward flowing stream channels in the geological past. When the conditions of climate changed to dry, the wind from the north sculpted these sediments into various dune forms and sand sheets. This suggests that the Great Sahara is a region of sand export; an area of negative sediment balance. The transported sand accumulates in the Sahel belt south of the Sahara; an area of positive sediment balance (Mainguet, 1992 and 1995).

Lessons from Dune Patterns

Dune patterns in the eastern Sahara were depicted by Gemini photographs, Landsat images, Skylab, and Apollo-Soyuz photographs (El-Baz and Warner, 1979). In the Western Desert of Egypt, which covers 681,000 km^2, over 23% of the total area (159,000 km^2) is covered by sand dunes. The Great Sand Sea alone covers 72,000 km^2, where densely packed dunes are confined in a relatively low area in the north and linear forms in the south with sand-free corridors in between (El-Baz and Warner, 1979).

In the Great Sand Sea, long sand bodies were called "whaleback" dunes by Bagnold (1941) who theorized that they grew so large that they no longer could move. However, dunes move because individual sand grains are dislodged by the wind, as Bagnold himself noted. Furthermore, cross-sections made into these dunes show that the sand is horizontally laminated rather than curved parallel to dune profiles as in the case of the *seif* dunes that overlie the whaleback forms and the nearby barchan dunes (El-Baz and Warner, 1979). This suggests that what Bagnold named whaleback dunes are residual sand ridges of horizontally laminated sand, left behind as the wind preferentially eroded the sand in what are seen today as sand-free, inter-ridge corridors (El-Baz, 2000).

Views from space allow the realization that the single most important characteristic of areas with high concentrations of sand dunes, including the Great Sand Sea, is their location within topographic depressions (El-Baz, 2000). All the major sand fields of the Great Sahara occur in topographic basins. In some cases, sand emanates from these low areas as it is driven to higher ground by the wind.

Therefore, it was proposed that the dune sand originated by fluvial erosion of sandstone rocks such as those of the "Nubian Sandstone" to the south of, or close to, the dune fields of the eastern Sahara (El-Baz, 2000). The rounding of the grains would have occurred in turbid water as the particulate matter was transported during humid phases in the past by rivers and streams. The sediment load must have been deposited in low areas at the mouths of these water channels. As the climate became drier, the particulate matter was exposed to the action of wind, which locally mobilized the sand and sculpted it into various dune forms.

River Channels Beneath the Sand

Much as satellite images and photographs helped explain concentrations of sand fields and dune patterns, radar images unveiled sand-buried topography. This was due to the capacity of radar waves to penetrate through fine-grained and dry sand, as if it does not exist, and bounce back from the features of solid rock below.

Shuttle Imaging Radar (SIR-C) and Radarsat data unveiled the location of numerous channels of former rivers and streams in the eastern Sahara. The sand cover of these features inhibited their observation in other types of satellite images. The main channels of significance are those in southwest Egypt, northwest Sudan, and southeast Libya.

The SIR-C data depicted drainage channels in the southwestern part of the Western Desert of Egypt. Many of these channels emanate from the Gilf Kebir plateau, a prominent topographic high in southwestern Egypt.

The Gilf is a nearly circular sandstone mass with a diameter of 320 kilometers. The plateau is bordered by numerous dry valleys (wadis) indicating that its edges were shaped by surface water erosion. As Landsat TM images show, the wadis are truncated at the top, which suggests that an upper surface layer of softer sediments had been eroded by both water and wind processes.

Radar data also enhance wadi definition, particularly in the plains. Three major drainage systems, Wadis El-Gharbi, Hamra, and El-Malik start at the edge of the plateau and trend due north toward the Great Sand Sea. Another, Wadi El-Rimal, starts northeast of the plateau and also trends toward the Great Sand Sea region. These channels of former rivers support the interpretation that sand was produced by water erosion and transported to inland depressions by the water of rivers and streams.

Similarly, in Northwestern Sudan there is a vast flat plain over 600 km in diameter. It is known as the Great Selima Sand Sheet after the Selima Oasis, which lies along its southeastern border. This oasis was a rest stop along the Darb El-Arbain (the 40-day track) of camel caravans. Five major drainage lines in the vicinity of the Great Selima Sand Sheet were revealed by SIR-C images with four major lines leading directly to it from the southwest. Such broad channels usually develop under sheet flood conditions with plentiful surface water.

Of particular note is that several of these broad channels display small braided streams in their floors, as revealed by enlargements of SIR-C data. Braiding usually develops by smaller amounts of surface water, indicating several episodes of water flow. Field observations of trenches indicate that moisture begins to appear at 25 centimeters depth in the sand cover of shallow channels in the Bir Safsaf region of southern Egypt (El-Baz, 2000). This suggests that moisture from occasional rainstorms is still carried through, and retained by, the sand cover of the former water channels.

In addition, satellite images clearly show the Kufra Oasis, which had been an important stop along the camel caravan route from Chad northward to the Mediterranean Sea. The images display the pattern of circular irrigation farms northeast of the Kufra Oasis. These farms were developed starting in the 1960s by Oxidental Petroleum Company, as part of a concession to explore for oil. The farms are visible from space due to the contrast (in the visible, near-infra red, and radar data) between the vegetation and the surrounding sandy plain (El-Baz, 2000).

Radar data reveal the courses of two sand-buried former water courses to the southwest of this region. The narrower channel passes through the Kufra Oasis and appears to originate from the direction of the border with Chad. The wider channel is oriented in a NW-SE direction. A Radarsat image of its extension toward the east indicates that it originated from the Gilf Kebir plateau in southwest Egypt. Both the location of the Kufra Oasis and the circular irrigation farms are due to the presence of these two former rivers.

These data confirm that the desert belt of the Arab World experienced earlier periods of greater effective moisture. In addition to the unveiling of dry courses of ancient rivers, this is evident from archaeological sites associated with remnants of lake deposits. Archaeological evidence of previous human habitation, coupled with remains of fauna and flora, suggests the presence of surface water in the past.

As documented by radiocarbon dating and geo-archaeological investigations, the Sahara as well as the Arabian Peninsula experienced a period of greater effective moisture about 10,000 to 5,000 years ago. Prior to that, alternating wet and dry cycles persisted for at least the past 300,000 years.

Implications to Ground Water

As stated above, dune accumulations in the deserts of the Arab region, as in all other deserts, occur within or near topographic depressions. This must be explained in any theory regarding the origin of the sand and the evolution of dune forms in space and time. Two other important observations must also be taken into account.

The first is that wind in the Arab desert belt moves towards the south during most of the year, except where it is locally affected by topographic prominences. The second observation is that sands in these dune fields are composed mostly of well-rounded quartz grains. The exposed rocks to the north of the sand seas are mostly limestones, which could not have been the source of the vast amounts of quartz sand (El-Baz, 2000).

These two observations discount the possibility of the origin of the majority of the sand by wind erosion and transportation from the north. Therefore, it is more likely that the areas covered by dune sand were relatively low areas that received sediments from northward flowing stream channels in the geological past. When the conditions of climate changed, the wind sculpted these sand accumulations into various dune forms, sand ridges, and sand sheets.

As explained above, the patterns of dunes in the eastern Sahara support this theory (El-Baz, 2000), which has a far-reaching implication. Because the sand was transported by ancient rivers, the depositional basins would have received vast amounts of freshwater. Most of that water would seep, through primary and secondary porosity, into the substrate. Thus, areas that encompass large sand dune accumulations may host vast ground-water resources. This means that the vast dune fields of the Arab region including the Great Sahara and the Arabian Peninsula may be underlain by much ground-water.

This theory has been tested in the eastern Sahara, for example, where concentrations of ground water abound in topographic basins abound in Libya. Because of the encroachment of sea water into the coastal aquifers, Libya had to transport sweet ground water from the southern part of the country to where the population is concentrated along the Mediterranean seacoast. Hundreds of wells were drilled for ground water in five basins: Kufra, Sarir, Sirt, Hamra, and Murzuq. The water is transported in a pipeline, which is capable of delivering up to 2,000,000 m^3 per day (El-Baz, 2000).

Indications of a similar hydrogeologic setting exist in the Western Desert of Egypt. Ground-water exploration in the East Oweinat region of the northern part of the Great Selima Sand Sheet confirmed the presence of resources to support agriculture on 200,000 hectares for 200 years (El-Baz, 1998). When wells were drilled in this region to 350 m depths, the water rose to only 30 meters below the surface.

In addition, two wells near the northern and eastern edges of the Great Sand Sea proved the presence of vast amounts of water. These wells were drilled south of Siwa Oasis and southwest of Farafra Oasis, respectively, to the depth of 1,200 m in the course of exploring for oil. The two wells penetrated thick sandstone sequences that were saturated with ground water. The water in these two wells fountains under artesian pressure up to 20 m into the air, indicating vast resources at depth (El-Baz, 2000).

Conclusion

A better understanding of the origin and evolution of desert landforms is afforded by image acquisition from space. These images allow the identification of desert landscapes and a practical means to monitor changes in space and time.

The system that produces images that are most applicable to desert study include: a) digital sensors in high and low orbit that acquire low and high resolution images, respectively; and b) radar systems that are particularly useful in revealing the buried courses of ancient rivers beneath desert sands.

Data from space imaging systems are particularly applicable to the investigation of processes that act upon desert surfaces. Their analyses have shown that the Arab desert belt stretching from North Africa to the Arabian Peninsula hosted much wetter climates in the past. Much of the water from the humid phases remains trapped beneath the desert surface, particularly under areas of large sand dune accumulations. This must be taken into account in the search for ground-water reserves for future economic development in the Arab World.

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