Low-Cost Mapping of Sabkha-Ecosystems Using Satellite Imagery: An Example from SE Qatar

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Abstract The article tries to show up an easy way to acquire satellite images (SPOT monochromatic/grayscale) for free, using the internet portal "Geoengine", maintained by the National Imagery and Mapping Agency (NIMA) of the United States. In a second step, these images (in this case sabkha-dune ecosystems in south-eastern Qatar) are loaded into a GIS (Geographical Information System)-program (ArcView® 3.2) and analysed for reflectance values, correlated with the values for known sabkha areas, that were taken during earlier field trips in Qatar.

The combination of satellite imagery and ground control points within areas of known geomorphological and geoecological characteristics produces an approximate map of the spatial extent and distribution of sabkha ecosystems in south-eastern Qatar.

1 Introduction

Systematic mapping of ecosystems using satellite imagery – especially for education purposes – is often hindered by the availability of adequate metadata and sufficient financial support to acquire the necessary scenes. Even though this is still true for most of the actual and high resolution data, there are few possibilities to acquire satellite images through the internet free of charge, except online-fees.

The online distribution of satellite images was limited by the data transfer rate for a long time. Up to the end of the 1990s, only enterprises, universities or other governmental institutions could afford fast internet access. In the meantime, the demand for high-speed internet connection has risen, so that a complete coverage system of fast internet access is available in most industrial countries.

Following the spread of fast and reliable internet access, some companies – like Microsoft®'s Terraserver – developed systems that allowed the user to view and print small parts of satellite images for private purposes. However, the user could not save whole images to disk or print large scenes, nor were the images ready to use in Geographical Information Systems or other professional digital imaging tools.

2 The Geoengine: Data Acquisition

One of the rare opportunities to acquire images at a larger scale is provided by the Geospatial Engine (http://geoengine.nima.mil) (Fig. 1). Managed by the National Imagery and Mapping Agency (NIMA), this internet portal offers satellite images, digital elevation data and vectorized basemaps for many parts of the world.

The data coverage includes the western central part of the United States, Europe/Eurasia excluding Portugal, Ireland and Scandinavia, major parts of the Arabian Peninsula including the Sinai and some scattered areas (e.g. Central America, Libya, Korea and South Eastern Asia). South America, major parts of Asia and Africa, as well as Australia and Antarctica are not covered (Fig. 2).

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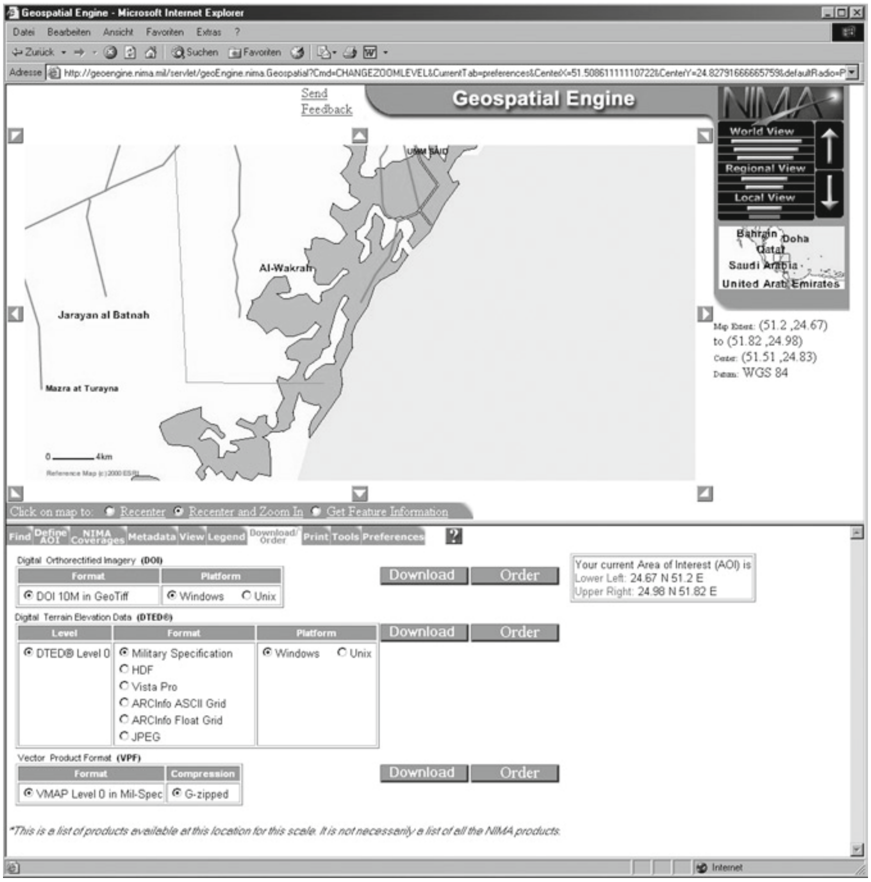

Fig. 1 The Geoengine website

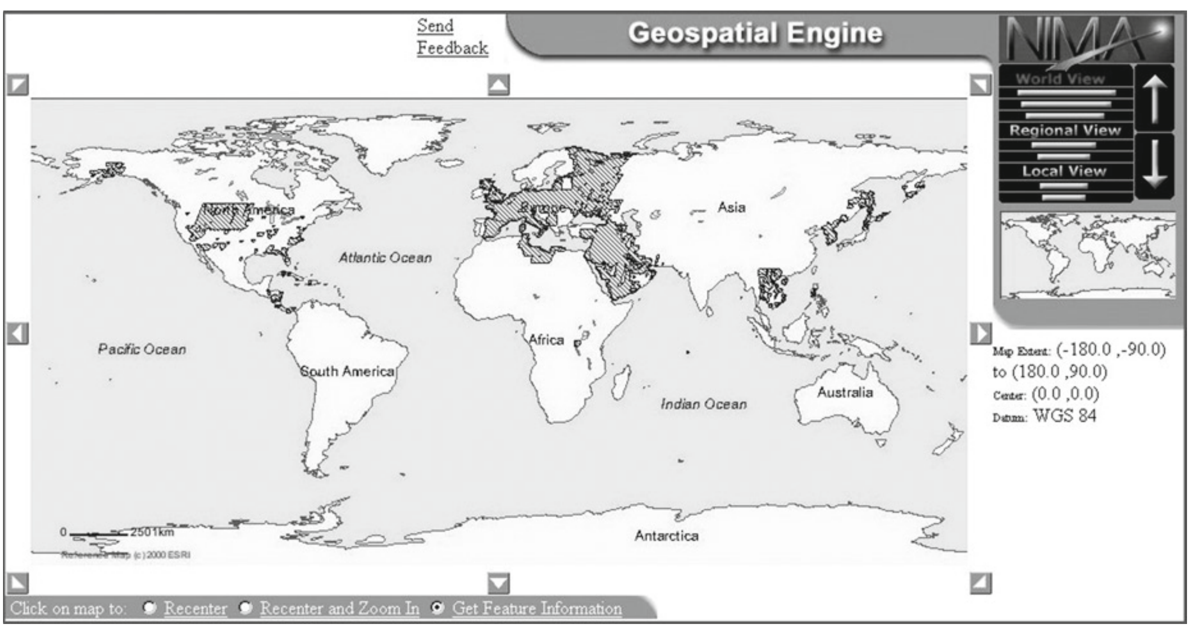

Fig. 2 Spatial coverage of DOI 10M satellite images

The offered satellite images were originally obtained from the SPOT Image Corporation under an unrestricted license. They are delivered as 10 m digital resolution orthorectified imagery (DOI-10M) and were acquired between 1992 and 1994. Depending upon operating system, the images are delivered in the georeferenced GeoTiff-format for Windows or UNIX and can be used in professional GIS-Software as well as in conventional low cost image processing systems without making full use of all advantages of the given format.

Data access is very simple. The website is divided into two frames: the upper frame contains a browsable map of the world, based on ESRI®'s mapserver technology. The window allows users to choose their area of interest via browsing and zooming on a "world" to "local view" level. The lower frame is subdivided into several categories regarding file format, data source, date and extend of data acquisition, download proceedings and data find, which allows users to search images via spatial coordinates.

When the reference map in the upper frame is centred on the appropriate area of interest, the data can be downloaded in the required format from the "download" button in the lower frame. If the user is not sure, whether the requested spatial extent is covered by the DOI-10M or needs a preview of the area, the "view" button gives a quick (low quality) overview of the availability and quality of the existing imagery. The initial download request is followed by the determination of the estimated download size, which has to be below 50 MB to reduce the server load of the Geoengine-Website. If the file-size is bigger than 50 MB, the user is asked to reduce the spatial extent and an optional part of the area is presented. To speed up the download time, the satellite imagery is automatically compressed to a ZIP-archive afterwards, which reduces the file-size to about 50% of the original image. This process takes several minutes (depending on server load), but the building progress is documented on the website every few seconds. When the build of the compressed file is finished, the server indicates the final size of the ZIP-archive and draws attention to the licence conditions that are implied in the use of these images. The download time of the compressed archive depends on the size of the original image, the type of the internet connection and the server load of the NIMA Geoengine. Given a high speed internet access, download time should be in the range of minutes with maximum transfer rates of about 400–500 KB per second. Users with slower access can use download managers to stabilize the data connection, because the Geoengine-Server supports the "resume"-function of most of these programs. After download is complete, the ZIP-file has to be decompressed using an unzip utility. The resulting GeoTiff-file can now be viewed or analysed in the corresponding software programs.

A similar procedure is necessary for the download of digital elevation data (DTED®), that is available in various specifications like ARCInfo ASCII or Float Grid, JPG or HDF etc. The Digital Terrain Elevation Data (DTED®) Level 0 was developed by the NIMA to provide the scientific community as well as the interested public with basic quantitative terrain data on a digital basis. In contrast to other high resolution elevation data that is intended for military purposes, the DTED® Level 0 data was deliberately "thinned" from the original NIMA DTED® Level 1 to a nominal resolution of 1 km per pixel (= 30 Arc Second Terrain Data). This specification is suitable for the modeling of whole regions or countries, but only of limited use on a local level. The diverse specifications of the data permits the use of the data in most GIS-systems and makes it accessible to the general public.

Apart from the described satellite imagery and digital terrain data, the Geoengine-website offers many other features that can be used in a geographical context, but are not listed here for clarity reasons. One example for additional data is the availability of vectorized basemaps (VMAP Level 0 in military specification) in the Vector Product Format that can be used in most GIS programs. The map preview in the upper frame is based on the VMAP Level 0 and gives a first impression of the quality of the downloadable files available on a CD-ROM sized basis.

3 Geographical Aspects of the Study Area

The study area is located in the southeastern part of Qatar, south of Umm Said Industrial City (Fig. 3). It is part of an approximately 60 km long and 30 km wide belt of active dunes, that are moving from NNW to SSE (Embabi and Ashour 1993). The up to 40 m high dunes are orientated perpendicular to the dominant "Shamal" winds from NNW and increase their density towards the SSE (Al-Sheeb 1998). In upwind direction the sand accumulations mainly consist of single barch-

Fig. 3 Location of the study area

ans, whereas they coalesce into complex/compound barchans and transverse dunes further downwind due to a higher sediment supply.

Most dunes – especially in the inland area – are underlain by Eocene limestones and dolomites of the Upper Damman Formation, that crops out in major parts of Qatar peninsula. Near the southeastern coastline, these Tertiary rock formations are overlain by an up to 30 m thick sequence of sabkha deposits, mainly composed of siliciclastic sands and minor parts of dolomite or other carbonate fragments (Shinn 1973). This approximately 500 km^2 large area of sabkha is partly covered by sandsheets and active sand dunes that are migrating over the damp surface towards the sea. In contrast to most coastal dunefields, where dunes are driven inland by onshore winds, the Umm Said Dunes are prograding offshore, thereby creating small pools between dune-arms that are frequently flooded during high tides.

The origin of the dunes in southeastern Qatar is still uncertain. Most researchers believe that the siliciclastic sands of the Umm Said dunefield are of external origin and were not generated on Qatar Peninsula (Shinn 1973; Ashour 1987). The mineralogy of the dune sands indicates to an origin on the Arabian mainland, that nowadays is separated from Qatar peninsula by the Gulf of Salwa. It is speculated that during late glacial lowstands of the Arabian Gulf, combined with the enhanced "Shamal"-Winds of this time period, dunes were piled up in the Eastern Province of Saudi Arabia and moved onwards in SSE direction towards the Gulf of Salwa (Shinn 1973). Sandbars (former transverse dunes today covered by coastal waters) which are detectable on satellite images of this area (Al-Hinai et al. 1987), point to the fact that the dunes moved over the then dried out Gulf and reached the northwestern coast of Qatar. As sea-level rose in the early Holocene, the dunes were cut off from the sediment source areas in the NW and were eroded by undersatured winds, thereby moving further to the SSE. Due to an almost flat territory, the sands passed the Eocene limestone formations of central Qatar without major disturbances and reached the southeastern coast, where huge amounts of sand were spilled into the low-lying coastal areas and the sea.

Interspersed with small portions of local carbonate grains, these siliciclastic sands were responsible for the development of the sabkha sequence, whose thickness is controlled by the sea-level as an absolute erosion basis. Given the limited to exhausted sand supply and steady winds from the NNW, the sand dunes of the Umm Said area will be gone in a matter of 1,000 years (Shinn 1973), thereby producing larger sabkha areas, that will be overformed by coastal processes after the depositions of quartz sands ends.

4 Methods

This study uses Esri's ArcView 3.2 GIS program to analyze the satellite images. Although most image processing programs are able to execute the basic manipulation processes of this study like grouping of color values, GIS-systems simplify and enlarge the possible modifications to a certain degree. To make full use of ArcView's image processing capabilities, it was necessary to load the Spatial Analyst 2.0 extension in addition to the core program.

After downloading the selected sample imagery of southeastern Qatar (Fig. 4) from the Geoengine website, the GeoTIFF satellite image was extracted from the ZIP-archive and loaded into ArcView using the

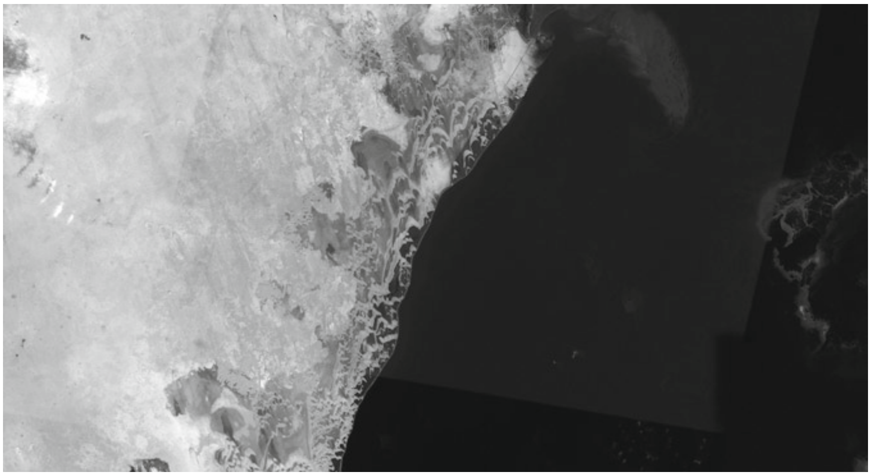

Fig. 4 Unchanged original satellite image from the Geoengine website. See Fig. 3 for scale (© CNES/SPOT Image 1992–1994)

TIFF 6.0 Image Support module. Due to its data format that contains spatial references, the image is directly placed in its correct geographical position. This feature makes it possible to avoid problems with the Geoengine's limitation of 50 MB per image because related files can be placed in the right position without further efforts, thereby facilitating the analysis of larger areas.

Afterwards, the GeoTiFF was converted into an ArcView Grid using the Spatial Analyst extension. Even though basic information like gray values can be directly derived from the original image, this transformation is necessary to classify single color values into distinct groups and to mark areas with special characteristics. By default, the image conversion produces nine distinct classes (equal distance) of color values and one field for missing data using a random color ramp. Although no intentional modifications of the image were made at this point, the combination of single values into groups results in the basic structuring of dominant landscape elements. This effect can be recognized extremely well in the northeast of the grid, where underwater features like longshore-drift of sediments are detectable, that are barely visible in the original satellite image (Fig. 5). Something similar applies to the sabkha areas that are marked by dark (original) values due to their high water content, whereas the sea is characterized by its unmistakable black value.

To refine this random classification, ground control points were set in the study area during an earlier field trip. These points were taken in areas that were visually identified in the field as sabkha areas using a handheld GPS (Garmin etrex, 5 m average resolution). They were converted into shapes (point theme) and loaded into the ArcView project. Comparison of the ground control points with the color values of the grid theme showed that all known sabkha areas have values in the range of 30–90 (based on the original color scheme of the gray scale image). If applied to the random grouping, setting values below 30 as sea and above 90 as other terrestrial environments, this classification produces an approximation of the sabkha areas in southeastern Qatar. To avoid the inclusion of marine elements like shallow waters in the "sabkha ecosystems group" (compare with Fig. 5), only pixels west of the coastline were included in the reclassification, whereas all pixels east of the coastline were classified as sea (Fig. 6).

Due to the simple processing measurements, this classification of the sabkha ecosystems in southeastern Qatar is far from perfect. As can be seen in the upper right corner of the random classification, reflectance values of sabkha areas with a high moisture content are very similar to those of very shallow waters. Sabkhas in a more continental setting are often covered by thin veneers of blown sand that falsify the readings as well. Taken all these things together, this method is not appropriate (and not intended) for high resolution interpretation of satellite images with the concentration on single elements, but for a quick low-cost overview of landscape elements with similar reflectance characteristics.

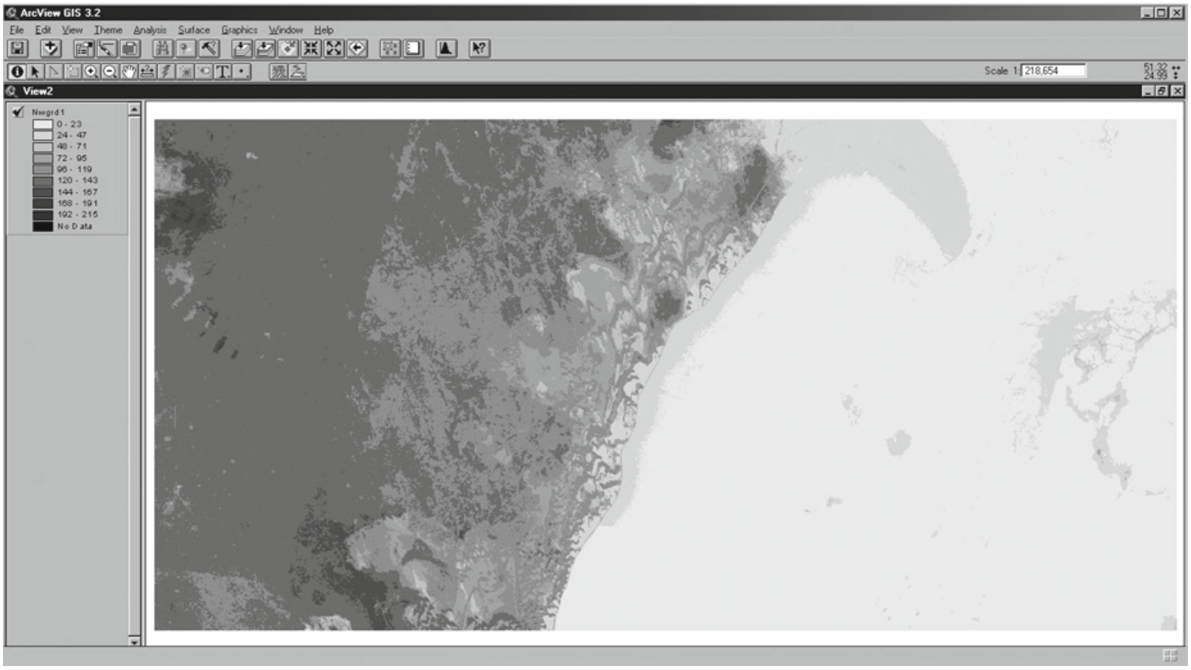

Fig. 5 Random classification after conversion into ArcView Grid. Please note the visibility of shallow water in the NE of the image that was barely recognizable in the original image

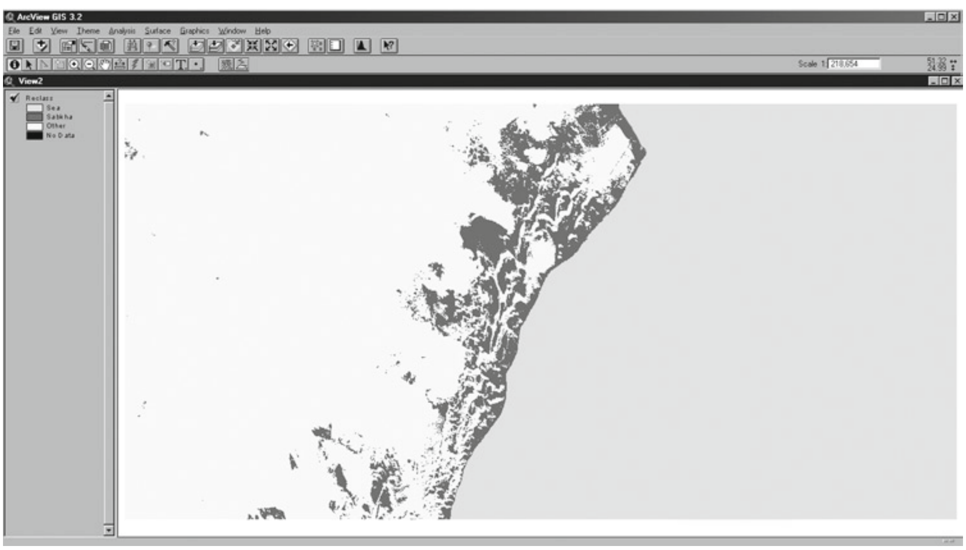

Fig. 6 Approximate map of sabkha ecosystems in southeastern Qatar after reclassification

5 Conclusion

The presented study shows that it is possible to acquire high quality satellite images for free, using the Geoengine internet portal. The images are not appropriate for the mapping and study of short-term processes like infrastructure planning, because of its pre-determined date, but are suitable for landscape classification purposes. This classification can be done by the use of GIS programs like ArcView without major efforts. The combination of image processing and comparison with reflectance values of known geoecological specification produces an approximate map of the existing landscape units.

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