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Detecting modern desert to urban transitions from space in the surroundings of the Giza World Heritage site and Greater Cairo

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ABSTRACT

During the last decades, Greater Cairo, Egypt, is increasing in population and in built-up extension. Some of the new buildings are informal, constructed in absence of government planning processes, and threaten the Heritage Cultural Site of the Giza Pyramids. In addition, the fertile land of the Nile floodplain is being urbanized despite the government's building prohibition since the 1990s. Therefore, constant monitoring of construction activity is crucial in the rapidly changing environment of this area. Here, we present a data fusion approach that overcomes the limitations of single medium resolution sensor approaches, and also identifies areas in transition from desert to urban. We use multi-temporal multi-sensor supervised land use classification and include a new land use class for detecting undefined disturbances. Synthetic aperture radar (SAR) data is combined with multi-spectral data for creating the land use land cover (LULC) maps using artificial neural networks (ANN). Specifically, ERS SAR data is combined with Landsat 5TM for 1998 and Envisat ASAR IMS with Landsat 7 ETM+ for 2004 and 2010. With this data fusion approach, it is measured an increase of 73% of Greater Cairo built-up extent from 1998 to 2010. Finally, we show the relationship between the aforementioned disturbances and the new built-up areas, detecting 26% of the total new built-up areas constructed from 1998 to 2010 where undefined disturbances were identified in previous land use maps.

1. Introduction

The world is becoming progressively urbanized. Especially in developing countries, this trend has been accelerating over the last two decades. Over the next 30 years, the world's population growth is expected to be concentrated in urban areas within the developing world [1]. The challenges for achieving sustainable urban development will be particularly significant in Africa [2]. This is certainly true for Cairo, the most populous urban agglomeration in Africa. The urban sprawl of Cairo during the last decades resulted in the replacements of the fertile floodplain of the River Nile by urban structures. From the time of the 1996 population census onwards, the Egyptian government has tried to avoid new constructions in the Nile floodplain by encouraging people to live outside the so-called 'green land' and settle in the arid areas of the eastern and western desert plateau [3]. Despite the restrictions introduced in 1996 inner-city slums grew, and informal settlements bloomed on the urban fringe [4]. What is particularly troublesome is the increasing urban pressure on the Giza pyramids plateau, designated as UNESCO World Heritage Site (WHS) and protected by the 1972 World Heritage Convention [5]. Debate between scholars, practitioners and activists over development activities within and around this unique site is leading to growing conflict between conserving the archaeological site on the entire plateau and developing the surrounding areas [6].

Detailed mapping and monitoring of the evolution of Cairo's urban structure and morphology is therefore needed for an effective management policy and a comprehensive view on urban governance and protection of cultural heritage. Several studies have discussed remote sensing techniques to monitor and analyse dynamic expansion and urbanization in Greater Cairo. Most of them have made use of optical sensors [7,8].

However, using just optical data, distinguish between different objects composed of the same material can be difficult. Stewart et al. [9] reported difficulties in spectrally distinguishing urban and desert features from optical sensors in the desert areas of Greater

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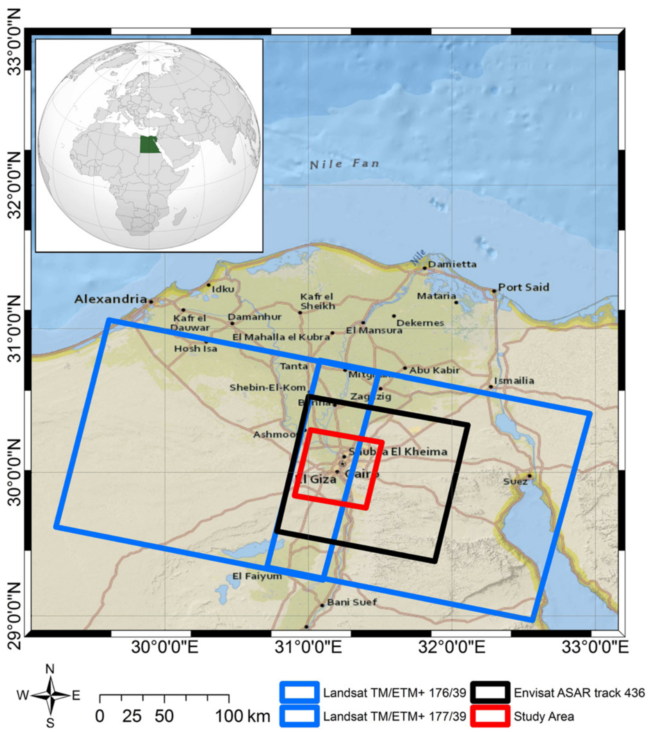

Fig. 1. Location of the study area in Greater Cairo, Egypt.

Cairo, due to the heavy layer of sand/dust that coats buildings and the fact that in this area construction materials are sourced from the nearby desert land.

Analysis using only synthetic aperture radar data and their derived coherence products might also produce misclassification of areas with high temporal variability [10]. Therefore, our assumption is that in this case, contrary to the natural behaviour of the coherence maps, low coherence does not represent only water or fields [11] but also areas where other activities are ongoing [12]. Hence, we define a new land use class for detecting these areas and differentiating them among other classes.

This paper proposes the analysis of the optical and SAR data fusion for land use classification over Greater Cairo and Giza to overcome the aforementioned limitations. In addition, we also checked if the introduction of a new land use class could better capture the differences between the optical and SAR based techniques (reported in [10]). This new class may represent areas with human-induced changes, that could be permanent or transitory, such as open pits, roads eventually covered by sand and ongoing building activities among others. This new class has been called 'undefined anthropogenic disturbances' (UAD) and is mainly located in desert areas.

In this paper, the effect of optical and radar satellite data fusion in medium spatial resolution is tested and applied to analyse the multi-temporal evolution of the urban extension of Greater Cairo for the period from 1998 to 2010.

2. Study area and remote sensing datasets

The study area is centred on Greater Cairo and its surroundings, which covers a total area of approximately 50 × 50 km (Fig. 1).

In 1996, Cairo's population was approximately 6.78 million citizens, while in 2006 it reached 7.78 million inhabitants, being reported in 2012 an approximate population of 8.76 (source: http://statoids.com/ueg.html). Over the twentieth century, the Egyptian population increased by nearly 60 million (Fig. 2), reaching over 11 million inhabitants in 1907 and more than 72 million in 2006 (source: CAPMAS). In the last decades the informal construction[1] [13] increased dramatically, threatening the Giza's Pyramids World Heritage site. Therefore, we have focused in analysing the built-up increase in the Pyramids Gardens area, named Hadayek Al Ahram, as well as in the entire Greater Cairo for which their results are analysed individually.

We used the freely available archives of Landsat 5 TM and 7 ETM+ optical data, as well as ERS1/2 and Envisat SAR data. The selected SAR datasets comprised the full archive of ERS-1/2 and Envisat ASAR satellites, both in track 436, jointly covering the entire period from 1992 to 2010. The chosen optical satellite imagery was Landsat-TM and ETM+ 1998, 2004 and 2010. The specific information is shown in Table 1.

3. Methodology

In order to study the land cover dynamics based on the data fusion of SAR and optical data, the implemented methodology follows this three steps (Fig. 3):

- data preparation;
- land use classification;
- temporal evolution analysis of the obtained classification maps.

3.1. Data preparation

The first step is preparing the various datasets. Initially, SAR imagery is calibrated considering the incidence angle, look angle and the antenna pattern using ESA specifications implemented in NEST [14]. Then, coregistration, resampling, interferometric coherence computation and geocoding are performed using the DORIS interferometric software from Delft University of Technology [15]. Precise orbits from Delft Earth Observation and Space Systems (DEOS) are used to recompute orbital information in order to reduce the coregistration errors. The interferogram image pairs are selected for the subsequent computation of the interferometric coherence based both on short temporal and perpendicular baseline criteria (maximum of 140 days and 120 m respectively for this study). Coherence can be affected by temporal, spatial and thermal decorrelation factors [16]. Hence, a short temporal baseline ensures that there will be minimum changes present in our scene due to the physical changes, and having a short perpendicular baseline minimizes geometric decorrelation [16]. This short temporal and perpendicular baseline condition is required to enable the preliminary identification of urban, desert and field areas using the interferometric coherence [11]. It is worth mentioning the seasonal effects of the sand storms characteristic of our study area around March–April every year. Hence, coherence maps with images acquired during the period with a higher frequency of sand storms in the region (i.e. March–April) were rejected for further analysis. Finally, calibrated SAR images and coherence maps are geocoded using SRTM DEM information [downloaded from the Consortium for Spatial Information (CGIAR-CSI)] in order to have them geometrically corrected.

Radiance Landsat values are computed using the data provided in the Landsat metadata using the radiometric calibration method suggested by USGS [17] and implemented in ENVI ESRI software. Four scenes are selected for 2004 and 2010, because of the scan

[1] The United Nations Centre for Human settlements (UNCHS) defines informal construction as building without getting its corresponding authorization. In addition, in many developing countries building permits were only issued in major towns so building outside of the towns would automatically be 'informal'.

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