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Flood risk assessment of the Abu Simbel temple complex (Egypt) based on high-resolution spaceborne stereo imagery

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A B S T R A C T

The ancient Egyptian Abu Simbel temple complex, located on the western bank of the Lake Nasser reservoir behind the Aswan High Dam, is increasingly vulnerable to natural and anthropogenic processes. Flooding by the rising waters of the reservoir is among the main factors that threaten this ancient structure. With the present construction of a series of large dams from the 2nd through 5th Nile River cataracts in Sudan as well as the building of Africa's largest hydroelectric dam, the Grand Ethiopian Renaissance Dam, there is growing concern about the safety of the structure. Accordingly, there is a dire need for the development of a novel tool to enable detailed and systematic monitoring of potential hazards that the ancient temple complex may face in the future. Therefore, in order to quantify the possible inundation of the temple complex and to locate potential segments at risk of flooding, stereo pair imagery from the Pleiades-1A satellite sensor were used to build a very high-resolution 2-meter digital elevation model (DEM). Using the derived DEM, a number of reservoir water level rise scenarios were simulated using GIS. The results showed that with a slight increase of the reservoir's water level from 175 m to 177 m ASL, only 4.9% of Abu Simbel peninsula would be inundated. Such flooded area would increase to more than 13% with a water rise of 181 m ASL. A hypothetical high water rise event of 185 m and 189 m ASL, as a result of potential catastrophic damage to the upstream neighboring dams, would submerge nearly one third (30.3%) and half (~53.7%) of the peninsula, respectively. In particular, the eastern portions of the Smaller Temple and the causeway of the Great Temple would be most severely impacted by the flooding. A new user-friendly Google Earth Engine tool, "Satellite Observations for Archaeological Preservation" (SOAP), was also developed to easily and dynamically display the flooding simulation results to in-country stakeholders and policy makers. The innovative approach used for this study is highly adaptable and with only a few minor modifications can be used for assessing vulnerability of similar archaeological sites to reservoir flooding worldwide.

1. Introduction

The use of remotely sensed data for the purpose of archaeological exploration and digital preservation has changed the trajectory of the discipline of archaeology over the past decades. The implication of using these high-resolution, temporally continuous satellite images for cultural preservation efforts is immense (Agapiou et al., 2015; Deroin et al., 2017; Spreafico et al., 2014; Cigna et al., 2014; Banerjee and Srivastava, 2013). Satellite remote sensing has proven to be a reliable tool for forecasting environmental change and when combined with GIS-based models, allows for the development of future change scenarios on cultural heritage (Agapiou et al., 2015; Ayad, 2005; Hadjimitsis et al., 2013). The non-invasive, non-destructive nature of remote sensing and other digital technologies allows for the safe analysis of an area (Gabellone et al., 2017; Tapete et al., 2013), making it a suitable tool for studying archaeological sites. The use of space data, including ultraviolet, visible, infrared, and microwave portions of the spectrum, is very useful in various archaeological applications. Over the last three decades, satellite remote sensing from moderate and high spatial resolution sensors (e.g. Landsat and Spot) has played a vital role in the field (McCauley et al., 1982; El-Baz, 1998).

Recently, the advent of very high resolution (VHR) satellite imagery, such as Ikonos, QuickBird and WorldView-2, has considerably increased the interest in the field of archaeology. That said, while access to spatial data has become readily available, the software needed to process it largely remains out of many archaeologists' reach, due to the high price and the technical background required to operate such software (Liss et al., 2017). Google Earth Engine (GEE), a free cloud-

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based computing platform for the processing, analysis, and visualization of satellite imagery helps to mitigate this problem. Earth Engine has great implications for archaeological preservation (Agapiou, 2016), as it allows for the fast and easy dissemination of critical information to other researchers and to the general public. For this reason, the integration of these aforementioned digital technologies can be very useful for not only detecting, monitoring, and identifying archaeological locations that are most vulnerable to natural and anthropogenic activities, but also for raising awareness about the threats these archaeological sites are under (Deroin et al., 2017).

Dam building, without proper surveying for ancient and historical sites within the river catchment area, is one such process that can have a detrimental effect on cultural heritage. The construction of the Three Gorges Dam in central China, for example, resulted in the inundation of hundreds of significant archaeological sites and historic buildings along the Yangtze River's bank (Morgan et al., 2012). The Glen Canyon Dam in the United States is another instance of the damaging effects of dam building on cultural heritage. Rising waters from the dam caused the direct destruction and inundation of numerous prehistoric and Native American sites, as well as the erosion of many others (Jones et al., 2016). The ancient Egyptian Temple complex of Abu Simbel in Upper Egypt could face a similar threat of inundation by the Nile River's waters. Located on the western bank of the Lake Nasser reservoir behind the Aswan High Dam, this almost 3300-year-old structure is increasingly vulnerable to inundation by the reservoir's potential rising waters (Fig. 1). At the start of the water year, in August, the water levels of the Lake Nasser reservoir are kept at preciously 175 m ASL to warrant sufficient water supply. When the water level of the reservoir reaches a height between 178 m and 183 m, excess water is directed to the Toshka Depression and, if necessary, by means of the emergency spillways on the western bank of the Nile (Muala et al., 2014). It is important to note, that the unforeseen abrupt change that would occur in the water level from a malfunction from the upstream dams would not warrant enough time for water to be released via the emergency spillways.

With many archaeological sites situated near water bodies, as is the case for the Abu Simbel temples, risk from inundation remains a primary concern. In order to analyze this risk, GIS-based flood inundation modeling relies namely on the use of Digital Elevation Models (DEMs). However, most publicly available global DEMs (e.g. GTOPO30, SRTM, Aster-GDEM) have considerably low spatial resolutions (30 m–1 km) and offer poor terrain detail, especially for lowland areas with gentle slopes, which are most susceptible to water inundation (Ghoneim et al., 2007). The lack of digital elevation models has forced many developing countries to depend solely on these coarser DEMs for flood modeling, which has affected the accuracy and reliability of the derived flood inundation maps. Sub-meter resolution terrain product, such as the Light Detection and Ranging (LiDAR) and Synthetic Aperture Radar (SAR) data using Interferometric SAR (InSAR), offers sufficient topographic detail for flood mapping. Yet these detailed terrain products are

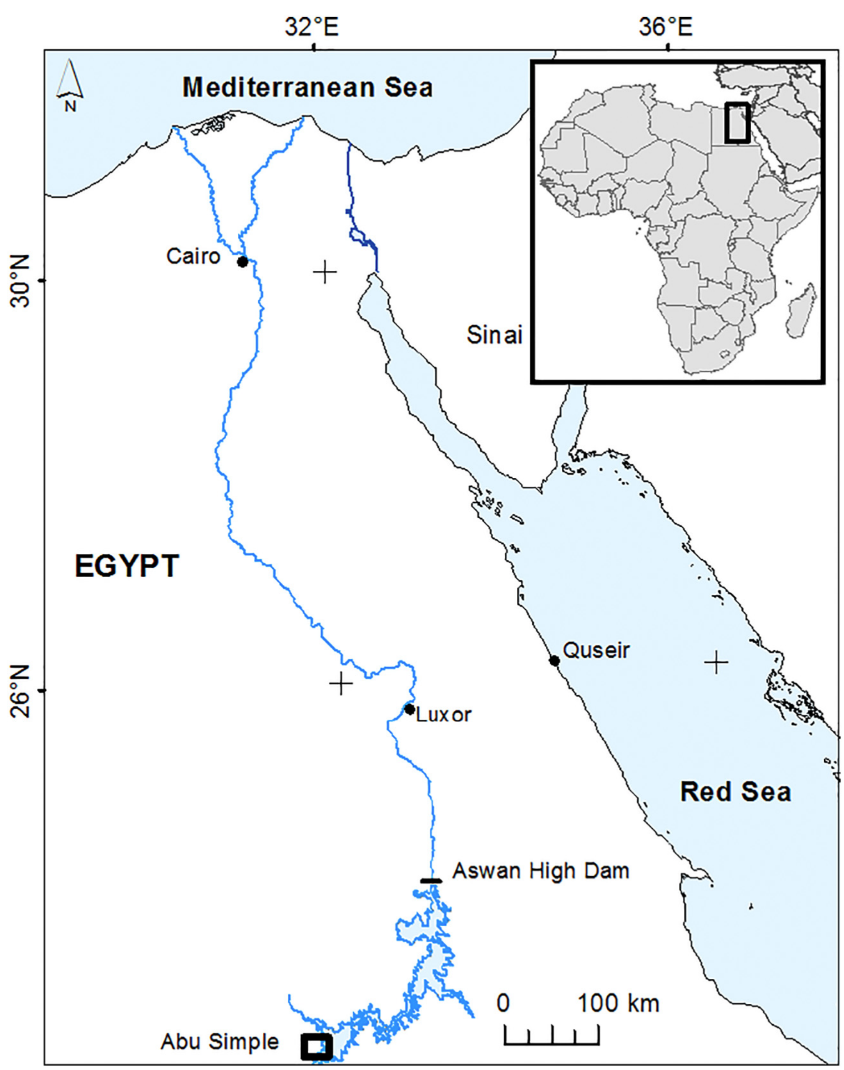

Fig. 1. Shows the location of the study area (marked by the black box) and the Aswan High Dam.