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Remote-sensing data-based Archaeological Predictive Model (APM) for archaeological site mapping in desert area, South Morocco

Ange Félix Nsanziyera [a,*], Hicham Lechgar [a], Said Fal [a], Mehdi Maanan [a], Omar Saddiqi [a], Aicha Oujaa [b], Hassan Rhinane [a]

[a] Geosciences Laboratory, University Hassan II Casablanca, B.P 5366 Maarif, 20100 Casablanca, Morocco
[b] Institut national de sciences de l'archéologie et du patrimoine (INSAP), BP 6828, 10000 Rabat, Morocco

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ABSTRACT

Morocco hosts numerous archaeological sites, some of which are part of the UNESCO world heritage. Many of these sites, especially funerary mounds also called tumuli, or rock engravings and ceramics, are located in remote areas with limited access, particularly in the Saharan Morocco desert. We developed a remote sensing and GIS model to identify areas with high potential for hosting archaeological sites in the Awserd region of southern Morocco. A field campaign in a "reference site" zone of 21 km^2 has revealed 233 archaeological sites. Here we use satellite images and Digital Elevation Models to examine with various techniques (spatial analysis, statistical techniques, and fuzzy logic functions) the relations between the distribution of the archaeological sites and geo-environmental variables such as ground geology, topographic elevation and slope, orientation (aspect), and distance to water sources. We derive empirical relations that reveal that the distribution of archaeological sites depends on the above geo-environmental variables. We then use the empirical relations to anticipate the potential locations of archaeological sites in a region of 980 km^2 enclosing the reference site area. The model proves capable of predicting 582 sites in the larger region. Subsequent field observations there confirmed that about 80% of the model anticipations were correct. Our Archaeological Predictive Model (APM) can be scaled to larger areas and varied geographic settings, and hence can be a useful guide for archeological studies in desert regions.

1. Introduction

Morocco hosts numerous archaeological relics, such as ruins of ancient roman cities in the northern part of the country, and funerary mounds (also called tumuli), rocks engravings, ceramics and paintings (Belmonte et al., 1999; Brooks et al., 2009; Nami, 2008; Souville, 1959, and Nami et al., 2012). The available literature on prehistoric funerary monuments emphasizes that most of such sites are located south of the High Atlas, especially in the pre-Saharan and the Saharan zones (Bokbot, 2000).

Plant and animal species distributions are categorized as random, systematic, or clustered (Brandt et al., 1992; Goings, 2010). Most populations, including human, and their associated behaviors, are naturally clustered. The selection of particular sites for human activity in the prehistoric times was not random, but associated with specific characteristics of the natural environment and to

* Corresponding author.
E-mail address: felixon87@gmail.com (A.F. Nsanziyera).

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factors related to human activity and human behavior norms (Balla et al., 2014). Therefore, it is commonly thought that prehistoric mounds were built in specific environments, and thus the probability of finding tumuli randomly is small. In the present research, we aim to establish which geo-environmental conditions were prevailing for funerary mound location in southern Morocco.

Over the last decade, the combination of remote sensing and Geographic Information Systems (GIS) opened new horizons and possibilities for archaeology. For instance, aerial photographs can be used to detect the surface imprints of subsurface relics (Haidar-Boustani et al., 2004; Rawlands and Sarris, 2007; Siart et al., 2008). Infrared and thermal electromagnetic radiations help detecting underground archaeological remains (Bewley et al., 1999; McCauley et al., 1982). High-resolution satellite images can also assist archaeology and heritage management (Pappu et al., 2010). Hence, remote sensing data have become a common tool of investigation, prediction, and forecast of archaeological site locations through the development of GIS-based models. However, these approaches have hardly been used yet in Moroccan archaeology (; Belmonte et al., 1999; Roeloffs et al., 2011; Linstädter et Blatt, 2013). Archaeological surveys in Maghreb regions including Morocco still generally use conventional methods such as field inventory, where local population testimonies play a key role to localize archaeological sites (Di Lernia, 2013; Galan et al., 2014). Such field surveys are time consuming, for they are supposed to survey large areas mostly on foot with teams of several people. When the areas are remote, this approach is especially difficult (Linstädter and Blatt, 2013). Morocco includes many remote areas with limited access, and thus locating archeological sites there is a critical challenge.

To overcome this situation, we present here an Archaeological Predictive Model (APM), which is GIS-based and uses geospatial techniques. This APM was developed in the Awserd area of southern Morocco and suggests the potential locations where tumuli may be found preferentially.

2. Geological setting

The study area covers about 1000 km^2 in the southern Moroccan Sahara near the Moroccan–Mauritanian border in the province of Awserd (Fig. 1). The area is a typical desert dominated by low-relief landscapes and extended sandy deposits. This desert area straddles the Archean part of the Reguibat Shield of the West African Craton to the east and the Adrar Souttouf or Oulad Dlim massif to the west.

The southwestern Reguibat Shield domain is underlain by granites, orthogneiss, migmatites, and greenstones of Archean age, intruded by a number of mafic dykes, mainly Archean to Paleoproterozoic (Bea et al., 2013, 2014; Ennih and Liégeois, 2008; Potrel et al., 1996; Youbi et al., 2013). In the past 600 Ma, the outskirts of the craton were involved in the Pan-African and Variscan orogenic cycles, which resulted in the emplacement of the Adrar Souttouf (Oulad Dlim) segment of the Mauritanides nappes (Michard et al., 2010; Sougy, 1962; Villeneuve et al., 2006). The limit of the autochthonous Archean shield and the allochthonous Adrar Souttouf–Oulad Dlim units (Cambrian quartzites, Archean gneiss, Neoproterozoic metagabbros, etc.) is marked by a narrow corridor of autochthonous/parautochthonous Ordovician-Devonian sedimentary rocks.

The allochthonous terrains and their Precambrian basement dip westward under the Cretaceous–Neogene formations of the Tarfaya–Laayoune–Dakhla Basin (Hollard et al., 1985; Leprêtre et al., 2015; Rjimati et al., 2011). Quaternary deposits are of small thickness and consist of detrital sediments of various types that are often weakly consolidated. The geomorphological landscape is a peneplain with rare prominent reliefs composed of pseudo-cuesta, outliers and scattered hills or inselbergs, locally known as “Glebs”.

3. Data

In order to produce a predictive modeling of archaeological site location, a well-constrained dataset (later referred to as “reference site”) is first required to derive statistical empirical relations describing which environmental factors control the location of recognized archaeological sites. The reference site is an area where archeological sites and geo-environmental factors are well known and can be well described (Kohler, 1988), especially with remote sensing data. Once empirical relations are derived from the reference site analysis, they can be applied to anticipate the distribution of archeological sites in other places. The comparison of model results with actual observations in several sub-zones of a large “validation zone” (i.e. the larger zone of Fig. 1C) allows quantifying the model's robustness.

3.1. Archeological data in reference and validation zones

We conducted different field campaigns between 2014 and 2017 in the reference site zone ($\sim$21 km^2) (Fig. 1C) and were able to survey archeological site distributions and geo-environmental factors. We worked with small mobile teams of three people equipped with a handheld GPS, a tape measure, and a compass. The task involved taking GPS coordinates, size and orientation of every observed tumulus. Ultimately, we were able to cover the entire area of interest, i.e. the validation zone ($\sim$1000 km^2), and we identified 815 tumuli in this larger zone. However, there were some challenges such as cases of tumuli ransacked to the point that it was almost impossible to discriminate them from the background or sites where sand deposition was hiding most of the sites. We eventually built a GIS database with information on the archeological sites (name of the site, geographic coordinates, type of site, geometry of the site, type of raw material of the site, height of the archeological construction, etc.) and geo-environmental factors in the zone (see below). These data from the reference site were used to develop the predictive model.

3.2. Types of archaeological sites observed

The sites observed correspond to a variety of tumuli. The most predominant tumuli in the Awserd area are conical-shape tumuli with different versions including simple conical tumuli, oval conical tumuli, and circular conical