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Mapping potential shallow groundwater in the Gobi Desert using remote sensing: Lake Ulaan Nuur

Troy Sternberg [a,*], Philippe Paillou [b]

[a] School of Geography and the Environment, South Parks Road, Oxford OX1 3QY, UK
[b] Observatoire Aquitain, University of Bordeaux, 2 Rue de l'Observatoire, BP 89, 33271 Floirac Cedex, France

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ABSTRACT

Access to water resources in desert environments is an endemic challenge in developing countries. Shallow water is an essential resource for rural communities and has become significant source for urban centres, agriculture and mining. In the past conventional methodologies were used in the search for water; today advanced remote sensing from space offer new techniques to identify and define potential untapped groundwater in drylands. This research investigates a potential major water resource in the Gobi Desert, Mongolia. Using remote sensing from space we integrated topography, radar images and optical images into GIS tools to investigate and identify potential shallow water correlated to large palaeolakes. This work integrates the palaeoclimatic history of southern Mongolia with present water circumstances in the region. Findings indicated Lake Ulaan Nuur as a promising site for hydro-geological testing and water resource prospecting as measurement suggests a past lake area of >19,000 km^2 in the Mongolian Gobi.

1. Introduction

Arid Inner Asia has experienced dramatic climate fluctuations over several millennia and remains highly sensitive to ongoing climatic change (Pederson et al., 2014; D'Arrigo et al., 2000; IPCC 2007; IPCC, 2012). However, there has been little research into how past climate records across extensive areas, such as the Gobi Desert of southern Mongolia and northern China, could serve as a baseline to identify potential future climate and environmental conditions (Hülle et al., 2010; Felauer et al., 2012). Zhang et al. (2012) theorize that improved knowledge of Holocene climate and physical changes in the region may suggest similar potential boundary conditions in the future. Mongolia's location at the junction of two northern hemisphere climate systems, the North Atlantic Oscillation and the East Asian Monsoon, associated with El Nino-Southern Oscillation, makes it a significant zone for climate reconstruction (Lee et al., 2013). The limited palaeoclimatic work done has concentrated on northern and western regions of the vast (1.56 million km^2) country (Tarasov et al., 2000; Lemkuhl and Lang, 2001; An et al., 2008) whilst the Mongolian Gobi is a dynamic region that has only recently begun to be investigated.

The fundamental palaeo work done in the greater Gobi (Yang et al., 2004; Feng et al., 2005; Rudaya et al., 2009; Zhang et al., 2012) and initial efforts in the southern Mongolian region (Mischke et al., 2005; Hulle et al., 2010; Lee et al., 2013) highlight the Holocene palaeoclimate, palaeohydrology and related implications (Fig. 1). Much cited work in Inner Asia relates to past water regimes, suggesting that there is potential to integrate findings from the Holocene into a current research context (Komatsu et al., 2001). Similar work in Africa established that palaeolakes and palaeodrainage channels can indicate productive aquifers in the Sahara (Robinson et al., 2006; Paillou et al., 2009); to date Holocene research has not been applied to groundwater detection in the Gobi.

Several studies have shown the usefulness of Earth observation data for generating structural maps that can then be used for water resources prospecting in arid areas, see for instance results of the European Space Agency's Tiger Initiative (TIGER, 2009), VanderPost and McFarlane's, (2007) work in the Kalahari and Gupta et al.'s (2011) research in the Thar Desert, India. Most of these studies considered space-borne optical data such as LANDSAT to map surface structures in regions where geological mapping is not available. A strong limitation of this process is the fact that most of the relevant geological features in arid regions are likely to be

* Corresponding author.
E-mail addresses: troy.sternberg@geog.ox.ac.uk (T. Sternberg), philippe.paillou@obs.u-bordeaux1.fr (P. Paillou).

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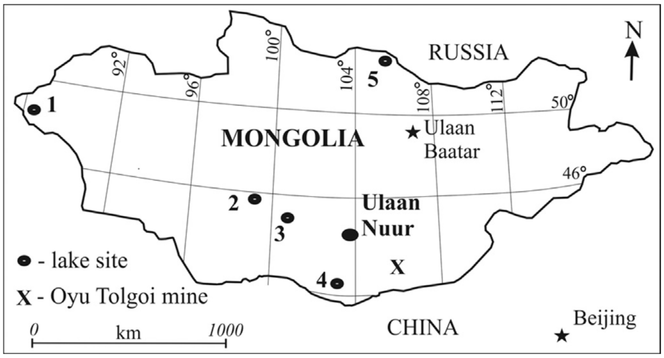

Fig. 1. Lake Ulaan Nuur (translation: Red Lake) in the Gobi Desert. Past palaeo investigation sites in Mongolia include: 1. Hoton Nuur, 2. Bayan (also Bon) Tsagaan Nuur, 3. Orog Nuur, 4. Bayan Tchomin Nuur, 5. Gun Nuur. Oyu Tolgoi mine (X) is representative of major new mining operations in the region.

hidden under aeolian sandy sediments. Nevertheless low frequency orbital Synthetic Aperture Radar (SAR) has the capability to probe from space the subsurface down to several meters in arid areas (McCauley et al., 1982) and is furthermore sensitive to surface and subsurface roughness. Few quantitative studies have been conducted to assess SAR's potential groundbreaking implications; in southern Egypt and eastern Libya orbital radars detected the existence of palaeochannels (Schaber et al., 1986, 1997; Paillou et al., 2003, 2009) yet quantitative assessment of fossil water resources has to be done (Robinson et al., 2007).

Shallow groundwater in the Gobi is a key resource as the region receives ~120 mm of precipitation annually Sternberg et al. 2009. The climate is marked by hot, dry summers and severe winters; drought and extreme cold (to −35 °C) are endemic challenge. Herders, communities and local governments have traditionally depended on shallow groundwater for basic needs (5–10 L p/p, per day) and livestock-raising (43 million in 2013) because of their feasibility, low cost and the lack of surface water (UNEP, 2011; National Statistical Yearbook, 2013). Recent mining discoveries have led to multi-billion dollar investments exemplified by Rio Tinto Corp.'s Oyu Tolgoi mine (see Fig. 1). Favoured by the government for tax revenue, such companies have both the funds and access to technology to tap potential deep aquifers, identify shallow water sources and implement long-distance water transfer schemes. As mineral extraction accelerates, the rural population faces changes in water resources as a result of mining, including reduced, inadequate or contaminated supply. Recent civil protests and social dislocation highlight how water affects the rural population (Byambajav, 2014); identifying new shallow groundwater sources may contribute to alleviating water stress.

We propose the novel applied use of remote sensing, taking into account the palaeo context, to identify potential shallow groundwater resources in the Gobi Desert, Mongolia. Our research stresses how to find potential sites for water exploration through radar satellite imagery and provides clarity on past climate in the desert. From a scientific context, previous studies have concentrated on past climate rather than water resources; here we focus directly on shallow groundwater detection. To our knowledge this method has not been used to identify present-day water resources in global drylands. Our work expands the field of palaeoclimate and palaeo hydrology research by developing its potential applicability and immediate utility to desert societies.

2. Background

2.1. Palaeoclimate in the Gobi

Drylands currently occupies 2.3 million km^2 in northern China and southern Mongolia (Sternberg, 2014) but have experienced various climatic conditions since the Last Glacial Maximum with features including wetlands to present-day deserts (Yang et al., 2004). As a consequence, Gobi lakes underwent major changes in level during the late Quaternary with high stages being associated with wetter climates. According to An et al. (2008), the early Holocene in Mongolia is characterized by increasing temperature and humidity, followed by a humid early-mid Holocene stage when lakes were at high volume. Enhanced aridity occurred during the mid-Holocene, but the beginning and end of the dry interval differs from location to location. In the late Holocene the humidity increased due to decreased evaporation when temperatures dropped in Mongolia. Yang and Scuderi (2010) report hydrological and climatic changes in the northern deserts of China: following a wet phase by the end Pleistocene significant lake desiccation took place before the early Holocene. The mid Holocene was warmer and wetter with a return to drier conditions in the Late Holocene. A review of previous investigation finds there is little scientific agreement on wet and dry periods across the Gobi (Table 1).

Present-day fossil and shallow groundwater resources in the Gobi Desert depend mainly on the Late Quaternary climatic history of the region. Climatically the North Atlantic and North Pacific Oscillations interact with the Siberian High to moderate the strength of the East Asian Monsoon. The El Niño Southern Oscillation and Intertropical Convergence Zone influence the East Asian Summer Monsoon on the Mongolian Plateau. In addition, westerlies moderated by the North Atlantic Oscillation affect the region (Feng et al., 2005). The systems make the region an important source for establishing Holocene climatic signals (Lee et al., 2013). Remains of past wetter climates can be found in today's topography in the form of palaeochannels and palaeoshorelines (Komatsu et al., 2001).

2.2. Previous related studies

Lehmkul and Lang (2001) performed geomorphological investigations in the Valley of the Gobi Lakes, a graben zone between the southern slope of the Khangay and the Gobi-Altai, providing evidence for Late Quaternary lake-level changes. They studied in particular the geomorphology of three lake depressions: Bon Tsagaan Nuur (N 45.59, E 99.14), Adagin Tsagaan Nuur (N 45.59, E 100.02) and Orog Nuur (N 45.05, E 100.68), all located about

Table 1
Recent assessment of dry/wet periods in the Gobi. Dates are years Before Present (BP). See Fig. 1 for site locations.

Site	Dry periods	Wet periods	Author	Year
Hoton Nur	10,000–9000, 4000–0	9000–4000	Tarasov et al.	2000.
Gun Nuur	7000–5000	9000–7000 4500–2500	Feng et al.	2005.
Gun Nuur	10,800–9800, 7000–5700 4100–3600, 3000–2500	9800–8500, 5700–4100 2500–1600, 1000–500	Zhang et al.	2012.
Bayan Tohomin Nuur	12,000–11,000, 8500–7500 5000–4500, 4000–0	11,000–8500 7500–5000 4500–4000	Felauer et al.	2012.
Ulaan Nuur	6500–6200, 3000–0	11,500–9500, early, middle Holocene	Lee et al.	2013.