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Taming the torrents: The hydrological impacts of ancient terracing practices in Jordan

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ABSTRACT

Extensive terracing was an important component of the water and agricultural management regime of Nabatean Petra. The exact function(s) of these terraces, qualitatively and quantitatively, is herein investigated. Field studies and computer modeling for two sites within the drainage basin of Petra show that these terraces were highly effective at reducing surface runoff. Different design features seem to have been adapted in order to achieve different objectives at varying sites. For example, the Beidha site in the lower reaches of the catchment area falls within the higher relief Ordovician Disi Sandstone formation area. Here, the terrace system was designed to slow water flow and trap sediments. The terracing greatly reduced surface water flow through the entrapment of sandy loam sediments behind it. On the other hand, the Baqa'a site falls in the upper reaches of the drainage basin within the Upper Cretaceous Amman Silicified Limestone formation. The effect of the terrace system here on runoff is significant, but less than that seen at Beidha. This system was more suited for soil conservation and agriculture, as the soil here in its natural state already had a high infiltration rate. Neglect and abandonment of these terraces at both sites have led to increased runoff, as evidenced by the development of gullies and by periodic flooding downstream in the core of the ancient city. Based on the six modeled cases, terraces can minimize the surface flow by an average of 28%, with values as high as 90% when 2010 precipitation data were used. Conducting an intensive survey within the catchment area surrounding the ancient city of Petra, mapping the ancient terraces, and reviving their function may produce significant results in flood mitigation and control there.

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1. Introduction

Arid regions present specific problems for people who live and work there. This is particularly true when adapting environmental conditions to large populations with sophisticated cultures. High on the list of challenges is the availability of water and the tendency of the water to arrive in the form of flash floods. Moreover, the intense rains that cause flash floods tend to be highly localized (Al-Qudah, 2011). This means that expensive infrastructure placed to harvest flash flood waters could be useless for many specific events. Moreover, areas with permeable substrates might not be suitable for building dams in any case. Thus, approaches relying heavily on damming and surface water storage are often inadequate or unfeasible.

In the arid region of Petra in southern Jordan, sophisticated water storage and management systems were developed by the Nabateans over 2000 years ago (Ortloff, 2005). These systems relied on the use of local springs as well as dams and cisterns, which, while important, were mostly suited for domestic and garden uses (Nasarat et al., 2012).

Quantitatively, significantly more water can be stored in soils through terracing than by dams and cisterns (Evenari and Koller, 1956). This is especially significant in arid and semi-arid regions, where water is a limiting factor for agriculture. Terracing is an old practice that has been in use since the Neolithic times (Kuijt et al., 2007). Through the millennia, the practice was optimized through experience, with emphasis on achieving the best results using the lowest amount of energy. Terraces were used to capture water and sediments and increase soil moisture capacity on slopes. Therefore, they contributed in anthropogenic soil development with the help of fertilizers and ash used for soil amendment (van

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Asperen et al., 2014). During rainfall events, run-off water from the nearby hill slopes would flow to the terraced fields along the wadis. Each terrace wall would capture and hold a certain amount of run-off water, which subsequently infiltrated into the soil (Evenari and Koller, 1956). Even if the infiltration rate is low, this raises the volume of capillary water available for plant growth considerably.

Qualitative descriptions of terraces in the Petra area and their distributions are abundant. For example, Kouki (2012) described the expansion of agricultural activity in the Petra region from the 2nd Century BCE to the 3rd Century CE. Special attention was given to the Jabal Haroun area to the south of Petra, where a map of the terrace systems in the area was presented. Beckers et al. (2013a) conducted some dating on the terraces of Petra using optically simulated luminescence (OSL). They determined that the construction of the terrace systems began in the first century and continued until the 8th century CE. This generally fits with the conclusions of Kouki (2012).

However, quantitative evaluations of the effects of these structures on runoff and infiltration are limited. Studies such that of Gallart et al. (1994) provide some insight on approaches that may be taken to quantify the effects of terracing on the hydrology of their catchments. Because of the climatic conditions of where these studies were carried out (in Spain), the results of this work have little relevance to the effect of terracing in the arid region of Petra. Herein we present a hydrological assessment of the terraces of Petra based on direct measurements and computer modeling.

1.1. History of archeological investigation of terraces in Petra

The earliest studies of Petra terraces were concerned with noting their existence and proposing their possible function. The earliest report of terrace systems attributed to the Nabataeans was made by Glueck (1939). Lawlor (1974) suggested the use of terraces in rainfall runoff management. Furthermore, Hammond (1967) suggested their use was for cultivating vineyards and orchards. Shanan (2000) proposed the main function behind terrace construction is silt collection by slowing water flow, although she did note a very low rate of silt accumulation at most of the large terrace systems.

Terraces that are referred to as ‘‘barrages” are stepped walls built across wadies. These have been mapped and studied as part of the hydraulic systems of Petra (Al-Muheisen, 2009; Amr et al., 1998; Tholbecq, 2001). The Finnish Jabal Haroun Project (FJHP) conducted the largest study of run-off farming systems, of which the terrace systems are a part. Their survey around Jabal Haroun yielded various barrage and terrace systems. This survey redefined ‘‘terraces” as walls built higher in elevation and running perpendicular to a wadi, assigning to them the sole function of soil preservation (Lavento et al., 2004).

Beckers et al. (2013a) conducted a systematic study of the ‘‘engineering landscape” of Wadi al-Ghurab (6 km North of Petra) and Seil of Wadi Musa to Umm Rattam. They not only mapped runoff agricultural systems, but also used optically stimulated luminescence (OSL) to date them (with a relatively high margin of error for historic studies) to Nabataean-Roman periods, with continuous usage until 800 CE Another team led by Brown University has conducted a similar research to the north of Petra, combining high-resolution satellite imagery and OSL dating of soils, dated terraces and water harvesting systems to the Iron Age. Unfortunately, not much of this research has been published in so far (University of Cincinnati, 2013).

Terraces were also approached ethnographically, as the local inhabitants of Petra continue to use them for stabilizing slopes and growing various crops such as wheat and barley (Russell, 1995).

1.2. Study area

1.2.1. Physiographic settings

The study area is part of the subcatchment of Wadi Musa, which drains the region of the well-known, tourist attracting, and ancient city of Petra. The subcatchment drains, in part, the western side of the Asharah mountain ranges toward Wadi Araba in southern Jordan (Fig. 1). The subcatchment of Wadi Musa is about 80 km^2, with a maximum relief of over 700 m. It drains steep rolling slopes of Upper Cretaceous carbonate rocks, and Lower Cretaceous sandstone mainly at elevations above 1050 m. The lower part of the basin (below 1050 m), consists of ragged, highly jointed, sandstones of Paleozoic age.

The area belongs to Mediterranean climatic zone, with an average precipitation of 180 mm (Jordan Meteorological Department, 2016), which mainly falls in the winter from October to April. The orographic effect on precipitation is very clear, with lower rainfall amounts observed at lower elevations. Seasonal mean temperatures at Petra vary from 6 °C in January to 22 °C in July. The maximum temperature in summer may reach 39 °C, while the minimum temperature in winter is slightly below 0 °C (Al-Weshah and El-Khoury, 1999). Oak and pine trees are found at the upper reaches of the basin above an elevation of 1500 m, and desert shrubs are relatively dense at the higher elevations as well. Sparse juniper trees are found at the lower elevations.

1.2.2. Study sites

Two sites were chosen to do the study on the impact of terraced surfaces on surface hydrology.

1.2.2.1. Beidha site. The Beidha site is found just 500 m north of Umm Sayhoun at an elevation of about 1030 m asl in the northwestern part of the subcatchment (Fig. 1). The terraces have been built on the Ordovician Disi Sandstone Formation. The slope of the surface ranges from 10 to 20%. Thick soil of more than 1 m has developed behind the terraced surfaces. Soil texture is loam to silty loam (clay, silt, sand average is 11, 52, and 37% respectively), with soil becoming progressively more clayey with depth. Clay increases from less than 10% in the top 10 cm to about 20% at 70 cm depth. In the upper 50 cm (A-horizon), soil has a weak structure and becomes hard in the lower part (B horizon). This layering suggests that translocation of clay material in the soil has occurred, implying a long period of pedogenic evolution. Soil erosion is very clear in places where the terraces are collapsed, with the soil completely removed and the bedrock exposed in places where terraces are non-existent. The vegetative cover is very sparse.

The Beidha terrace complex is concentrated around a natural gully in the sandstone outcrop (Fig. 2a). Beidha has a complex terrace system, which can be categorized as ‘‘hilltop conduit system”. These are medium sized catchment systems created generally around the slope of catchment area (greater than 10%; Prinz, 1996). The system is comprised of terraces running along and across contour lines. The main set of terraces run perpendicular to the wadi (valley), with an elevation interval between the consecutive terraces of around 5 m.

Seven consecutive terrace walls run along the slope. The terrace wall raises up to five rows at the highest. Their height varies from 40 cm at the lower slope and up to around 180 cm at the upper part. The length of the terraces also varies according to the width of the wadi. At the highest point of the incline, the length of the terrace reaches up to 40 m, while at the lowest point of the incline the terrace wall length is around 9 m.

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