Catena 162 (2018) 80–87

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Ancient through mid-twentieth century runoff harvesting agriculture in the hyper-arid Arava Valley of Israel

Ilan Stavi[a,*], Gidon Ragolsky[a], Rahamim Shem-Tov[a], Yanai Shlomi[a], Oren Ackermann[b], Henri Rueff[c], Judith Lekach[d]

[a] Dead Sea and Arava Science Center, Yotvata 88820, Israel
[b] Department of Land of Israel Studies and Archaeology, Bar Ilan University, Ramat Gan 52900, Israel
[c] Centre for Development and Environment, University of Bern, Bern 3012, Switzerland
[d] Department of Geography, Bar Ilan University, Ramat Gan 52900, Israel

ARTICLE INFO

Keywords:
Effective rain
Hillslope vs. channel hydrology
Human inhabitation
Rainfall:runoff ratio
Rainstorm and floods
Runoff coefficient
Small grain crops
Transmission loss

ABSTRACT

Many archaeological remains of runoff harvesting agricultural systems have been discovered throughout the hyper-arid central Arava Valley in southern Israel. The remains include stone terraces and conduits in 12 wadis (ephemeral stream channels). Other agriculture-related stone-made infrastructures included a rounded threshing floor and many livestock enclosures. Additionally, many farming-related hand tools and pottery fragments were also found. The pottery and tools were dated to a chronological sequence, ranging between the Late Neolithic (6450–4550 BCE) and recent Bedouin (until the mid-20th century) ages. Some of the archaeological findings suggest that barley and wheat were the dominant crops. This highlights the importance of runoff farming for the subsistence economy of ancient populations, playing a central role in the smallholder, mixed crop-livestock system's adaptation strategy. Agro-hydrological assessment of runoff harvesting potential under the current climatic conditions was conducted for selected six terraced fields. For conducting this, data on precipitation for a 16-year period (1999/00 to 2015/16) was obtained from two meteorological stations. Then, modeling of both alluvial- and fluvial- runoff processes was performed for each of the six terraced fields. Combining the alluvial and fluvial processes revealed that either 6-mm rainstorms, which occur on an average of once every year, or 10-mm rainstorms, which take place on an average of once every 1.8–3.2 years, would allow cereal production in only one of the terraced fields. Rainstorms of 20 mm, which took place only once during the 16-year period, would allow successful cropping in five of the terraced fields. Insights of this study concur with other studies, which revealed the considerably drier regional conditions at present compared to those in ancient times, and even compared to those in the mid-20th century.

1. Introduction

Runoff farming systems were prevalent in ancient times across the southern Levant and northern Africa. Most archaeological evidence of such agricultural systems has been located in semi-arid or arid regions (BSh class in the Köppen-Geiger classification: Kottek et al., 2006: Bruins, 2012; Haiman, 2012; Beckers et al., 2013; Vetter et al., 2014), and is generally dated to the Byzantine age (4th to 7th century CE: Erickson-Gini, 2012). In semi-arid regions, precipitation/evapo-transpiration ratio (P/ETP ratio) ranges between 0.2 and 0.5. In arid regions, P/ETP ratio ranges between 0.03 and 0.2 (according to the Penman method, or 0.05 and 0.2 according to the Thornthwaite method: UNESCO, 1977). An additional characterization of these climatic zones can be based on their inter-annual rainfall variability, ranging between 20–25% for semi-arid regions and 50–100% for arid regions (Bruins and Lithwick, 1998).

The runoff harvesting systems enabled the cropping of a wide range of cereals, such as barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.), legumes, such as lentil (*Lens culinaris* Medikus), and fruit trees, such as olive (*Olea europaea* L.), fig (*Ficus carica* L.), grape vine (*Vitis vinifera* L.), and date palm (*Phoenix dactylifera*) (Ramsay and Smith, 2013; Ramsay and Bedal, 2015; Bouchaud et al., 2017). In some locations across the semi-arid and arid Negev, fruit trees located in abandoned, ancient runoff harvesting systems are still alive, suggesting Bedouin use of the Byzantine terraced plots until the mid-20th century (Ashkenazi et al., 2015).

In drier, hyper-arid regions (BWh class in the Köppen-Geiger classification: Kottek et al., 2006), defined with extreme aridity, i.e., P/ETP

* Corresponding author.
E-mail address: istavi@adssc.org (I. Stavi).

https://doi.org/10.1016/j.catena.2017.11.027
Received 25 June 2017; Received in revised form 6 November 2017; Accepted 27 November 2017

ratio of < 0.03 (Penman method, or < 0.05 Thornthwaite method: UNESCO, 1977) and inter-annual rainfall variability of ~100% (Bruins and Lithwick, 1998), agricultural activities are more difficult, posing a higher risk of crop failure, and questioning the economic viability of agriculture.

Yet there is also evidence of runoff harvesting systems for irrigating agricultural lands in hyper-arid regions, such as the central (Bruins, 2012) and southern Negev (Avner, 2002; Stavi et al., 2017), and the southern Arabian Peninsula (Harrower, 2009). At the same time, no research has been done yet on agricultural runoff harvesting in the drier Arava Valley. Moreover, according to a recent study, ancient runoff harvesting agriculture in contemporary Israel has not been practiced south or east of the Machtesh Ramon (in the central Negev: ~30°50′ N, 35°00′ E), with the exception of the Uvda Valley (Bruins, 2012). Furthermore, the Arava Valley experiences extreme climatic conditions, even in comparison to other hyper-arid regions, such as the Yemeni inland, with much greater precipitation rates (50–100 mm annual rainfall: Harrower, 2009), or the Uvda Valley, with an average maximum summer temperature of almost 4 °C lower than that in the Arava Valley (36.5 °C and 40.2 °C, respectively), thus resulting in much smaller evaporation losses (Israel Meteorological Service website).

A comprehensive archaeological survey across the central Arava during the last decades revealed an abundance of remains, dated to a wide chronological sequence ranging between the Late Neolithic (6450–4550 BCE) age and the mid-20th century. The broad scope of this survey has allowed it to encompass extensive types of findings, including dwelling sites, ritual sites, agriculture-related findings, and hand tools (Ragolsky, 2016). Following this survey, a decision was made to further study the region in order to better understand the use of lands for agricultural production in past times. This was conducted by a thorough investigation of runoff harvesting systems, as well as supportive farming installations and a wide range of agricultural tools, allowing the assessment and modeling of runoff harvesting potential to be performed. An additional objective was to gain insights regarding the agronomic potential of this extreme environment under the present climatic regime. The study hypothesis was that despite allowing sufficient water runoff harvesting for crops in ancient to recent-past times, cropping in these systems could not be successful at present because of the considerably degraded climatic conditions.

2. Materials and methods

2.1. Regional settings

The central Arava Valley (Fig. 1) is a hyper-arid region, encompassing a section of the Great Rift Valley. The valley stretches along approximately 90 km between the southern Dead Sea and the Notza Highlands, and to a width of 5–15 km between the Israeli central Negev and the Jordanian Edom Mountains. The area's height ranges between ~350 m below sea level in the southern Dead Sea and ~270 m above sea level in the Notza Ridge. Topography is rather heterogeneous across the region, with inclines of predominant hillslopes ranging between ~30° and almost horizontal. Lithology of the uplifted margins of the Arava Valley is mainly comprised of the marine carbonates of the Cretaceous and Tertiary ages. The wadis (ephemeral streams) are covered with coarse gravel, with grain size decreasing upstream. The soil in the inter-stream plains is referred to in Israel as reg (or 'desert pavement'), corresponding to a gypsic-salic cumulic profile, developed in gravelly alluvial surface of the Holocence or Pleistocene.

Mean daily temperatures are 31 °C and 15 °C in July and December, respectively, and mean daily relative humidity is 33% and 58%, respectively (Bitan and Rubin, 1991). Rainfall in the southern Negev and the Arava occurs between October and May, and is characterized by high variability in time and space (Sharon, 1972; Dayan and Sharon, 1980; Dayan and Morin, 2006). Overall, rainstorms across the region are related to synoptic conditions associated with an Active Red Sea Trough (ARST), which creates large flood events across the region (Dayan and Morin, 2006; de Vries et al., 2013; Kahana et al., 2002). Mean cumulative annual precipitation was ~40 mm between the mid- and late 20th century (Bitan and Rubin, 1991), and decreased to 20 mm to 25 mm during the early 21st century (Ginat et al., 2011). Annual reference evapotranspiration is ~2100 mm (Central Arava R&D website).

Sporadic testimonies were provided between the mid-1990s and early 21st century, by an elderly Bedouin who had been living in the central Arava Valley. His testimonies revealed that until the mid-20th century, Bedouin inhabitants had grown mostly barley and, to a lesser extent, wheat, in extensive lands across the region. In some of these sites, remains of stone terraces and other farming installations were located by the author of this paper (G. Ragolsky).

2.2. Archaeological survey

An aerial survey was carried out between the late 1990s and 2014 by trained staff members (Ragolsky, 2016). Transportable findings were collected for preservation by the Israel Antiquities Authority. Since early 2015, a more focused survey was begun, implemented by the authors of this paper, specifically aimed at studying the runoff harvesting systems and agricultural-related installations. The installations, comprised of stone terraces, conduits, and other related facilities, were delineated and mapped on-site by using high-resolution GPS.

2.3. Assessment of source:sink ratio

The delineated agricultural plots were uploaded to GRASS-GIS (2012) software. The drainage area for each plot was then calculated. Drainage points were determined at the most downstream location among the studied terraces in each wadi. Elevation data were obtained from the ASTER Global Digital Elevation Model (ASTER GDEM). These data were of 1 arc-sec resolution. Using GRASS-GIS watershed modules, flow accumulation and flow direction grids, as well as a stream network, were obtained. Then, each of the predetermined outlet points was used to delineate the basin draining at that point. Lastly, the basins and agricultural plots were vectorized and their areas were analyzed, which aided in calculating the source:sink ratio.

3. Results and discussion

3.1. Agricultural installations

Many stone-made agricultural installations were located. The predominant type of finding was stone terraces, which is a simple technique for water runoff harvesting in dry riverbeds. A smaller number of stone or earth conduits were also discovered. Altogether, these installations were discovered in 12 wadis across the study region. Also, some farming-related stone-made installations were located, including a round threshing floor, approximately 20 livestock enclosures, and many field-storage sheds. Table 1 details these findings. More details for four of the 12 terraced wadis are provided below in sub-sections 3.1.1 to 3.1.4.

3.1.1. Lower Barak Wadi (site 532, #2 in Table 1)

A 1.53 ha agricultural plot, with one stone terrace, located in a 4th stream order wadi (Fig. 2). An ethnographic testimony provided to this manuscript's author (G. Ragolsky) by a local elderly Bedouin, revealed the growing of cereals across extensive lands in this wadi until the mid-20th century.

3.1.2. Dmama Wadi (sites 182 and 183, #5 and 6 in Table 1)

A 0.03 ha agricultural plot in a 2nd stream order wadi, with tillage-induced shallow soil furrows, positioned perpendicularly to the stream direction, and two stone terraces (Dmama 1st: Fig. 3). An additional