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Disconnected runoff contributing areas: Evidence provided by ancient watershed management systems in arid north-eastern Marmarica (NW-Egypt)

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ABSTRACT

This study presents the importance of disconnectivity in dryland area runoff demonstrated by manmade water harvesting structures dated to Greco-Roman times. Located on the coastal strip of some 20 km width along the Mediterranean coast of modern northwestern Egypt covering the north-eastern part of the region known in antiquity as Marmarica, the area receives winterly rainfalls of up to 140 mm. Further south, precipitation decreases quickly and desert conditions become more pronounced. Bedrocks are predominantly calcareous, soils are loamy, stony, calcareous, and shallow, except in relief sinks with sedimentary deposits. The land rises from the coast up to 230 m a.s.l. on the Marmarica Plateau in a sequence of zonal northsloping plains and scarps the northern parts of which are dissected and drained by wadis. Agriculturally suitable areas comprise some 9% of the coastal zone and adjacent tablelands. Overland flow controls the discharge dynamics and is the main source of wadi runoff and hence agricultural water supply. The land use pattern is scattered because cropping areas depend mainly on suitability of soils and the generation of runoff harvest, which are closely interrelated because of the arid water and sediment regime. The patchiness of runoff generation increases further south where aridity is higher and topography inhibits greater drainage patterns. The abundance of cisterns, many of them originally Greco-Roman, is strong evidence that tableland overland flows occur and are frequently disconnected from larger drainage systems. Abandoned ancient rainwater harvesting and watershed management systems are abundant all over the region and incorporate the hydrological experience of the former inhabitants, having been dated with OSL and pottery mainly from Greco-Roman times. While the region prospered some two millenia ago, the ancient water management schemes are generally abandoned today.

One of the most outstanding features of the ancient systems was the systematic harvesting of tableland and valley slope overland flow above the wadi beds. Part of this strategy was to separate the remote parts of large natural watersheds from the local parts by shallow stone bunds on the tableland. The collected tableland overland flow irrigated terraced fields on the tableland (*kurum*). The remaining water harvesting areas, mainly valley slopes, were obviously sufficient to supply water for small tributary wadis, large side terraces and the floodplains of large wadis. The artificial disconnection of local runoff areas from remote parts of the northern watersheds is hydrologically well adapted to the runoff dynamics in the flat landscape of the northern Marmarica because it protected valleys from low frequency high magnitude runoff events which are generated mainly on the remote parts of large catchments but which are inefficient in terms of water harvesting. Terracing and water harvesting structures are frequently buried in well-sorted, fine-grained sediment.

1. Introduction

The runoff response from arid and semi-arid catchments is a problem that is difficult to approach and is not satisfactorily answered yet. One of the reasons is that runoff events in dry regions are rare, and difficult to observe and to monitor. Another reason is the fact that overland flow, which plays a crucial role in dry watersheds, is difficult and complicated to quantify. The pattern of causative rains may be erratic, and the hydrologic surface parameters may be heterogeneous and temporally variable as for example the vegetation cover (Yair and Bryan, 2003).

There has been a discussion as to whether arid catchment surfaces necessarily have to be devoid of fine grain sizes to produce significant overland flow (Yair and Berkowicz, 1989; Yair and Kossovsky, 2002; Bruins and Ore, 2009). The question seems to be of secondary concern in the study area, also because the loamy Marmarican surfaces proved to be runoff-productive.

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It is generally agreed that runoff generation in drylands is caused by infiltration excess or Hortonian overland flow. Partial area contribution and variably contributing areas are a phenomenon in drylands as well. The basic ideas of the partial contribution area and the variable source area concepts (Betson, 1964; Hewlett and Hibbert, 1967; Dunne and Black, 1970; Engman, 1974; Lane et al., 1978) apply, although they were developed for humid catchments. The basic hypothesis applicable to the modern north-western coastal zone of Egypt (north-eastern Marmarica) is that the potential maximum catchment contributes to wadi runoff only during very rare events, if ever. In most cases only the nearest sub-areas of catchments effectively contribute to wadi runoff. In terms of connectivity, which is increasingly being discussed (e.g. Bracken and Croke, 2007), larger or smaller parts of the watershed are hydrologically disconnected with reference to a catchment outlet, e.g. a runoff gauging station or run-in area. The implication is that wadi runoff events are clearly less frequent than overland flow events. The spatial distribution and area portion of the contributing areas may change from event to event as well as the runoff efficiency of the contributing areas.

It is assumed that sub-areas of the catchments may become active without being connected to wadi drainage and that in antiquity this principle was used for a sophisticated water harvesting and management system resulting in surplus agricultural production. Runoff contribution and hydrologic connectivity refer to discrete points of the drainage network or run-in areas, most commonly discharge gauges in valleys. Outlets of artificially confined catchments or footslopes are appropriate reference points as well. As a consequence, a number of patches within a potential valley catchment area may actively be generating overland flow, each for their adjacent run-in areas, although the runoff patches are not connected to each other or to linear drainage. The resulting effect of reduced channel runoff is referred to as transmission losses although on a smaller scale, runoff–run-in processes are significant. Wadi runoff gives an incomplete idea of runoff behaviour of the potential catchment area, which is supported (Yair and Klein, 1973: 15) by evidence from the southern Negev: "… the frequency of overland flow events was significantly higher than that of channel flow."

The variability of contributing areas is particularly high in the study area because of specific relief characteristics: only the northernmost parts of the gently northward sloping plains are dissected and potentially drained by valleys; the vast southern plains that are also part of the potential catchment areas contribute to wadi runoff only after extreme rainstorms. Because of the high variability of extraordinary runoff events they are unreliable sources for water harvesting, besides the fact that their rainfall–runoff efficiency is insignificant and the resulting floods are difficult to manage.

Medium magnitude, but higher frequency rainfall–runoff events are easier to handle, more efficient and more reliable in terms of temporal availability. Implementing this rationale required close-by (local) catchment areas to keep transmission losses small and thus increased the efficiency of water resource utilization.

The runoff efficiency in arid areas can conceptually be separated into a runoff coefficient for the actively contributing partial area and a runoff coefficient accounting for the losses from that area, both being highly variable and depending on environmental parameters such as rainfall amount, intensity and duration, type of surface (grainsize distribution of soils, biological crusts), vegetation cover, and antecedent soil moisture, each being spatially variable as well.

For this study, abandoned ancient water-harvesting and watershed management systems in the northwest of Egypt have been surveyed, dated and interpreted in order to draw conclusions about their function and about regional runoff characteristics and dynamics. The combination of modern data records with the interpretation, and theoretical and experimental reconstruction of ancient water-harvesting systems was first systematically conducted in the Negev (Yair and Klein, 1973; Ben-Zvi and Cohen, 1975; Yair and Lavee, 1976; Shanan and Schick, 1980; Evenari et al., 1982; Yair, 1983; Bruins and van der Plicht, 2007; Bruins, 2007, 2012). In arid Tripolitania, floodwater harvesting was analyzed from a geoarchaeological perspective (Barker et al., 1996). The environmental conditions in this study area are different but a landscape archaeological approach was employed as well. The relief characteristics, as outlined above, are different from most other study areas, resulting in different water management requirements and systems, e.g. tableland water harvesting systems and lateral valley terraces. Their design parameters allow for conclusions about runoff generation under the general environmental conditions of the region and quantification of runoff production with the objective to comprehend the rationales and assess the potentials of the abandoned management systems for agricultural use. The main hypothesis underpinning field work was that separating sub-watersheds from natural wadi catchment areas was a key element of hydrologically adapted ancient water management systems in the Marmarica.

The main objectives of the study were to show that

- generally rainwater harvesting systems in Northern Marmarica in antiquity relied on naturally or artificially restricted, "disconnected" runoff areas,
- tableland areas and valley slopes were significant runoff areas under the prevailing regional climatic and pedologic conditions,
- ancient runoff management systems evolved over centuries, reflecting both arid runoff dynamics and regional topographic characteristics, and
- soil harvesting on run-in areas was significant both in valleys and on the tableland.

2. The study area

The study area is located on the north-western coast of modern Egypt between Fouka (28°E) and Ras el Gargoub (26.5°E) (Fig. 1). It is a sparsely populated semi-desert area with a rural Bedouin population, some minor villages and the governorate capital Marsa Matruh. Most settlements are aligned along the highway from Alexandria to the Libyan border, and numerous smaller ones are scattered within a zone of app. 20 km width. Further south, settlements cease as desert conditions become more pronounced.

The climate and aridity classification of the region is based on more general systems due to the lack of evaporation data. The study area has a BSh-Climate classification, according to Köppen-Geiger. Annual mean temperatures range from 19 °C to 21 °C; precipitation ranges from 108 to 148 mm along the coast. Some places experience up to three humid months according to Walter and Lieth (1967), for example Marsa Matruh and Sidi Barrani (40 km west of Negeila). However, most of the region, particularly the inland area, is arid.

In dry regions, precipitation is the limiting climatic parameter for growing crops. At the Marsa Matruh meteorological station, long-term average seasonal rainfall (P_μ) from Sep. 1951 to Aug. 1992 amounts to 138.5 mm, with a range of annual totals from 47 to 277 mm and a standard deviation (P_σ) of 59.7 mm (according to the US Dept. of Commerce (1967, 1985, 1993) and unpublished data of the Egyptian Meteorological Agency cited in Vetter (1998a)). In the 41-season observation period, rainfall exceeded 198.2 mm ($P_\mu + P_\sigma$) in six seasons and undershot 78.8 mm ($P_\mu - P_\sigma$) in eleven seasons. There was one dry period with three successive seasons of <78.8 mm and another with two successive seasons of <78.8 mm.

During the summer periods (June to August) from 1951 to 1992, no rainfalls greater than 0.1 mm/month occurred at the meteorological station at Marsa Matruh Airport (acc. to Egyptian Meteorological Authority data), but did occasionally in September. Rain in September may be assumed to contribute to soil moisture of the rainy winter season; the hydrological year is therefore assumed to start in September. December and January are the most humid months with monthly averages of 33 and 32.4 mm, respectively (1951–1992).

Detailed climatic records with an emphasis on rainfall data have been introduced and evaluated by Vetter (1998b, 2001). There is a