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Water harvesting based on the spatial distribution of thin and rocky soils in Almeria province, Spain
Collecte et stockage des eaux de ruissellement générées sur les sols rocheux, province d'Almeria, Espagne

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Introduction

The spatial distribution of rock outcrops and thin, stony soils on semi-arid hillslopes is related to slope gradient and slope curvature. Poesen *et al.* (in press) demonstrated the increase in rock fragment cover and decrease in soil thickness on steeper sections of hillslopes in range lands and on convex hilltops in cultivated areas. These thin, stony soils and rock outcrops frequently generate runoff which will infiltrate in the colluvial mantle during the majority of events (Yair, 1983; Lavee and Yair, 1990; Brown and Dunkerley, 1996; Nicolau *et al*., 1996; Lavee *et al*., 1997). Over the centuries, water harvesting systems have adapted to this patchy character of the runoff by delineating runoff generating areas with conduits in order to prevent loss of runoff by infiltration. The gradual building up of knowledge on water harvesting techniques by the local farmers has ensured that the catchments of these systems are located in areas that generate runoff at regular intervals. The size of their cisterns will indicate the amount of runoff to be expected from these catchments.

Collecting runoff from natural catchments in underground cisterns to provide water for domestic use and for livestock is common practice in semi-arid regions of Spain (Chapman, 1978; Cara Barrionuevo and Rodríguez López, 1989; Cara Barrionuevo, 1996), northern Africa (Claude and Bourges, in press) and India (Samra *et al*., 1996, p. 102). At present, the rapid development of south-east Spain, the encroachment of greenhouses and the ever increasing use of groundwater, has led to the abandonment of many water harvesting systems. The documentation of this indigenous technique is therefore urgent as it can contribute to its use in other regions as a means of sustainable development (Le Houérou, 1996).

The aim of this study is to investigate the relationship between the soil properties of the catchments and the runoff to be expected.

Materials and methods

The mountain ranges of Almería province (south-east Spain) are part of the Betic system consisting of a variety of parent materials such as mica-schist, dolomite and andesite. As a result of centuries of agricultural and mining activity in a fragile environment, vegetative cover is low (Chapman, 1978). The climate is semi-arid with strong gradients in annual rainfall and temperature from the coast to the mountain ranges in the interior: P=150 mm and T=17-18^{o}C at the south eastern coast and P=650-700 mm and T=8-9^{o}C on the summits of the mountain ranges (Lazaro and Rey, 1991).

The cisterns, which are used for collection and storage of hillslope runoff, will be referred to by their local name derived from Arabic: *aljibes*. They are rectangular basins lined with walls of masonry and sunk to a depth of 2-3 metres in the ground. They are covered with a dome shaped roof in stone to keep temperatures low in order to maintain a reasonable water quality over a prolonged period. Runoff water from the hillslope is directed via conduits and a settling tank to the entry of the aljibe.

Topographical maps and local information enabled us to locate 34 aljibes with their catchment. The catchments characteristics (size, rock outcrop, rock fragment cover, vegetation cover and presence of a soil crust) and the volume of the aljibes were determined in the field. The runoff curve number method (CN) was used to estimate runoff from the catchments based on daily precipitation records of nearby rainfall stations over the period 1963-1985 (Soil Conservation Service, 1986). Curve numbers for the entire catchment were calculated by an area-weighting of the curve numbers of particular land use or cover (Table 1). The curve numbers during average antecedent moisture conditions (CN II) were adjusted for very dry conditions (CN I) or wet conditions (CN III; Tragsatec (1994)).

Table 1 Runoff curve numbers for different catchment surfaces under average antecedent moisture conditions (CN II; Soil Conservation Service, 1986)

Land use	hydrological condition	curve numbers for hydrologic soil group: B (coarse textured valley bottom)	C (thin, rocky soils)	D (sealed surfaces)
Fallow	poor	86	91	94
Small grain	poor	76	84	88
Semi arid pasture	<30% cover	80	87	89
or range land	30-70% cover	71	81	89
	>70% cover	62	74	85
Dirt roads		90	90	90

Results and discussion

The catchment area is limited by the spatial extent of thin stony soils and rock outcrops and the topography diverting the runoff away. The decrease in percentage rock outcrop with catchment area already points to the limited availability of sites with a high runoff generating potential (Fig. 1). Over the years the volume of the aljibes has been adjusted to the amount of runoff that can be collected on a regular basis. Hence the increase of the volume of the aljibes with catchment area is significant (R^2=0.57, n=34; Fig. 2). The logarithmic character of this relationship suggests that the efficiency of runoff generation decreases with increasing catchment area. This observation is confirmed by measurements of runoff along hillslope sections of different length in the Negev (Yair, 1983; Lavee and Yair, 1990). During simulated rainfall with an intensity of 26 mm h^{-1} the upper section with steep rocky slopes produced runoff which infiltrated in the colluvial mantle downslope. Similarly, runoff plots on steep slopes with thin soils on mica-schist in the Rambla Honda catchment (south-east Spain) produced runoff with daily rainfall of 10 mm, whereas the occurrence of runoff in plots on the sedimentary body was very rare (Nicolau *et al*., 1996).

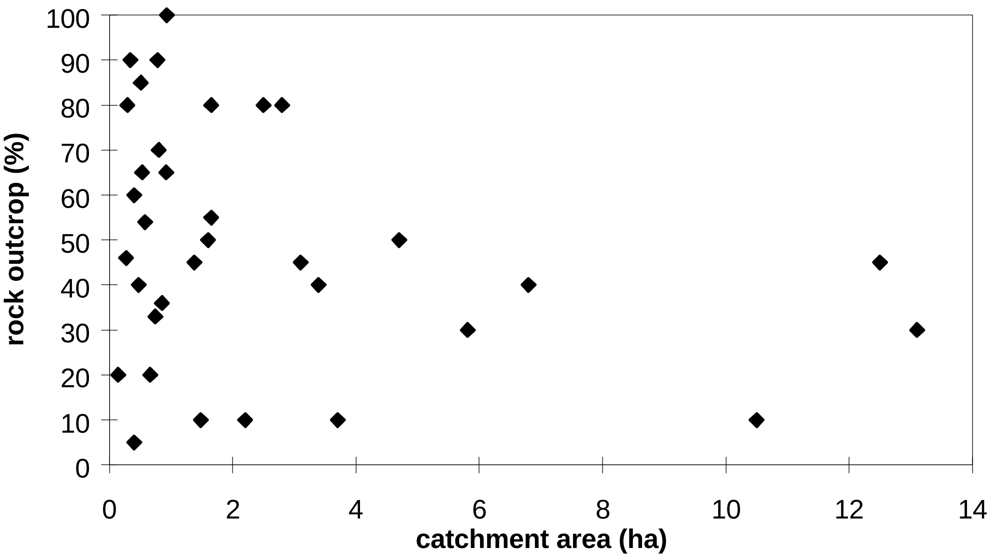

Figure 1 Relationship between catchment area and percentage rock outcrop.

Although the runoff shows a large interannual variation, small aljibes with a high curve number (CN = 95) in the central mountain ranges (median annual rainfall of 380 mm) will fill quite easily each year (Figure 3). Larger less efficient catchments (CN = 83) in the coastal mountain ranges (median annual rainfall of 225 mm) yield lower annual runoff depths, and although the aljibes connected to such large catchments will require less runoff depth to fill(<3.5 mm), they will remain nearly empty for consecutive years (Figure 3). The differences in annual runoff between these two types of catchments can only partly be explained by the differences in median annual precipitation. Another explanation for the differences in runoff depths would be the difference in runoff coefficient. Runoff is only generated when the daily rainfall exceeds a threshold depending on the storage within the catchment (Soil Conservation Service, 1986). This threshold varies with the curve number (CN) and the antecedent moisture conditions (Table 1). The threshold ranges between 1.57 mm for catchments consisting mainly of rock outcrops during wet conditions (CN(III) = 97) to 25 mm for vegetated slopes with thin soils during dry conditions (CN(I) = 67). The wide range between these thresholds once again demonstrates the importance of the surface characteristics of the catchments in order to provide a regular runoff supply. The thresholds calculated above for rocky hillslopes are in agreement with measurements of the minimum amount of rainfall that produces runoff in other (semi)arid landscapes: 5 mm on rocky slopes in the Negev, Israel (Lavee *et al*., 1997), 5 mm of high intensity rainfall or 15 mm of low intensity rainfall on coarse stony slopes in New South Wales, Australia (Brown and Dunkerley, 1996), 4.5 mm h^{-1} on bare bedrock to 7.5 mm h^{-1} on rocky slopes in the Negev, Israel (Yair, 1992) and 10 mm on slopes with thin soils on mica-schist in Rambla Honda south-east Spain (Nicolau *et al*., 1996).

This research indicates that the management of this traditional water harvesting system should concentrate on careful selection of catchments with a high runoff curve number, artificial surface sealing of catchments, maintenance of conduits and design of the system to obtain a suitable volume to catchment ratio. Although these indigenous systems are more and more abandoned, they could play an important role in the sustainable development of semi-arid and arid regions, where the demand for water is ever increasing due to threats of desertification and an increasing population density (Le Houérou, 1996).

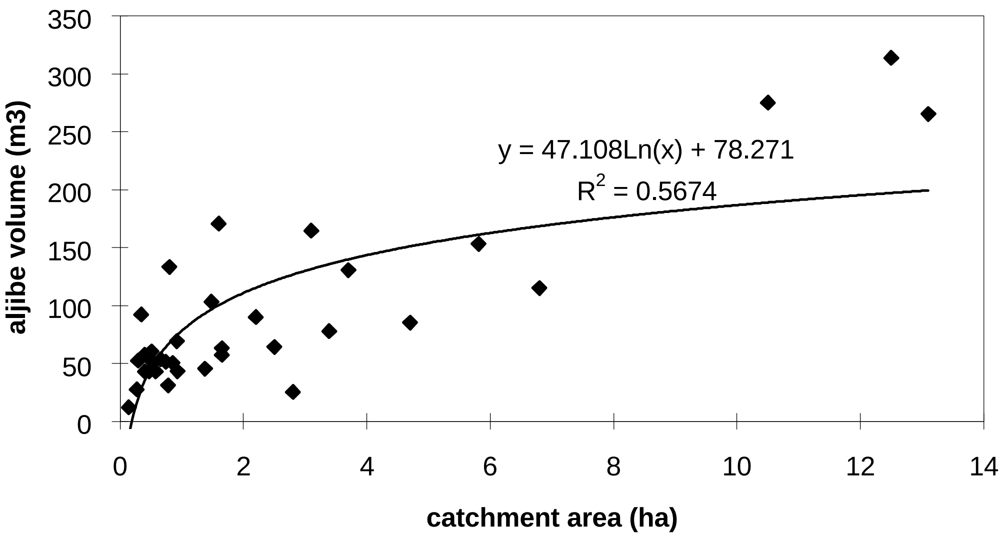

Figure 2 Relationship between catchment area and volume of the aljibes.

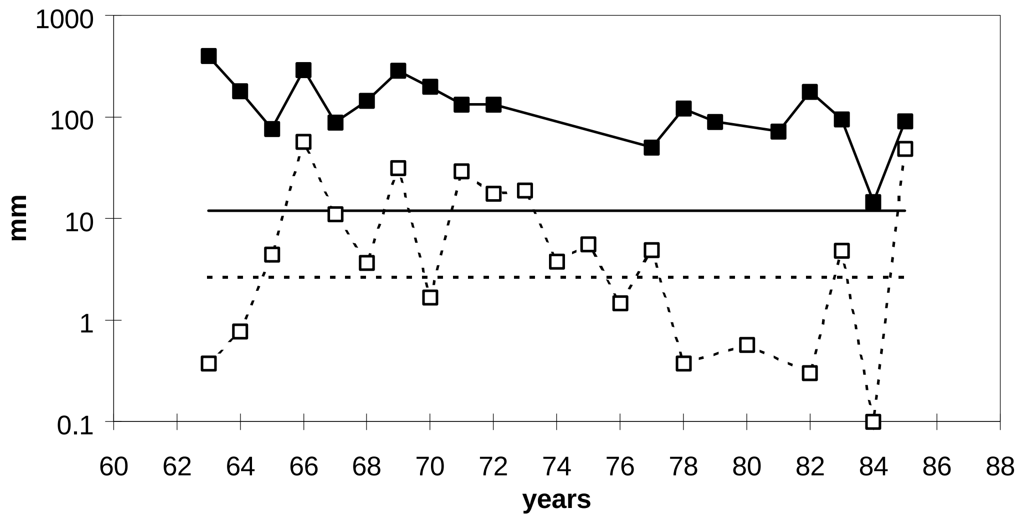

Figure 3 Variation in annual runoff from a small catchment (CN = 95; median annual rainfall equals 380 mm; solid line), and a large catchment with a low runoff curve number (CN = 83; median annual rainfall equals 225 mm; dashed line). The horizontal lines indicate the runoff required to fill the corresponding aljibe.

Conclusion

Collection and storage of runoff from hillslopes in underground cisterns (aljibes) is an old and well established technique in the semi-arid part of south-east Spain. The water in these aljibes is mainly used for livestock and for domestic purposes. The aljibes are built in such a way that they collect runoff from hillslopes with a high percentage of rock outcrops via conduits. The logarithmic relation between catchment area and aljibe volume demonstrates that the systems were designed to collect a maximum of runoff and that the runoff coefficient decreases with catchment area. In particular the geomorphic position of the aljibes (immediately downslope of the steep slopes with rock outcrops and avoiding the colluvial mantle) is in agreement with the discontinuous character of runoff in (semi)arid landscapes. The large temporal variability of rainfall determines the viability of the aljibes. At present, the areas with around 250 mm annual rainfall fail to produce enough runoff to fill the aljibes during periods of drought. Indigenous techniques such as the aljibe system could provide an additional source of water to alleviate the ever increasing demand in semi-arid and arid regions.

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