Influence of soil surface types on infiltration in a karstic area (Sierra de Gador, SE Spain). Implications for aquifer recharge.

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Introduction

The Sierra de Gador is a mountain range to the west of the town of Almeria (SE Spain). It reaches 2242 m a.s.l. and consists of a thick series of Triassic carbonate rocks, mainly dolomites, resting on impermeable metapelites of Permian age. The Sierra de Gador is connected through a zone of extensive fault systems to the coastal plains of the Campo de Dalias. The Sierra de Gador is the most important recharge area for the aquifers of the Campo de Dalías where water demands are progressively increasing due to expansion of agriculture and tourism (Pulido-Bosch et al., 1993). Previous studies (Vallejos et al., 1997, Frot et al., 2002; Vandenschrick et al., 2002) using water stable isotopes to characterize the sources of the karstic aquifer system indicate that though the annual dominant precipitation is from Atlantic fronts, only shallow groundwater has this origin, while a few intense events with Mediterranean signature, are the main water source of deep aquifers (main groundwater in the coastal plain). According Pulido-Bosch et al (1993), main channels would be the main input places for aquifer recharge from such Mediterranean precipitations. However it is known that in arid and semiarid areas most runoff generated by moderate events do not reach ephemeral streams because runoff water infiltrates along hillslopes as shown by Yair & Lavee (1985) in Israel and VanWesemael et al (1998) and Puigdefábregas et al (1999) in SE Spain. Within this framework, an instrumented area was set in the Llano de los Juanes, central high plain of structural origin in the Sierra de Gador, assuming its potential as recharge area from minor events, with the aim to assess its infiltration capacity. An hydropedological characterization is being carried out along with the monitoring of the runoff produced by a small catchment area, as well as the evaluation of actual evapotranspiration (AET). The first results after one year are presented. Infiltration data could validate the drainage assessments (potential aquifer recharge) made from precipitation and AET evaluation.

Material and methods

The instrumented area consists in a meteorological station where the following variables are measured: rainfall amount and intensity, wind speed and direction, air temperature and humidity, and solar radiation. AET is evaluated through a model for semi-arid sparse vegetation by Domingo et al. (1999) based on the Penman-Monteith model and validated by the Eddy correlation technique. Runoff in a 1.44 ha catchment area is monitored through the water level in an underground cistern (*aljibe*) built as a water harvesting technique (Van Wesemael et al., 1998). Also 70 rainfall simulations at an average intensity of 52 mm h^{-1}

(maximum rainfall intensity for the area with a return period of 10 years according Elias-Castillo & Ruiz-Beltrán, 1979) have been carried out on representative ground cover types, on different geomorphic positions, on dry and wet soil surface, measuring continuous runoff from bounded plots of 0.25 m^2, time to ponding, time to crack closing, time to runoff, infiltration front, and soil moisture before and after the rainfall experiment. The relative percentage of characteristic ground cover types has been estimated by means of counting about 600 points in 34 transects across the area.

Results and discussion

Four main soil surface types have been identified: Vegetated ground (> 50% plant cover + litter) occupy an estimated 30.2% of the area. Bare soil (without rock fragments > 2 cm), 8.6%. Rock fragments (RF), > 2 cm, resting on the soil, 20.4%. Rock outcrops (RO) and RF embedded in the soil surface, 32.3%. These latter contribute much more to runoff than RF resting on the soil surface (Poesen and Lavee, 1994).
From the rainfall simulations, in general quite high infiltration coefficients (IC), were obtained, from both dry ($\theta = 3.66 \pm 0.35$ %) and wet ($\theta = 28.28 \pm 0.56$ %) conditions. The infiltration coefficient is complementary to the measured runoff coefficient assuming that evapotranspiration is negligible during rain simulations. Table 1 shows that plant cover and litter act as thorough sinks for rainfall on both dry and wet conditions. Bare soil produces some runoff mainly when wet, once all cracks have closed. RF cover with RF on the top behave like plant cover patches, acting as sinks for rainfall. Ground cover dominated by embedded RF and RO are essentially runoff producers, especially under wet conditions. However, when RO are fractured (vertical cracks and fissures), infiltration becomes dominant. Fig 1 shows two pairs of rainfall simulations over embedded RF (plot 21) and over bare soil (plot 35). Runoff coefficients on both dry and wet soil conditions of plot 21 double those for plot 35. Geomorphological positions seem much less related to infiltration than to the surface cover type (table 1).

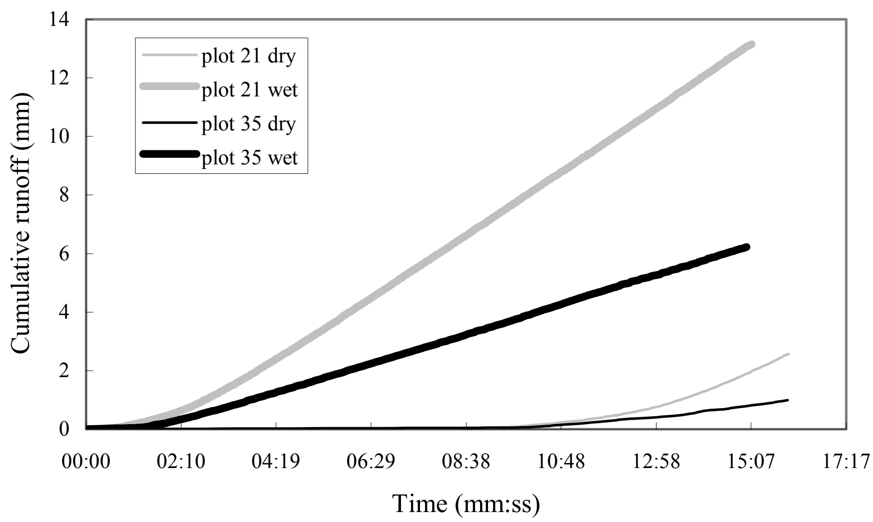

Fig 1.- Cumulative runoff and time to runoff in two contrasted bare plots under dry and wet soil condition during a rainfall simulation. Plot 21 is mainly covered by embedded rock fragments and plot 35 by bare soil.

The underground deposit (aljibe), has a capacity of 50.2 m³ and drains an area of 1.44 ha. Each millimetre of water level within the *aljibe* is equal to 0.00155 mm of runoff in the catchment area. To fill completely the *aljibe* requires a total runoff of 3.37 mm.

Table 1.- Average infiltration coefficients (avg) with standard error (std er) and coefficient of variability (CV) from rainfall simulations according types of soil surface (A) or position within the hillslope (B). RF = rock fragment, RO = rock outcrop, * fractured rock.

		dry soil			wet soil		
		avg	std er	CV	avg	std error	CV
		%	%	%	%	%	%
	plant cover + litter	99.99	0.01	0.03	99.95	0.06	0.19
	bare soil	92.43	3.10	10	79.61	7.71	29
A	RF on top	99.14	0.93	2.3	96.86	2.61	6.6
	RF embedded + RO	42.50	19.09	44.9	22.50	7.78	34.6
	RF embedded + RO *	96.47	4.21	6.2	90.14	11.62	18.2
	upper position	93.72	4.66	19.2	90.35	5.74	24.6
B	middle position	96.66	2.01	6.6	86.90	7.33	26.6
	lower position	91.23	6.09	17.7	85.91	9.51	29.3

From Fig 1 it can be observed that in general low runoff coefficients are produced at the beginning of the hydrological year, between 1st of September (when the aljibe is totally empty) and the 18th of November, when the *aljibe* reaches its maximum water level. After a dry September (P = 1.63 mm), October and November recorded 80.55 mm and 71 mm respectively (until the 18th Nov). The overall runoff coefficient during that 79-day period was 2.2%. However, zooming Fig 1 to a shorter period, between 2003/11/17 20:00 and 2003/11/18 14:00, we obtain a runoff coefficient of 5.38% (P = 49.63 mm, R = 2.67 mm), or in the 30 min of maximum rainfall intensity, we get a maximum runoff coefficient of 8.85% (P = 4.88 mm, R = 0.43 mm).

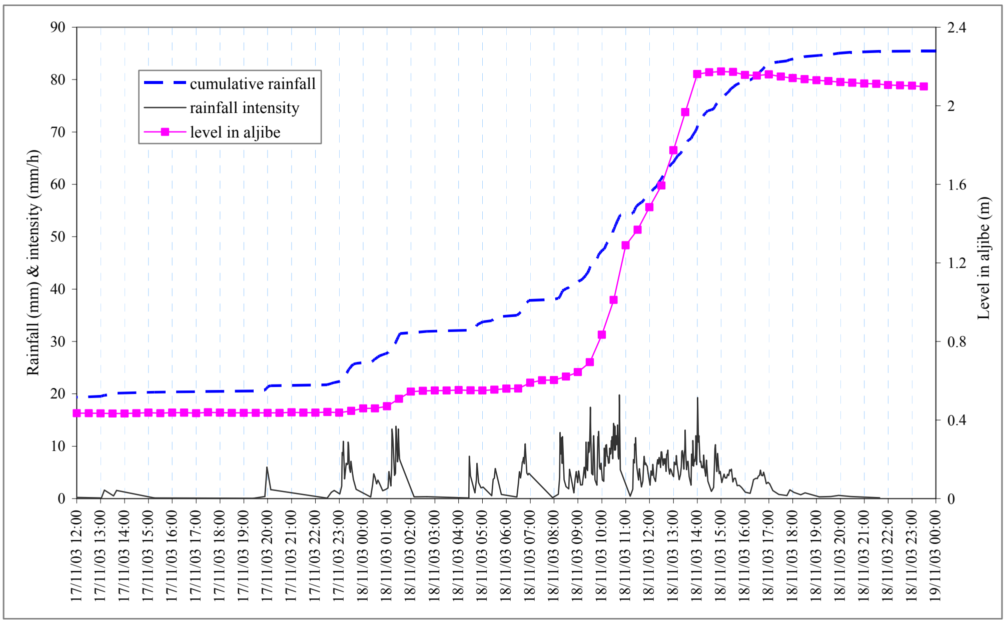

Fig 2.- The aljibe fills when the rainfall intensity exceeds a given threshold. Exemple during a rainfall event in Novembre 2003 (with rainfall accumulated since 15th November).

These latter results agree with the results obtained with the rainfall simulations and with what stated by Yair and Lavee (1985) and Puigdefábregas et al (1999): only some parts of the catchment area with particular surface characteristics contribute to runoff. Moreover, in this catchment area, runoff is produced when rainfall intensities exceed 10 mm/h during 15 min or when total rainfall exceeds 10 mm with intensities over 5 mm/h.
As the catchment area of the *aljibe* can be considered fairly representative of most of Llano de Los Juanes, the results obtained in the catchment might be at least indicative of what occurs in the whole high plain and even in other similar areas in Sierra de Gador. As two thirds of the area are formed by highly infiltrating surfaces, it can be assumed that most of the annual rainfall is infiltrated as only 20% has evapotranspirated during such a period (P = 151 mm, AET = 32 mm).
Between 2003/09/15 and 2004/06/15, the total precipitation for the area has been 496 mm, while accumulated AET has been 163 mm, giving a drainage estimate of 333 mm. This result agrees with that obtained with the soil moisture balance method, 312 mm, assuming a daily net drainage from the difference between actual volumetric soil moisture (θ) and θ at 33 kPa. All theses results suggest an effective contribution to water recharge, in agreement with the infiltration values from the rainfall simulations.

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