LONG TERM HYDROLOGICAL MONITORING OF TWO MICRO-CATCHMENTS IN SEMI-ARID SE SPAIN

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ABSTRACT

Arid and semi-arid lands are characterised by a combination of high temporal variability in rainfall and spatial heterogeneity of soil surface properties. As a consequence, little information is available about their hydrology. In addition, during the past half century, changes have occurred in most semi-arid lands in the Northern Mediterranean: agricultural abandonment and consequently a change in land use. In order to investigate the hydrological consequences of such abandonment, two representative field sites on contrasting lithologies in SE Spain were instrumented in 1989 and 1991. Additional field observations, experiments and model simulations were performed with a variety of soil, plant, water runoff, and atmospheric parameters. A summary of the first long term results of analyses of runoff, erosion and other hydrological variables at plot and micro-catchment scales is presented here, including the main monitoring problems encountered.

Keywords runoff, erosion, long-term monitoring, soil water content, semi-arid environment

INTRODUCTION

The Rambla Honda (37.1297°N, 2.3713°W) and the El Cautivo (37.0109N, 2.4391°W) field sites, both in Almeria province, SE Spain, are permanently equipped research sites, aimed at gathering information on climate, vegetation, and hydrological and geomorphic processes and their interactions at two lithologically contrasting locations in a dry Mediterranean climate (see references). Both sites are under very low grazing pressure after the abandonment of agriculture.

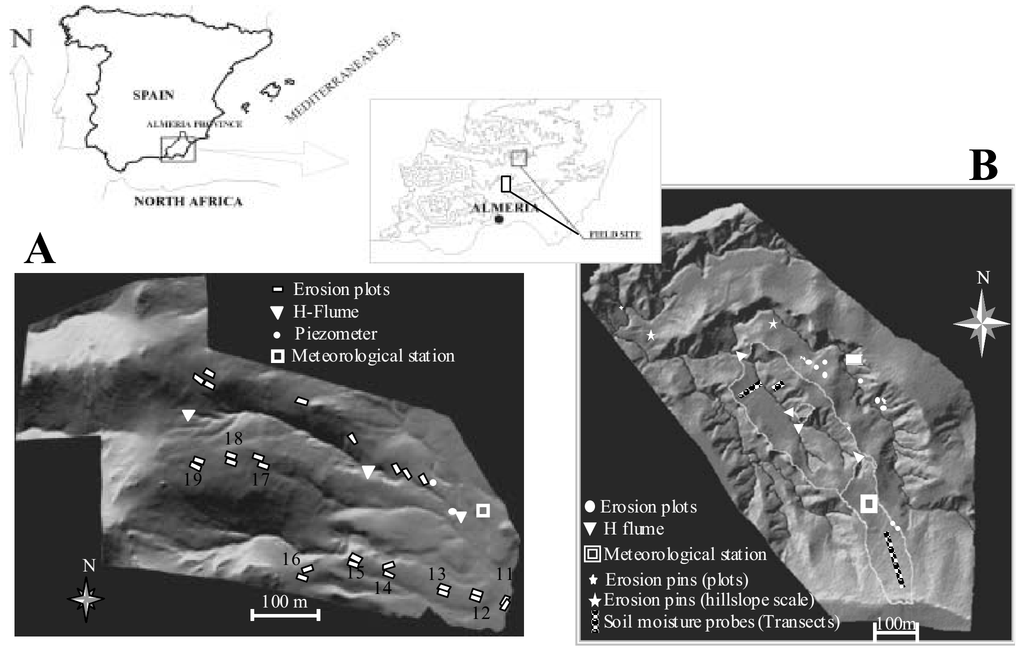

Fig 1: Location and maps compiled from DEM, showing runoff and erosion plots (Nº 11 to Nº 19, from the lower to the upper part of the catena). H-flumes are gauging devices in micro-catchments 1 to 3 in Rambla Honda (Fig 1A) and micro-catchments 1 to 4 in El Cautivo (Fig 1B) (numbered from the lower to the upper part of the catchment).

Rambla Honda (Fig 1A) is a semi-arid Mediterranean rangeland on top of mica schist bedrock including: a) tussock grasslands of *Stipa tenacissima* on shallow sandy-loam soils at the rocky upper part; b) open shrubland of *Anthyllis cytisoides* on thick loamy-sand soils developed on the alluvial fans at the foot slope; and c) open shrubland of *Retama sphaerocarpa* on very thick loamy-sand soils over the river bank terrace at the bottom of the catena (Nicolau et al., 1996; Puigdefábregas et al., 1996).

El Cautivo (Fig 1B) is located in one of the most extensive badland areas in Spain over calcitic gypsiferous mudstone. Main geomorphic features include valley asymmetry and a variety of different soil-surface types over silt-loams, including many types of both mineral and biological crusts, with contrasted erosion and hydrological behaviour (Calvo and Harvey, 1996; Solé-Benet et al, 1997; Cantón et al., 2001b).

Meteorological, hydrological and ecological variables are being monitored at several time scales at both field sites. Runoff and sediment yield is monitored in plots ranging from 0.25 m^2 to 20 m^2, some equipped with divisors and tipping buckets, and in micro-catchments from 57 to 45,000 m^2, equipped with H-flumes and automatic samplers. The sites also have dielectric sensors (TDR). Other variables have been monitored during specific campaigns: soil hydrology (Nicolau et al., 1996; Puigdefábregas et al., 1996), actual evapotranspiration for three main plant communities (Domingo et al., 1999), rainfall interception and rainfall partitioning (Domingo et al., 1998), as well as plant biomass budgets and fluxes, such as net primary productivity, death biomass and litter fall (Puigdefábregas et al., 1996).

RESULTS

In both sites a strong seasonal and inter-annual variability in rainfall is observed. On average, up to 75 % of the annual rainfall is recorded during autumn and winter (Fig 2). Temperatures show mild annual averages with warm summers and mild winters, due to a high insulation and mild winds. There is a strong spatial variability in runoff along hillslopes in both field sites due to soil surface types (crusted), soil depth (< 30 cm in rocky slopes and > 1 m in the alluvial fans or pediments), plant cover (Fig 4) and spatial vegetation pattern. The widespread occurrence of structural surface crusts (coarse-pavement sieving crusts, Fig 3, in Rambla Honda and slaking crusts in El Cautivo) explains rainfall thresholds for runoff occurrence of around 18 mm in the alluvial fan and 3 mm in the upper slopes of Rambla Honda, and about 5 mm in bare areas of El Cautivo.

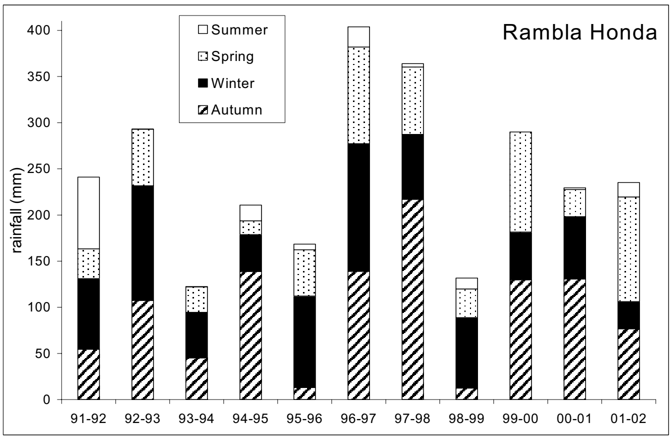

Fig 2: Seasonal rainfall from 1991 to 2002.

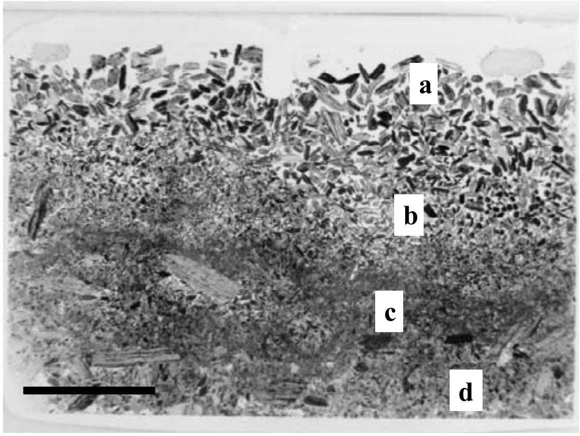

Fig 3: Coarse pavement sieving crust from Rambla Honda. a = gravel and coarse sand layer, b = sand layer, c = very fine sand layer, d = heterogeneous layer. Length of black bar = 15 mm.

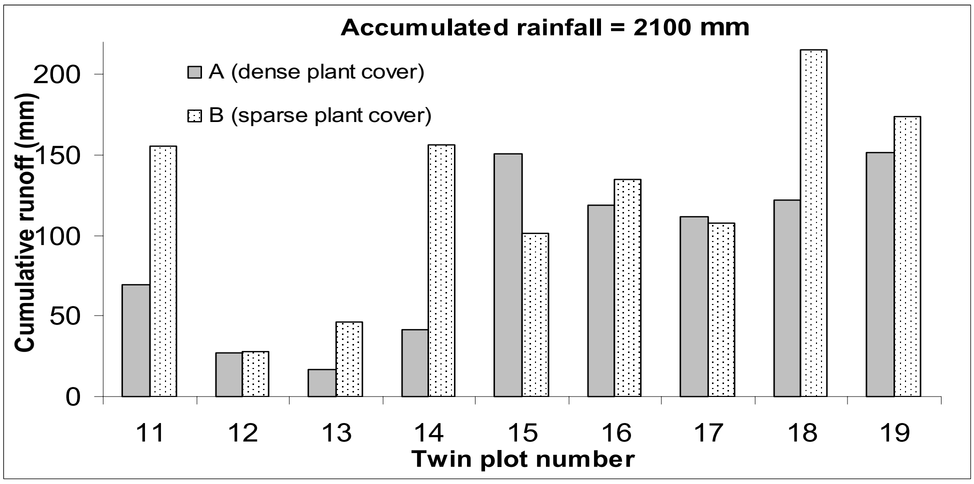

Fig 4: Accumulated runoff (from Sept 91 to Aug 2000) along the catena, from lower (nº 11) to upper hillslope (nº 19). A and B are twin runoff-erosion plots as shown in Fig 1.

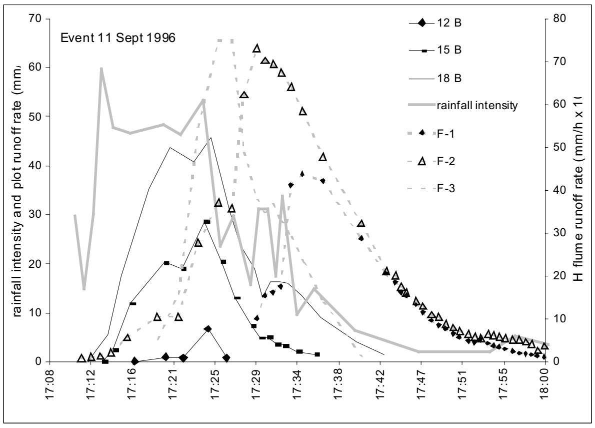

Fig 5: Cumulative saturation of subsurface layers in Rambla Honda

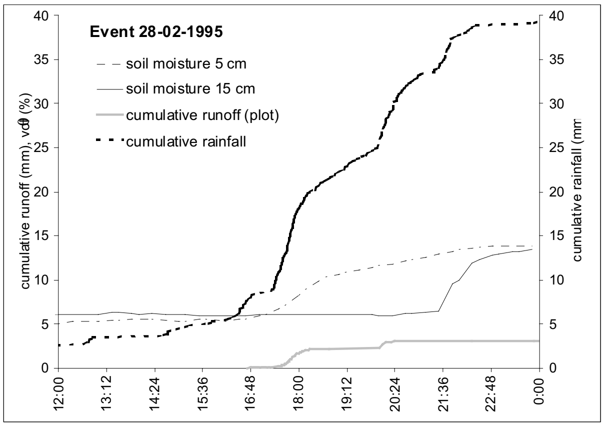

Fig 6: Runoff by infiltration excess (Horton).

Two mechanisms of overland flow generation have been identified (Puigdefábregas et al, 1998). The first mechanism is saturation from subsurface layers (low frequency, high magnitude events in Rambla Honda). An example is shown in Fig 5. The second mechanism is infiltration excess. These are frequent but short lived, high intensity events in Rambla Honda and always in El Cautivo (Fig 6). Hillslope connectivity is rare, as in most arid and semi-arid regions, and only occurs with the first runoff mechanism. The relation between the area of the catchment and runoff coefficients is relatively similar at both sites (Figs 7A, 7B).

The influence of scale and soil surface types on runoff is evident when the cumulative runoff in different micro-catchments is compared. As an example, the event of 31 October 1993 in El Cautivo is shown in Fig 8: micro-catchments 2 (260 m^2) and 3 (60 m^2), mainly covered by bare soil surfaces with low infiltration capacity, show the highest runoff (Solé-Benet et al., 1997; Cantón et al., 2001), while micro-catchment 4, mostly covered by vegetation with medium to high infiltration rates, shows the lowest runoff. Micro-catchment 1 (2 ha) shows also a quite reduced overall runoff due to its heterogeneous mosaic of soil surfaces, where runoff from bare areas can reinfiltrate in plant-covered areas downslope (Cantón et al., 2001, 2002).

Soil erosion is very limited in Rambla Honda (up to 9 g m^{-1} $year^{-1}$ in erosion plots and < 0.01 g m^{-2} $year^{-1}$ in a 5 ha catchment) and more significant in El Cautivo (up to 628 g m^{-1} $year^{-1}$ in small plots and up to 0.037 g m^{-2} $year^{-1}$ in micro-catchment 1 (2 ha), with a runoff threshold of 5 mm to produce over 300 g m^{-2} of sediment).

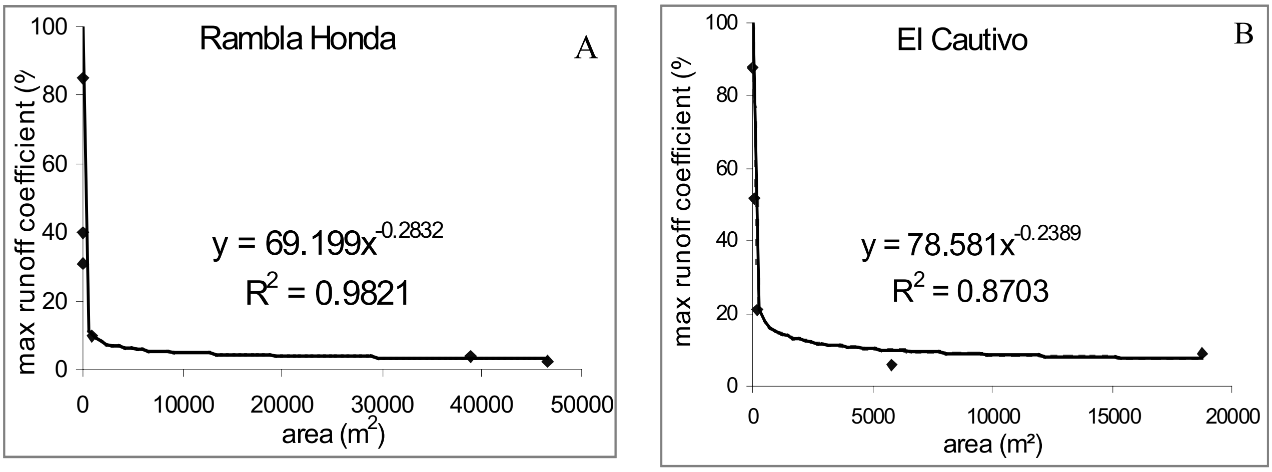

Fig 7: Relationships between catchment size and runoff coefficients.

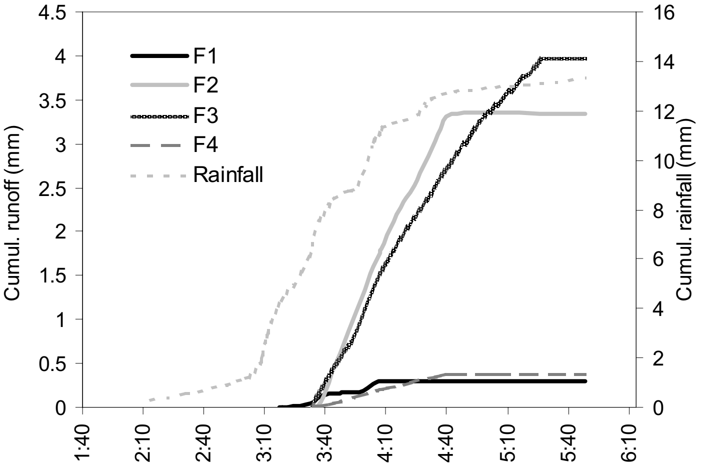

Fig 8: Accumulated runoff and accumulated rainfall for micro-catchments 1 (F1), 2 (F2), 3 (F3) and 4 (F4) during the event of 31 October 1993 (Cantón et al., 2001).

Soil erosion in El Cautivo also shows a strong correlation with the dominant soil surface type. Where plant cover is scarce, as in micro-catchments 2 and 3, soil erosion can be very high. During some events, highly charged (up to 0.4 kg L^{-1}) to hyper-concentrated flows (up to 0.8 kg L^{-1}) are recorded. In areas mostly covered by annual and perennial plants, as in micro-catchment 4, the erosion rates are low (during one event a maximum of 60 g m^{-2} was measured).

Flow peaks coincide with the highest sediment discharge peaks. Fig 9 shows the evolution of both runoff and sediment yield (particles < 1 mm) during a rainfall event in micro-catchment 1.

The research on erosion at a patch scale has particularly focused on the role of vegetation as a source of spatial heterogeneity that affects the short-range distribution of water and sediments. Results from Rambla Honda, based on field observations, experiments and simulation models (Sánchez and Puigdefábregas, 1994), show that a range of positive feedback mechanisms, like the trapping of water and sediments by vegetated patches and the concentration of flow between herbs and bushes, leads to nucleation or to the increase in spatial heterogeneity by concentrating resources of the soil beneath plant clumps at the expense of neighbouring bare ground (Puigdefábregas et al, 1999). Concerning sediment at the micro-catchment scale, channels are the main redistribution structures as well as the main sources when they cut into alluvial fans (Puigdefábregas et al., 1999).

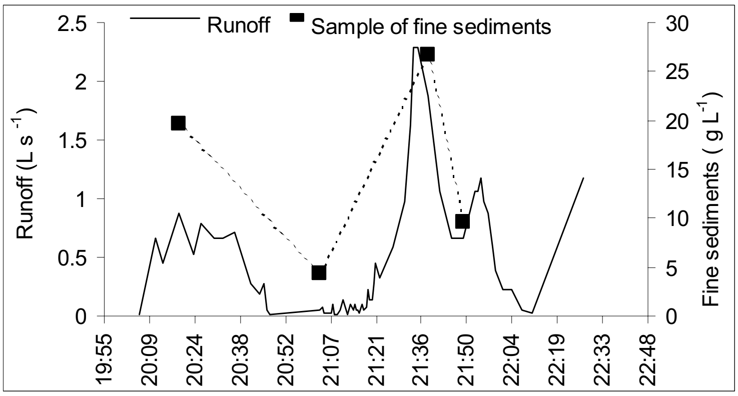

Fig 9: Hydrograph and sedimentograph (particles < 1 mm) for the event of 1 February 1993 in micro-catchment 1.

A validated evapotranspiration model applied to an area of about 2 ha in the lower section of the catena in Rambla Honda shows that actual evapotranspiration (ET_{act}) largely exceeds (by about 100 mm per year) precipitation (P) at annual scales. The estimated deficit may be compensated by: a) infiltration of local rainfall during extreme events; b) runon from the surrounding hillslopes; or c) infiltration of channel flow during flash floods originating from the upper part of the catchment. Data from long term monitoring show that possibilities a) and b) cannot explain the water deficit but do show that deep storage of water during floods in the main channel can be as much as 60 mm to 150 mm per event, and may have been 160 mm year^{-1} to 400 mm year^{-1} during a period of four years (1994-1997) (Domingo et al, 2001).

DRAWBACKS AND SUSTAINABILITY OF LONG TERM MONITORING

Several problems occurred during the experiments on the runoff plots: A) Bounded runoff plots stop sediment flux from upslope and therefore might suffer from sediment exhaustion after several years of no runon. B) Soil moisture surplus near a collector trough enhances the growth of annual plants, thus triggering a feedback mechanism of progressive sediment trapping and enhanced plant growth. C) An important part of runoff collected from runoff plots comes from a few decimetres upslope of the collector trough. D) The changes in spatial structure of vegetation within runoff plots during the monitoring period may influence the magnitude of the measured variables. E) Several types of external changes (galleries and/or latrines of rabbits or other vertebrates, feeding grounds or rooting areas of wild boars, ant nests, etc.) may cause an important non-homogeneity in the monitored variables, a fact especially acute in bounded runoff plots. F) Periodical calibration of tipping buckets and levelling flow divisors is highly recommended to avoid a progressive drift in the measured variables. All these problems, because of the small scale of the experiments, make it difficult to upscale the results.

Detected problems in small instrumented catchments: A) It is not easy to select the right gauging device for ephemeral channels, nor its right dimension. A combination of large devices (large range, reduced precision) with small ones (short range, higher precision) seems to be the most adequate approach. B) Hyper-concentrated flows, where they occur, usually cause clogging of gauging devices and sensors. C) No simple devices are adequate for sediment measurements from hyper-concentrated flows. Weight sensors coupled to water levels in gauged channel sections are a promising technique which should be improved. D) In semi-arid areas, where runoff events normally occur with low frequency (1 year^{-1}), it may take a long time to collect a good data series in order to test homogeneity assumptions.

Data obtained in micro-catchments from arid and semi-arid regions should be used with caution when trying to extrapolate to either larger or different areas: because of the occurrence of spatial heterogeneity (in soil depth, vegetation type and cover and rooting depth) along with high temporal variability in rainfall and other meteorological data. This may have very important hydrological consequences, and thus extrapolations might only apply for very similar environmental conditions.

In dry environments, looking at fine time scales is essential to obtain information on processes, especially those leading to extreme events (such as rainfall), which are the main drivers of landscape change. Moreover, permanent research facilities afford the paradox that funding is mainly through specific research projects the time scale of which is usually not compatible with the longer term evolution of the geomorphic processes. The approach should be to develop and monitor low cost indicators, including remotely sensed data.

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