Journal of Hydrology: Regional Studies 9 (2017) 18–33

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

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

# Controls on runoff generation along a steep climatic gradient in the Eastern Mediterranean

Fabian Ries[a,b,*], Sebastian Schmidt[b], Martin Sauter[b], Jens Lange[a]

[a] Chair of Hydrology, University of Freiburg, Fahnenbergplatz, 79098 Freiburg, Germany
[b] Applied Geology, Geoscience Centre, University of Göttingen, Goldschmidtstrasse 3, 37077 Göttingen, Germany

ARTICLE INFO

*Article history:*
Received 31 March 2016
Received in revised form 28 October 2016
Accepted 1 November 2016

*Keywords:*
Mediterranean
Catchment hydrology
Semi-arid areas
Climatic gradient
Physical catchment properties
Runoff generation processes

ABSTRACT

*Study region:* Lower Jordan River.
*Study focus:* The main aim of this study was to identify differences in catchment runoff reactions across a variety of scales and a strong climatic gradient and to correlate them to physical catchment properties. For this purpose we observed rainfall and runoff responses on a hillslope (1000 $m^2$) and in several nested catchments (3.2–129 $km^2$) over a period of five years. Catchment characteristics and surface cover types were derived from high-resolution aerial images. To gain process understanding a single high magnitude event was analysed in detail using information from soil moisture plots.
*New hydrological insights for the region:* Our results show that runoff in the semi-arid headwater area is strongly related to long lasting rainfall events of high amounts and is predominantly generated by saturation excess overland flow (SOF). Observations from the arid runoff plot indicated a strongly contrasting behaviour with dominating Hortonian overland flow (HOF). At catchment scale we found an accentuated runoff response when we compared arid with semi-arid conditions, which can be attributed to different geological substrate, more abundant rock surfaces, shallower soil and sparser vegetation cover. Identified strong correlations between event rainfall and runoff volumes may provide promising options for the assessment and management of surface runoff as a water resource.


## 1. Introduction

In the Mediterranean region, runoff generation and its relationship to climate, rainfall, soil cover and landuse has considerable influence on phenomena such as soil erosion, land degradation, desertification and flooding that impose considerable problems on society (García-Ruiz, 2010; Hill et al., 2008; Martinez-Mena et al., 1998; Llasat et al., 2010). For that reason, it has gained increased attention in recent years (e.g. Cantón et al., 2011; Cammeraat et al., 2010; Ziadat and Taimeh, 2013; Marchamalo et al., 2016; Ochoa et al., 2016). Furthermore, in the light of water scarcity, surface runoff may be regarded as an additional water resource (Thornes and Wainwright, 2004; Kalogeropoulos and Chalkias, 2013), which is however not regularly used. Additionally, flow in ephemeral channels usually leads to transmission losses (e.g. Lange, 2005) i.e. focussed aquifer recharge, with implications for water resources management and protection. Semi-arid catchments often comprise a climatic transition from wetter headwaters to dryer downstream sections. In combination with different scales of observation (plot, hillslope and catchment scale) this poses challenges for hydrological process studies.

* Corresponding author at: Chair of Hydrology, University of Freiburg, Fahnenbergplatz, Freiburg 79098, Germany.
*E-mail address:* fabian.ries@hydrology.uni-freiburg.de (F. Ries).

http://dx.doi.org/10.1016/j.ejrh.2016.11.001

On the plot scale, overland flow is first triggered on isolated rock outcrops or soil surfaces with limited infiltration capacities due to e.g. crusts, from where it contributes to saturation of adjacent soil pockets (Cantón et al., 2002; Lange et al., 2003; Sohrt et al., 2014). Once soil patches are saturated or local infiltration rates exceeded, surface runoff can continue downslope. A major impact on hydrological response is often assigned to the presence or absence of vegetation cover (Cantón et al., 2011), which has led to the concept of vegetation-driven spatial heterogeneity (Puigdefábregas, 2005). Vegetation is usually reported to enhance infiltration (e.g. Cerdà, 1997; Quinton et al., 1997; Cantón et al., 2011), while in some rare cases, even the opposite may be true due to the reduction in infiltration as a result of the presence of organic litter and its hydrophobic effect (e.g. Nicolau et al., 1996). Further, the spatial distribution of vegetation patches, which is often associated with livestock grazing (Kröpfl et al., 2013), influences runoff generation (Calvo-Cases et al., 2003; Puigdefábregas, 2005). With certain patterns overland flow resistance may be reduced and thus flow velocity increased. With increasing aridity, vegetation and other biotic factors become less and abiotic factors more important for infiltration and runoff behaviour (Lavee et al., 1998; Ruiz-Sinoga et al., 2011). At the same time runoff generation gradually changes from saturation excess (SOF) to Hortonian overland flow (HOF) as shown by Cerdà (1997, 1998).

On the hillslope and sub-catchment scale, physiographic factors such as the connectivity of runoff generating areas, as well as rainfall characteristics are relevant for runoff generation. Runoff coefficients were observed to drop with increasing slope length mainly due to run-on effects and increased infiltration losses (Puigdefábregas et al., 1998). Hillslope scale runoff generation and amounts were found to be mainly controlled either by rainfall intensity, rainfall depth and antecedent precipitation (Li et al., 2011), or by surface properties (Yair and Kossovski, 2002; Arnau-Rosalén et al., 2008). Puigdefábregas et al. (1998) described two types of runoff generation, HOF at the beginning of short intensive storms and SOF by saturation of shallow soil patches or locations with decreasing permeability with depth during long-duration rainfall events with high amounts.

On the catchment scale, stream runoff is composed of contributions from sub-catchments and single hillslopes, sometimes with considerable variations in climatic conditions and surface properties, such as soil type, thickness and bedrock permeability (Ries et al., 2015). Yair and Raz-Yassif (2004) found that ephemeral streams in arid regions receive most runoff from headwater areas. Generally, runoff coefficients decrease with increasing catchment size (e.g. Goodrich et al., 1997; Yair and Raz-Yassif, 2004). This is partly due to the limited size of storm cells, runoff concentration time, differences in lithological composition, slope length and morphology as well as transmission losses in tributaries and the main channel alluvium (e.g. Kirkby et al., 2002; Yair and Kossovsky, 2002; Lange, 2005; Zanon et al., 2010). Also human caused transformation of the landscape such as urbanization (Grodek et al., 2011; Perrin and Tournoud, 2009; Lange et al., 2001) or land cultivation (Koulouri and Giourga, 2007; Kosmas et al., 1997; García-Ruiz, 2010) might play an important role on the catchment runoff response.

At all spatial scales in arid and semi-arid areas, runoff generation is characterized by high variability in time and space. Despite considerable advances in the understanding of runoff generation on the plot and hillslope scale, there is still a lack of knowledge on how small scale runoff patterns are reflected in catchment scale runoff response.

Our aim was to identify differences of dominant runoff generation processes within and between several carbonate rock catchments along a strong climatic gradient in the Eastern Mediterranean. For this purpose, we installed a dense monitoring network in hitherto basically ungauged basins (three major ephemeral streams including four headwater basins) to measure rainfall, wadi runoff, hillslope overland flow and soil moisture in high temporal resolution. Runoff events covered a period of five years and were correlated with amounts, intensities as well as spatial and temporal distribution of rainfall. The runoff response was further related to soil, rock lithology, land use and surface cover. This analysis provides new insights into runoff generation across different spatial scales and sub-climate types.

## 2. Study area

The study catchments are located in the central and eastern parts of the West Bank, northwest of the Dead Sea and east of Jerusalem (Fig. 1). Deeply incised ephemeral streams (Wadis) drain the area and discharge into the endorheic Lower Jordan River/Dead Sea basin. Catchment elevations range from 1016 m a.s.l. to 240 m b.s.l. Gauged catchment sizes for the main watersheds (Wadi Auja, Wadi Nueima and Wadi Qilt) vary between 54.8 and 129 $km^2$ and between 3.2 and 14.5 $km^2$ for individually gauged headwaters of Wadi Auja (H1–H4).

Precipitation shows a pronounced seasonality with a rainfall period from October to April. During this period, most rainfall occurs within few intense storm events originating from large-scale low-pressure systems (mainly Cyprus-Lows) over the Eastern Mediterranean Sea (Goldreich, 2003). These storms usually last for several days, cover large areas and provide high overall rainfall amounts of mainly low intensity. Nevertheless, they can be accompanied by localized high-intensity rainfall for short periods of time (Dayan and Morin, 2006). Convective rainfall events with high precipitation intensity but relatively low depths occur in spring and autumn and are often associated with air masses originating from the south (Active Red Sea Troughs). Seasonal rainfall amounts are highest in the elevated mountain range (semi-arid conditions) and decrease rapidly towards the Jordan Valley (arid conditions) eastward due to the topographic gradient (rain–shadow desert). Mean annual long-term precipitation is 532 mm in Jerusalem (810 m a.s.l.) and only 156 mm in Jericho (290 m b.s.l.) (Morin et al., 2009), with a high interannual variability. Potential evapotranspiration largely exceeds seasonal precipitation with annual values of 1350 mm in the mountains and up to 1650 mm in the Jordan Valley (Israel Meteorological Service – http://www.ims.gov.il).