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RAINFALL AND WATER YIELD IN MACIZO DEL CAROIG, EASTERN IBERIAN PENINSULA. EVENT RUNOFF AT PLOT SCALE DURING A RARE FLASH FLOOD AT THE BARRANCO DE BENACANCIL

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ABSTRACT. Floods are a consequence of extreme rainfall events. Although surface runoff generation is the origin of discharge, flood research usually focuses on lowlands where the impact is higher. Runoff and sediment delivery at slope and pedon scale receiving much less attention in the effort to understand flood behaviour in time and space. This is especially relevant in areas where, due to climatic and hydrogeological conditions, streams are ephemeral, so-called dry rivers ("wadis", "ramblas" or "barrancos") that are widespread throughout the Mediterranean. This paper researches the relationship between water delivery at pedon and slope scale with dry river floods in Macizo del Caroig, Eastern Iberian Peninsula. Plots of 1x1, 1x2, 1x4, and 2x8 m located in the "El Teularet" Soil Erosion and Degradation Research Station were monitored from 2004 to 2014 to measure soil and water delivery. Rainfall and flow at the dry river Barranco de Benacancil were also monitored. Results show that runoff and sediment discharge were concentrated in few events during the 11 years of research. A single flood event was registered in the channel on September 28, 2009, however, the runoff was registered 160 times at the plots. Runoff discharge was dependent on the size of the plots, with larger plots yielding lower runoff discharge per unit area, suggesting short runoff-travel distance and duration. Three rainfall events contributed with 26% of the whole runoff discharge, and five achieved 56% of the runoff. We conclude that the runoff generated at the plot scale is disconnected from the main channel. From a spatial point of view, there is a decrease in runoff coefficient along the slope. From a temporal point of view, the runoff is concentrated in a few rainfall events. These results show that the runoff generated at plot and slope scale does not contribute to the floods except for rainfall events with more than 100 mm day^{-1}. The disconnection of the runoff and sediment delivery is confirmed by the reduction in the runoff delivery at plot scale due to the control of the length of the plot (slope) on the runoff and sediment delivery.

Precipitación y producción de agua en el Macizo del Caroig, Este de la Península Ibérica. Evento de escorrentía a escala de parcela durante una crecida torrencial en el barranco de Benacancil

RESUMEN. Las inundaciones son consecuencia de lluvias extremas. Aunque la generación de escorrentía superficial es el origen de la descarga, la investigación de inundaciones generalmente se enfoca en las tierras bajas donde el impacto es mayor. La escorrentía y la distribución de sedimentos a escala de pendiente y pedón reciben mucha menos atención en la comprensión del comportamiento de las inundaciones en el tiempo y el espacio. Esto es especialmente relevante en zonas donde, debido a las condiciones climáticas e hidrogeológicas, los cauces son efímeros. Son los llamados ríos secos ("wadis", "ramblas" o "barrancos") muy extendidos por todo el Mediterráneo. Este artículo investiga la relación entre el suministro de agua a escala de pedón y ladera con las crecidas de ríos secos en Macizo del Caroig, este de la Península Ibérica. Las parcelas de 1x1, 1x2, 1x4 y 2x8 m localizadas en la Estación de Investigación de Erosión y Degradación de Suelos "El Teularet" fueron monitoreadas de 2004 a 2014 para medir la producción de suelo y agua. También se monitorearon las precipitaciones y el caudal en el río seco Barranco de Benacancil. Los resultados muestran que la escorrentía y la descarga de sedimentos se concentraron en pocos eventos durante los 11 años de investigación. Se registró un solo evento de inundación en el canal el 28 de septiembre de 2009, sin embargo, la escorrentía se registró 160 veces en las parcelas. La descarga de escorrentía dependió del tamaño de las parcelas. Las parcelas más grandes produjeron una menor descarga de escorrentía por unidad de área, lo que sugiere una corta distancia y duración del recorrido de escorrentía. Tres eventos de lluvia contribuyeron con el 26% de la descarga total de la escorrentía y cinco lograron el 56% de la escorrentía. Se concluye que la escorrentía generada a escala de la parcela está desconectada del canal principal. Desde un punto de vista espacial, hay una disminución en el coeficiente de escorrentía a lo largo de la pendiente. Desde un punto de vista temporal, la escorrentía se concentra en unos pocos eventos de lluvia. Estos resultados muestran que la escorrentía generada a escala de parcela y pendiente no contribuyen a las inundaciones excepto para eventos de lluvia con más de 100 mm día^{-1}. La desconexión de la escorrentía y la entrega de sedimentos se confirma por la reducción de la escorrentía a escala de parcela debido al control de la longitud (pendiente) sobre la escorrentía y la entrega de sedimentos.

Key words: Runoff, sediments, rainfall, extreme events, dry rivers, ephemeral floods.

Palabras clave: escorrentía, sedimentos, precipitación, eventos extremos, ríos secos, inundaciones efímeras.

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1. Introduction

Floods are a consequence of the interaction of nature and humans (Hamilton, 1987). Nature determines that lowlands and other areas prone to be flooded along the catchments will be covered by water during some periods due to extreme rainfall events (Downs and Thorne, 2000). Human activities taking place in the floodplain, as well as wrong planning and land use mismanagement the upstream, can increase the economic damage and casualties caused by floods.

Within the factors that control flood events, extreme rainfall is the most relevant (Guhathakurta *et al.,* 2011). Extreme rainfall events, either in volume or intensity, result in extreme floods (Smith *et al.,* 2001). This has been documented at different scales, from large basins (Parida *et al.,* 2017) to small watersheds (Daliakopoulos and Tsanis, 2012). Most of the research carried out in areas affected by floods focuses on the lowlands as they are the areas that suffer more and where the damages from a life and property point of view are higher (Bauer *et al.,* 2018). However, damages from floods in mountainous terrain, from small creeks, are becoming more frequent (Wu *et al.,* 2019). Moreover, the lowlands are also very dynamic from the fluvial and geomorphological perspective (Keesstra, 2007; Kalantari *et al.,* 2018; Yousefi *et al.,* 2018). Although most of the attention by policymakers, land-users, and practitioners after a flood is located in the lowlands, from a geomorphological and hydrological point of view, the runoff delivery from the upper mountainous areas is relevant to understand the mechanism of the floods and to learn how to prevent them.

It is accepted that the origin of the floods can be found in the runoff generated at pedon and slope scale, although few papers focuss on this origin of the runoff discharge that can result in dramatic events. In northern France, Martin (1999) researched the effect of agriculture practices (no-tillage, moldboard plowing, mustard intercrops, and superficial plowing) on runoff production and soil loss and found a positive effect of the use of cover crops to control floods. Hümann *et al.* (2011) in the forest land of Southwest Germany found that forest land contributes to reducing the floods as runoff was higher in the agricultural land. Similar findings in the Loess Plateau in China were measured by Zhang *et al.* (2018) who analyzed 371 flood events (1963-2011) and demonstrated that floods accounted for 49.6% to 91.8% of their mean annual totals of runoff. The reduction of surface runoff and associated sediment yield in floods explained about 85.0% to 89.2% of the sediment yield.

The connection between soil erosion and floods is a classic topic in soil erosion research that is much less studied in recent years. Robinson and Blackman (1990) researched soil erosion of arable farmland on the South Downs in East Sussex that used to cause episodic flooding and they demonstrated that the on-farm costs of the erosion were smaller than the off-farm costs. Bannari *et al.* (2016) assessed the flash-flood impact on soil redistribution in the foot of the western Anti-Atlas Mountains in the south of Morocco. Wilkinson *et al.* (2010) show the impact of floods in the runoff in the Belford catchment in Northumberland and Bronstert *et al.* (1995) in Germany and Saghafian *et al.* (2008) in the Golestan region of Iran. The research of Poesen and Hooke (1997) in the Mediterranean updated the knowledge on soil erosion and flood issues with a general overview. Other researchers contributed with regional data to understand how runoff is generated and floods formed. The works of Romero-Diaz *et al.* (2010) contributed key information to understand how the afforestation in semiarid land can result in higher erosion rates. Ecosystems response to soil erosion and flood generation is complex such as the land abandonment show (Romero-Díaz *et al.,* 2017) along climatological gradients in Mediterranean ecosystems (Ruiz-Sinoga and Díaz, 2010). Dry rivers (ephemeral rivers) are studied from different perspectives in the Mediterranean region: flood events; channel changes; and mapping upon land-use indicators (Yousefi *et al.,* 2020)). But little research has been developed to link the runoff and sediment detached at pedon and slope scale with the floods triggered on the talweg.

An example of the connection between the pedon and watershed-scale takes place during extreme rainfall events such as the one on September 12, 2019, when 300 mm were registered in Ontinyent, Spain, in one day (see Fig. 1). Similar examples can be found in the review of López-Bermúdez (1993) when rainfall events of high magnitude – low frequency are analyzed. Then the overland flow was extreme in the river Canyoles with a flash flood and evidence (rills and gullies) found in the headwaters of the watershed. The key scientific question here is the frequency of these extreme rainfall events. These events have also formed most of the geomorphologic features of the Mediterranean Type-Ecosystems, and this is relevant as they determine also the landforms. To answer this key scientific and development question, we need long-term measurements in the field and an assessment of the floods. Long-term monitoring is the key contribution of this paper.

Figure 1. Views of the impact of the DANA of 12 September 2019 at the study are of river Canyoles watershed. View of the river Canyoles talweg after the flood in Granja de la Costera, (A), gully formed as a consequence of the mismanagement of the railway flows at Font de la Figuera (B), talweg of the river Canyoles in Moixent with the removal of the sediments (C), almond plantation affected by rilling in Font de la Figuera (D), rill development in sunflower fields in Moixent (E), and barley field after tillage with wide gullies in Font de la Figuera (F).

Previous research approached this topic at a single spatial scale. This was the conventional approach. However, recently some authors applied different techniques to determine the runoff and soil losses at different scales. To develop a better understanding of the floods in Japan and to determine how the forest management practices determine the runoff generation, sediment transport, and soil erosion, Onda *et al.* (2010) conducted field observations and monitored the discharge, water quality, and soil erosion in forest plantations through catchments (> 4 ha), plots (0.1-4 ha), hillslope plots (0.5-2 m) and splash cups. The effect of the scale is relevant such as was found by Bagarello *et al.* (2018) where plots of different sizes resulted in runoff coefficients and soil erosion with different orders of magnitude. The larger the plot, the lower the soil losses, which is due to the low degree of connectivity of the flows (Keesstra *et al.,* 2018). The importance of the plot size was also a key factor during the recovery of the plant cover after land abandonment such as Cerdà *et al.* (2018) found in El Teularet research station. Floods are also enhanced by human activities in the headwaters of the watersheds and basin. Deforestation has been one of the main human impacts on the mountain terrains that enhanced floods and activated the erosional cycle and result in fluvial adjustments (Begueria *et al.,* 2006). Although other factors are relevant to understand and foresee the runoff generation during floods, extreme rainfall events are the ones that trigger the runoff initiation, sheet and rill flows, and finally the floods (Smith *et al.,* 2011).

Most of the research was carried out at a watershed scale to determine the runoff discharge and sediment delivery. The contribution at slope and pedon scale is much less researched to understand flood behavior in time and space, although the runoff generation at smaller scales is the origin of the large-scale water discharge. This paper researches the role of low frequency-high magnitude events in the water delivery at pedon and slope scale on flood generation in Mediterranean mountainous terrains.

2. Material and Methods

2.1. Study area

Macizo del Caroig was selected to determine the soil erosion and water yield in a typical Mediterranean mountainous area dominated by rainfed agriculture and rangelands. There, the Department of Geography (University of Valencia) developed in 2002 the El Teularet Soil Erosion and Degradation Research Station to monitor and assess the impact of land management and land uses on soil erosion and runoff generation (Fig. 2). Climate is the typical Mediterranean with a mean annual temperature of 12.7°C registered at the nearby Las Arenas Enguera meteorological station. January is the coldest month (9.8°C) and August is the warmest (25.7°C). Rainfall is characterized by a mean annual rainfall of 540 mm and a typical Mediterranean dry summer. The highest rainfall intensities were recorded from September to December when some rainfall events with a 10-year return period can reach 100 mm day^{-1} (Cerdà, 2017). Four erosion plots were installed on a slope of marl parent materials which used to be agricultural land. The overall landforms are characterized by a succession of plateaus and deeply incised valleys. This is a consequence of the weathering (dissolution) of the Cretaceous carbonate rocks which are the main parent material in the study area and Eastern Spain; on patches of marls in the landscape, most of the (abandoned) agriculture fields can be found. Soils at the study site are classified as Typic Xerorthents (Soil Survey Staff, 2014) (Cerdà *et al.,* 2018).

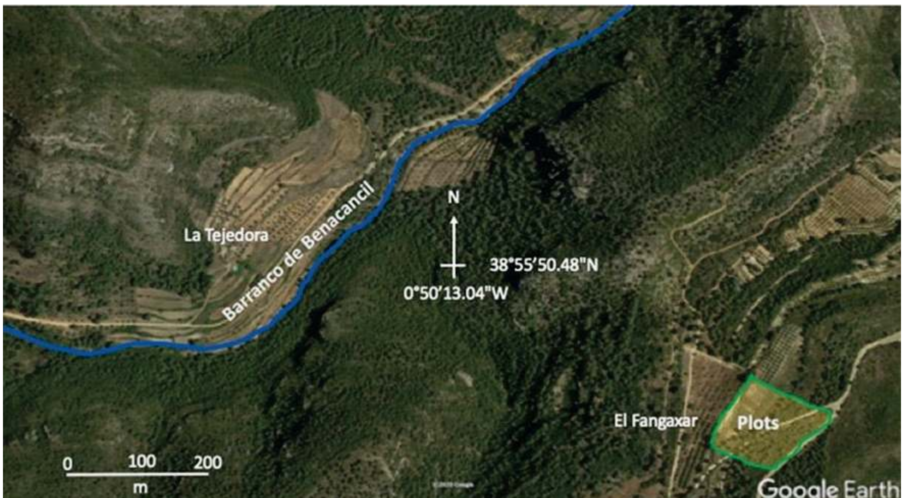

Figure 2. Location of the study sites. The main creek is Barranco de Benacancil located 706 m from the soil erosion plots in the Macizo del Caroig, inland Valencia province.

2.2. Methods

A set of 4 plots was established in 2002. Plots were delineated with aluminium sheets, 1 mm thick by 50 mm height, that prevented surface and subsurface flow to and from each catchment. Each plot consisted of 1x1, 1x2, 1x4, and 2x8 m (width x length) (Fig. 3). The plots were tilled 4 times per year (April, May, June, and August) to remove vegetation as traditionally done for soil management of almond, fruit, olive, and vineyard crops in the region. The first measurements took place in January 2004. After each rainfall event, runoff discharge and runoff sediment concentration were measured, and plots borders, drainage, collectors, pipes, and deposits were checked for damages.

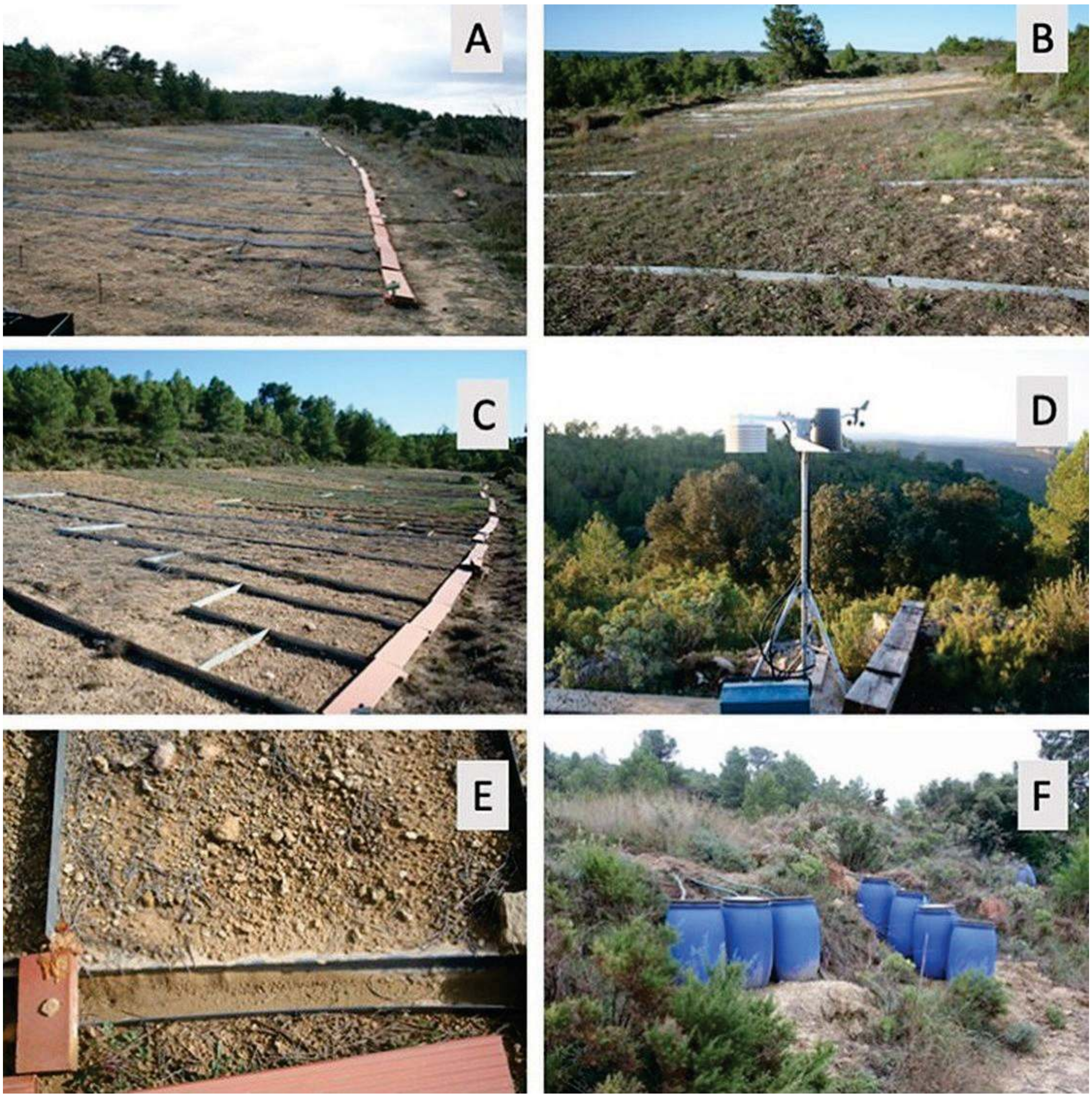

Figure 3. View of the plots in January 2006 (A), April 2007 (B), and May 2008 (C), meteorological station in October 2005 (D), detail of one of the collectors in June 2007 (E) and runoff deposits in July 2008 (F).

Soil and vegetation descriptions and sampling were made in December 2003 before the measurements were initiated and maintained during the experimental period. Rainfall (mm) was measured in the nearby Las Arenas meteorological station located 5 km from the study site. More than 6 hours without rainfall was used as the threshold to determine the rainfall events. Runoff (l) was collected from the plots using a collector (gutter) that was 0.15 x 1 m (2 m in the 16 m^2 plots, 2 x 8 m^2) and 0.15 m depth. The collected runoff was drained into 125 and 250 l tanks connected to the collector by a 0.4 m-diameter pipe. Total storage capacities were 125, 250, 375, and 600 l for the 1, 2, 4, and 16 m^2 plots, respectively.

3. Results and Discussion

The measurements carried out in El Teularet Soil Erosion and Degradation Research Station during the 11 years of the study untangle the connectivity regime of the flows along the slope, and from the slope to the stream Barranco de Benacancil.

3.1. Rainfall

The total rainfall measured during the 11 years of research reached 6,280.8 mm. The rainfall distribution per year shows that although the average rainfall was 571.0 mm for the eleven-year study period, the variability was very high as it ranged from 288.0 mm in 2005 to 749.0 mm in 2007. The seasonal distribution of rainfall was characterized by dry summers which are typical in the Mediterranean ecosystems and last from July to August (Vicente-Serrano *et al.,* 2004; López-Moreno *et al.,* 2009). The negative trend of the mean annual rainfall was not significant (y: -3.13x + 6,848.2; R^2: 0.0058) but the period is too short to conclude that there is a trend. Although changes in the rainfall trend in the Mediterranean have been observed, they are not registered in other Western Mediterranean long-time series of data (Peña-Angulo *et al.,* 2020). The decrease in annual rainfall found by other authors is paradoxical with the increase in the mean daily rainfall (Alpert *et al.,* 2020). Those changes will affect the vegetation growth and then the soil and water yield in Mediterranean Ecosystems (Sarris *et al.,* 2007; Keesstra *et al.,* 2009).

The largest daily rainfall events at the El Teularet study site took place in 2009 (140.0 mm) and 2013 (111.0 mm). The largest rainfall events (consecutive rainy days) amounted to 230.0 mm in 2009, 176.8 mm in 2012, and 167.0 mm in 2004 (Table 1). Daily rainfall has been increasing in the Mediterranean (Ribes *et al.,* 2019) although not in all the regions (Serrano-Notivoli *et al.,* 2018) were found the same trend. The highest rainfall events show a good correlation with the highest mean annual rainfall at the study area such as has also been found in other research sites (Mathbout *et al.,* 2018) (Fig. 4).

Table 1. Rainfall distribution per year and for the 1st, 2nd, and 3rd largest daily rainfall and rainfall event.

Year	Total mm	Day 1st mm	Day 2nd mm	Day 3rd mm	Event 1st mm	Event 2nd mm	Event 3rd mm
2004	699.8	66.0	49.0	43.5	167.0	110.5	62.5
2005	288.0	44.0	31.5	18.0	44.0	31.5	19.8
2006	485.0	64.0	50.0	30.0	89.9	88.0	50.0
2007	749.0	80.0	68.0	67.0	131.0	80.0	68.0
2008	609.4	58.0	52.0	52.0	119.0	66.0	65.5
2009	728.5	140.0	52.0	51.5	230.0	59.2	58.0
2010	554.2	45.0	32.3	31.5	48.2	33.5	33.4
2011	590.4	93.0	49.0	35.0	145.5	83.5	70.0
2012	593.7	90.0	90.0	70.0	176.8	98.0	70.0
2013	560.4	111.0	90.0	48.0	111.0	100.5	70.0
2014	422.4	48.1	41.0	38.6	72.9	48.1	41.0
Average	**571.0**	**76.3**	**55.0**	**44.1**	**121.4**	**72.6**	**55.3**
Max	**749.0**	**140.0**	**90.0**	**70.0**	**230.0**	**110.5**	**70.0**
Min	**288.0**	**44.0**	**31.5**	**18.0**	**44.0**	**31.5**	**19.8**

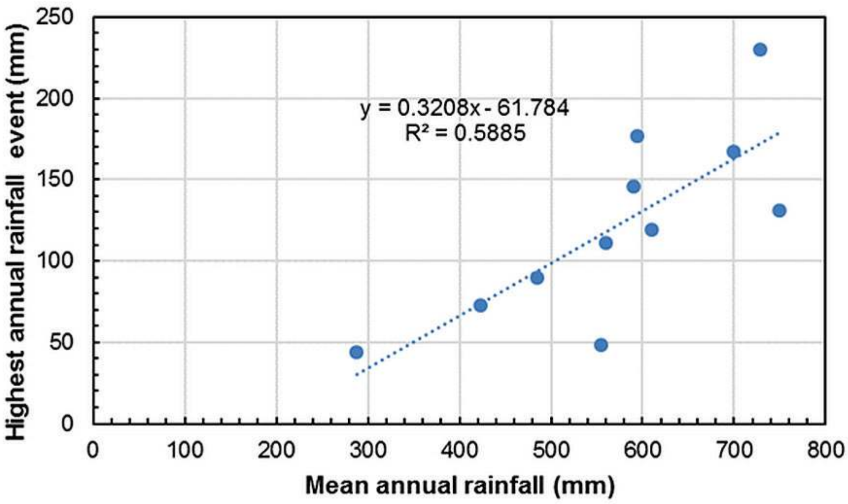

Figure 4. Relation between mean annual rainfall and highest daily rainfall and vice versa.

The daily rainfall for the period from September 12, 2009, to September 30, 2009, accounted for 340.5 mm with 230.0 mm from September 27th to September 30th and 140.0 mm on September 28th. This extreme rainfall event accounted for 46% of the total rainfall in 2009, which was a wet year with a total of 728.5 mm mainly due to this extreme rainfall event. The rainfall events of September 2009 accounted for 5.4% of the total rainfall registered in the study area from 2004 to 2014. Table 2 shows the daily distribution of the rainfall from September 12 to September 30, 2009.

Table 2. Rainfall per day and for the five events registered during the rainy season of September 2009. On September 9th we registered a flash flood at the ephemeral stream of Barranco de Benacancil.

Period Days 10	**Daily Rainfall mm**	**Event Rainfall mm**
12.9.09	7.0	
13.9.09	24.0	31.0
15.9.09	14.5	14.5
17.9.09	10.5	10.5
22.9.09	36.0	
23.9.09	18.5	54.5
27.9.09	52.0	
28.9.09	140.0	
29.9.09	11.0	
30.9.09	27.0	230.0
Total	**340.5**	**340.5**

The rainfall event of September 2009 was relevant as during the experimental period (2002-2014) we registered very dry years such as 2005 when 288 mm were recorded. The 140 mm registered on September 28th is not a rare event. Other extreme events have taken place in the area, e.g. October 21-22, 1982, with 623 mm in two days registered in Casa del Barón en la Muela de Cortes de Pallas and 580 mm in the nearest town (Enguera). The October 1982 precipitation event led to a catastrophic Xúquer river flood and the collapse of Tous Dam and the flood of the La Ribera district.

The distribution of the rainfall at El Teularet during the research period is shown in Figure 5, for daily and event measurements, respectively.

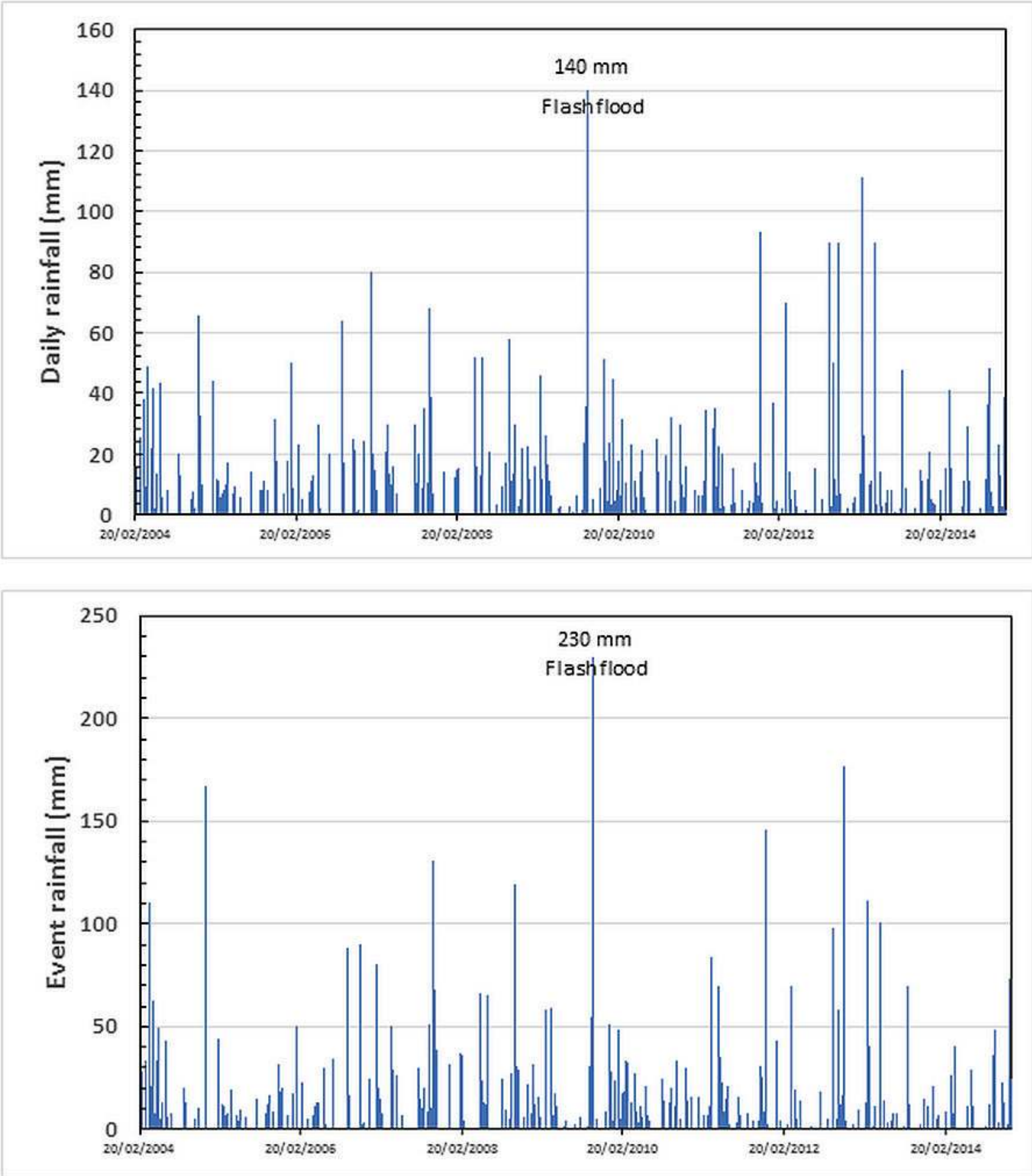

Figure 5. Daily rainfall (mm) at the El Teularet Soil Erosion and Degradation Research Station.

3.2. Runoff

During the entire 11 years of the study, the stream Barranco de Benacancil had runoff discharge only on September 28, 2009, after 140 mm of rainfall in one day. The discharge was a flash flood such as was described by farmers due to the sudden arrival of the runoff discharge wave. However, the runoff discharge at the plots under tillage in the El Teularet Soil Erosion and Degradation Research Station contributed to 169 runoff events during the 11 years of the study.

Annual runoff was measured at each of the four plots of 1, 2, 4, and 16 m^2. The total runoff during the 11 years (6,280.8 mm of rainfall) amounted to 868.5, 1,066.7, 1,438.7, and 3,678.4 l for the 1, 2, 4, and 16 m^2 plots, respectively. Annual variability was high, with the dry year 2005 yielding 9.8, 13.8, 20.8, and 40.4 l and wet 2007 yielding 176.1, 208.6, 300.7, and 708.1 l of runoff for the 1, 2, 4, and 16 m^2 plots, respectively (Table 3).

Table 3. Runoff discharge per plot and year (l). Total and average values.

Plot Surface Year	Plot 1 1 m^2 (l)	Plot 2 2 m^2 (l)	Pot 3 4 m^2 (l)	Plot 4 16 m^2 (l)	All plots 23 m^2 (l)
2004	138.6	181.7	227.5	677.7	1,225.5
2005	9.8	13.8	20.8	40.4	84.8
2006	74.3	101.1	171.9	344.0	691.3
2007	176.1	208.6	300.7	708.1	1,393.5
2008	69.3	78.5	122.6	262.0	532.4
2009	124.7	155.4	223.1	620.2	1,123.4
2010	20.8	27.4	30.8	70.3	149.4
2011	44.2	53.2	66.3	148.4	312.1
2012	122.4	139.7	150.4	434.2	846.7
2013	65.4	80.2	88.2	280.9	514.6
2014	22.9	26.9	36.5	92.3	178.6
Total	868.5	1,066.7	1,438.7	3,678.4	7,052.3
Average	79.0	97.0	130.8	334.4	641.1

Runoff discharge measured during the 11 years of research shows that the discharge is dependent on the plot size. Table 4 show that the total runoff per plot upon the 6,280.8 mm of rainfall move from the 868.5 mm till the 533.3, 359.7, and 229.9 l m^{-2}, with an average of 497.8 l m^{-2} (Table 4).

Table 4. Runoff discharge per plot and year (mm). Total and average values.

Plot Surface Year	Plot 1 1 m^2 (mm)	Plot 2 2 m^2 (mm)	Pot 3 4 m^2 (mm)	Plot 4 16 m^2 (mm)	All plots 23 m^2 (mm)
2004	138.6	90.9	56.9	42.4	82.2
2005	9.8	6.9	5.2	2.5	6.1
2006	74.3	50.6	43.0	21.5	47.3
2007	176.1	104.3	75.2	44.3	99.9
2008	69.3	39.3	30.7	16.4	38.9
2009	124.7	77.7	55.8	38.8	74.2
2010	20.8	13.7	7.7	4.4	11.7
2011	44.2	26.6	16.6	9.3	24.2
2012	122.4	69.9	37.6	27.1	64.3
2013	65.4	40.1	22.0	17.6	36.3
2014	22.9	13.4	9.1	5.8	12.8
Total	868.5	533.3	359.7	229.9	497.8
Average	79.0	48.5	32.7	20.9	45.3

The runoff coefficient also shows that runoff discharge is dependent on plot size. In average values, a decrease in the runoff coefficient is observed from 12.1, 7.8, 5.3, and 3.3% for the 1, 2, 4, and 16 m^2 plots, respectively (Table 5).

Table 5. Runoff coefficient per plot and year (%). Total and average values.

Plot Surface Year	Plot 1 1 m² (%)	Plot 2 2 m² (%)	Pot 3 4 m² (%)	Plot 4 16 m² (%)	All plots 23 m² (%)
2004	19.8	13.0	8.1	6.1	11.7
2005	3.4	2.4	1.8	0.9	2.1
2006	15.3	10.4	8.9	4.4	9.8
2007	23.5	13.9	10.0	5.9	13.3
2008	11.4	6.4	5.0	2.7	6.4
2009	17.1	10.7	7.7	5.3	10.2
2010	3.7	2.5	1.4	0.8	2.1
2011	7.5	4.5	2.8	1.6	4.1
2012	20.6	11.8	6.3	4.6	10.8
2013	11.7	7.2	3.9	3.1	6.5
2014	5.4	3.2	2.2	1.4	3.0
Average	12.7	7.8	5.3	3.3	7.3

The influence of the scale of measurement on runoff generation has been measure in a few research sites. The review of De Vente and Poesen (2005) on this topic demonstrated that the scale is a factor of the soil erosion rate measured. Most of the approaches to this topic were developed at catchment or basin scale (Bhattarai and Dutta, 2007), and much less information is found at the plot scale. Bagarello *et al.* (2018) already found in similar plots (under herbicide treatment) a strong control of the length of the slope: as longer the slope lower is the soil losses. Smets *et al.* (2008) found that the length of the plots (0.5 to 31.5 m) control the effectiveness of the mulches to control the soil and water losses. Kirkby (2010) already highlighted the importance of the distance on the slope, and scale effect, when researching the soil erosion processes. Parson *et al.* (2006) used eight runoff plots (2-28 m length) in Walnut Gulch Experimental Watershed in southern Arizona to determine that the sediment yield increased until 7 m plot length and later decreased. Santos *et al.,* (2017) developed research in the semiarid region of Brazil with 116 rainfall events with plots of 1, 20, and 28,000 m^2 to determine the impact of slash and burn on soil erosion. They found that the highest water losses were measured at 20 m^2 plots. Cammeraat (2004) utilizing a nested approach that the runoff was initiated under lower rainfall intensities at the pedon scale than at the slope (and watershed) scale in the Murcia region of the Eastern Iberian Peninsula. Moreno de las Heras *et al.* (2010) used length plots from 1 to 15 m on reclaimed land and they agree that a general decrease of unit area runoff was observed with increasing plot scale for all slopes. Langhans *et al.,* (2019) studied the impact of conservation tillage on different plot sizes (5, 30, and 180 m^2) and found that as larger were the plots lower the runoff coefficient, and that the impact of the management was affected by the scale of measurement.

In the El Teularet soil erosion experimental station we found a similar behavior of the plots: a reduction in the runoff delivery per unit area from the small to the large plots. Figure 6 shows a decrease in the runoff discharge (mm) from the 1 m^2 plots to the ones with 16 m^2. The maximum values registered in 2007 show this trend under the wettest conditions and year 2005 during the driest conditions. For the runoff coefficient (%) the trend shows how runoff is reduced by three times from 1 to 16 m^2 (Fig. 7). Figure 6 shows the trend along with the changes in the scale of the total runoff (l). The increase is because the plots are larger, but the runoff per unit area (% or mm) shows a reduction such as figures 6 and 7 shown.

The total rainfall at year scale influences the total runoff. The largest runoff coefficients were registered in the wettest year (2007) with 23.5, 13.9, 10, and 5.9%, and the lowest in 2005 with 3.4, 2.4, 1.8, and 0.9 % for the 1, 2, 4, and 16 m^2 plots. The relation between the rainfall and runoff also is affected by the control that the size of the plots exerts on the runoff yield. We found that within the relation between rainfall and runoff the size of the plots also is relevant (Fig. 7).

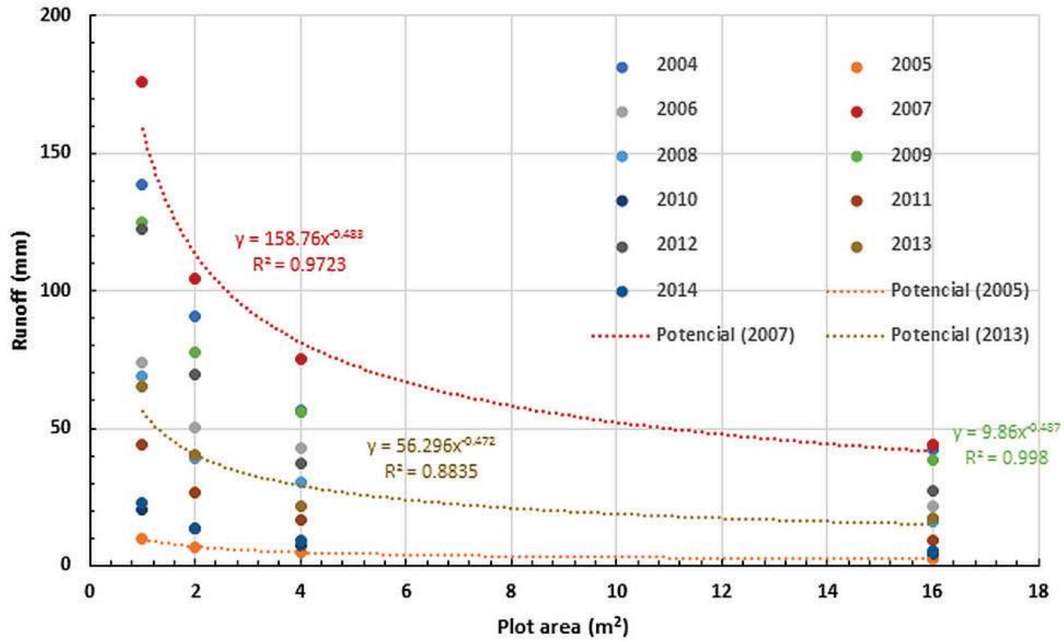

Figure 6. Event rainfall (mm) at the El Teularet Soil Erosion and Degradation Research Station.

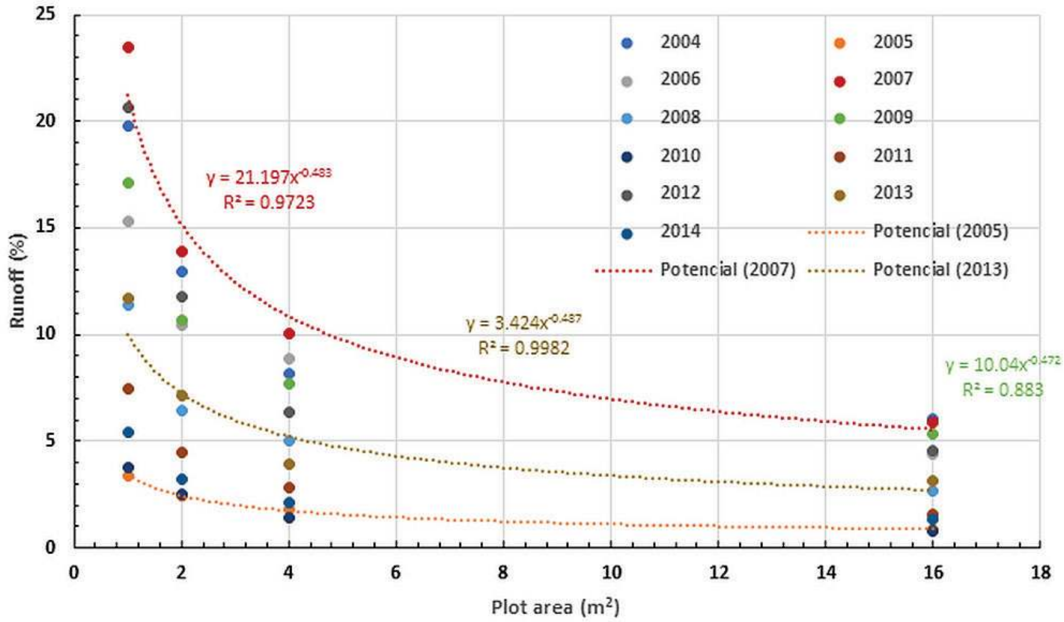

Figure 7. Runoff discharge (l) per year and plot per size of the plots (m^2).

3.3. Event rainfall and runoff

The runoff collected in the 4 plots during the runoff events shows that the runoff events do not take place when the rainfall is below 10 mm. Although we registered 470 daily rainfall grouped in 311 events, only 169 events were effective to deliver runoff, which is an average of 15.4 runoff events per year. Within the 311 rainfall events recorded (28.3 per year), 140 events of rainfall did not contribute to runoff due to the low rainfall volume below10 mm. Within the 109 rainfall events between 10 and 30 mm, 107 rainfall events contributed to runoff. All the rainfall events with rainfall values higher than 30 mm contributed to runoff (Table 6).

Table 6. Rainfall and runoff event distribution (nº, mm, %) for the 4 plots at the El Teularet Soil Erosion and Degradation Research Station.

Ranks	Rainfall nº	Rainfall mm	Rainfall Event nº	Rainfall Event mm
>100	2	251.0	9	1,291.3
>60	11	842.0	14	1,046.8
>30	41	1,649.8	39	1,548.5
>10	153	2,397.7	109	1,752.7
>5	122	809.8	71	470.8
>0	141	330.5	69	170.7
Total	**470**	**6,280.8**	**311**	**6,280.8**

Ranks	Runoff Event nº	Runoff Event mm	Runoff Event mm	Runoff Event mm	Runoff Event mm
		1 m²	**2 m²**	**4 m²**	**16 m²**
>100	9	458.0	273.1	176.4	133.6
>60	14	198.0	121.8	85.0	41.8
>30	39	145.4	93.0	63.8	36.7
>10	107	67.1	45.5	34.6	17.8
>5	0	0.0	0.0	0.0	0.0
>0	0	0.0	0.0	0.0	0.0
Total	**169**	**868.5**	**533.3**	**359.7**	**229.9**

Ranks	Runoff Average %	Runoff 1 m² %	Runoff 2 m² %	Runoff 4 m² %	Runoff 16 m² %
>100	52.8	52.7	51.2	49.0	58.1
>60	21.9	22.8	22.8	23.6	18.2
>30	17.0	16.7	17.4	17.7	16.0
>10	8.4	7.7	8.5	9.6	7.7
>5	0.0	0.0	0.0	0.0	0.0
>0	0.0	0.0	0.0	0.0	0.0
Total	**100**	**100**	**100**	**100**	**100**

The runoff yield (mm) was determined by the size of the plot, but the runoff initiation did not. All the plots have shown that when runoff took place, the runoff was present in all plots, which is because under tillage conditions the soils contribute to surface runoff when the rainfall intensity is higher than the soil infiltration capacity (Horton, 1933). The Hortonian overland flow mechanism induces that when runoff is present it is found along the whole slope. In agricultural land, Hortonian overland flow is generated due to the impact of tillage that reduces that induce soil degradation, the formation of surface crusts, and then the runoff initiation. Ziegler *et al.* (2001) found that Hortonian overland flow was present in an agriculture watershed in northern Thailand where the soil hydraulic conductivity was low. The low infiltration rates of the soils are the key factor to enhance the Hortonian overland flow (Dunne and Dietrich, 1980). Agriculture land induces low infiltration rates and high runoff discharges. This has been found in areas where tillage is present. Tillage induces the degradation of the soils in different regions of the world and induced the highest runoff discharges and also quick overland flow. Chalise *et al.,* (2019; 2020) found this in Nepal, Cerdà *et al.,* (2020) in eastern Spain, Takken *et al.,* (2001) in the loess belt in Europe, and Tullberg *et al.,* (2001) in Australia.

On the other hand, the magnitude of the runoff discharge was determined by the size of the plot as the larger plots contributed with the lowest runoff discharge (per unit area, mm); however, the total amount of runoff in the larger plots was higher as the contribution area was larger (see Fig. 8).

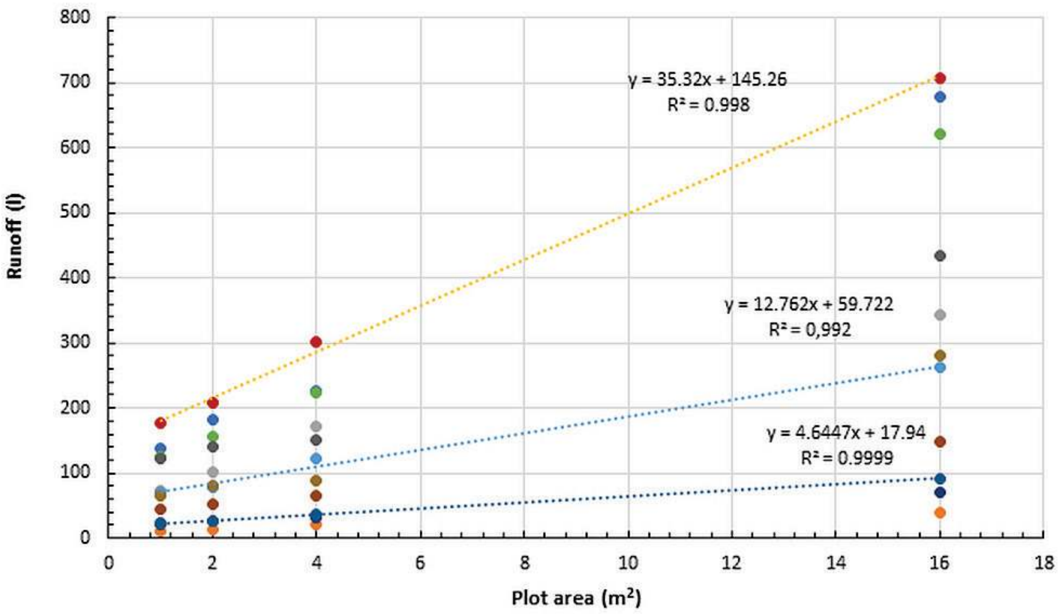

Figure 8. Runoff discharge (%) per year and plot per size of the plots (m^2).

Table 6 also shows that the high magnitude of low-frequency rainfall events is rare. Only 2 out of 470 rainfall days were higher than 100 mm day^{-1}, but they generated most of the runoff. The 9 rainfall events with more than 100 mm contributed 1,291.3 mm of rainfall, and they contribute 458.0, 273.1, 176.4, and 133.6 mm of runoff for the 1, 2, 4, and 16 m^2 plots, respectively. On the contrary, the 416 rainfall events (2,394.2 mm) were registered in rainfall events below 30 mm day^{-1}, contributed with 67.1, 45.46, 34.55, and 17.75 mm of runoff. Table 7 shows the rank of the 20th most intense day and event rainfall event.

Table 7. The rank of the 20 more intense rainfall days and events.

	Day Date	**Day mm**	**Event Date**	**Event mm**
1	28.9.09	140.0	30.9.09	230.0
2	28.2.13	111.0	15.11.12	176.8
3	22.11.11	93.0	9.12.04	167.0
4	28.9.12	90.0	23.11.11	145.5
5	11.11.12	90.0	12.10.07	131.0
6	25.4.13	90.0	11.10.08	119.0
7	26.1.07	80.0	28.2.13	111.0
8	20.3.12	70.0	29.3.04	110.5
9	18.10.07	68.0	25.4.13	100.5
10	11.10.07	67.0	28.9.12	98.0
11	4.12.04	66.0	9.11.06	89.9
12	11.9.06	64.0	14.9.06	88.0
13	12.10.07	64.0	24.3.11	83.5
14	9.10.08	58.0	26.1.07	80.0
15	8.5.08	52.0	30.11.14	72.9
16	8.6.08	52.0	25.4.11	70.0
17	27.9.09	52.0	20.3.12	70.0
18	14.12.09	51.5	29.8.13	70.0
19	28.1.06	50.0	18.10.07	68.0
20	20.10.12	50.0	10.5.08	66.0

Runoff events with over 100 mm event^{-1} contribute with 52.77% of the whole runoff generated along the 11 years of research. This means that 9 runoff events within the 311 measured from 2004 to 2014 control the runoff generation at the agriculture plots in El Teularet study site. Fourteen runoff events generated with total rainfall between 60 and 100 mm event^{-1} contributed with 21.87%. The ones from 30 to 60 mm event^{-1} (39 events) reached 16.97 % and the ones from 10 to 30 mm (107 events) contributed with 8.39 % of the total runoff. This information confirms that few rainfall events are responsible for the runoff yield. González-Hidalgo *et al.,* (2009) informed that the USLE database from the United States Department of Agriculture with 310 plots and 3,195 plot years of data found that 10% of the rainfall events contribute to 50% of the eroded soils. At the El Teularet study site, 1.9% of the rainfall events contribute to 52.77% of the runoff. The importance of the runoff event of high intensity is usually a consequence of specific weather types as Nadal-Romero *et al.* (2014) found. At the study sites Rodrigo Comino *et al.* (2020) found that 60% of the runoff is due to the East winds, the ones from the Mediterranean Sea that contribute to wet and warm air masses. González-Hidalgo *et al.* (2013) used 1800 catchments to be found that the contribution of the suspended sediment load at continental scale was dominated by the 25-largest daily events that delivered 46-63 % of the load, and the 5-largest daily events 23-39 %.

For instance, the mean contribution of the 25-largest daily events varies between 63% and 46% of the total load depending on the basin area, while the mean contribution of just the 5-largest events varies between 39% and 23%. González-Hidalgo *et al.* (2012) used 594 soil erosion plots from the USLE database to demonstrate that soil erosion is a compressed process in time, and that runoff such as has been demonstrated here is generated in few hours along the year. A few numbers of extreme events control the total runoff generated.

In semiarid ecosystems, the concentration of the rainfall results from a contrasted response between rainfall events. López-Bermúdez *et al.* (1998) found that isolated highly intensive rainfall events, mainly in autumns when there is no crop cover, are the main source of runoff and sediments. We found a similar response in El Teularet, where the most efficient rainfall events were found also in autumn such as the one with 140 mm day^{-1} that delivered 9.75 % of the total runoff after 11 years. The research of Romero-Diaz *et al.* (1998) along 9 years of measurements in Murcia (El Ardal research station) and with similar plot sizes (2 x 8 m) found that the wettest years are the ones with the higher runoff discharge and that the main runoff discharge was registered in one thunderstorm also in September (September 29th, 1997) when 86.2 mm contributed with most of the runoff yield.

Tables 6 and 7 show the rainfall and the runoff (for the 4 plots and the total) for the 20 highest largest rainfall events and the values for the 3, 5, and 10 highest rainfall events. The total runoff (mm) generated per plot concentrates on the three most intense rainfall events that yield 9.1 percent of the rainfall but 26 % of the runoff (29.3 % for the plot of 16 m^2). The five largest rainfall events contribute with 37.63 of the runoffs, the 10 highest (22.1 % of the rainfall) reached 54. 46 % of the runoff and the 20 largest rainfall events (34.19 % of the runoff) reached 71.8 % of the runoff. The 310 runoff events are measured in 11 years are concentrated into 10 rainfall events to reach more than one half of the runoff and the three highest rainfall events achieve more than ¼ of the total runoff. Table 8 ranks the runoff events. Table 9 and 10 shows the distribution of the runoff ranks for different rainfall intensities.

Table 8. The rank of the runoff (20 most intense rainfall events) for the four plots and the total discharge (mm).

nº	Runoff Date d/m/y	Rainfall mm Event	Plot 1 1 m^2 (mm)	Plot 2 2 m^2 (mm)	Pot 3 4 m^2 (mm)	Plot 4 16 m^2 (mm)	All plots 23 m^2 (mm)
1	30.9.09	230.0	80.66	49.28	37.61	25.95	193.51
2	15.11.12	176.8	76.60	44.78	24.15	19.39	164.92
3	9.12.04	167.0	65.35	44.77	27.55	22.01	159.69
	3 highest	**573.80**	**222.6**	**138.8**	**89.3**	**67.35**	**518.1**
4	23.11.11	145.5	30.22	18.29	11.42	6.31	66.24
5	12.10.07	131.0	75.56	39.06	27.57	22.83	165.01
	5 highest	**850.3**	**328.38**	**196.20**	**128.30**	**96.49**	**749.36**
6	11.10.08	119.0	41.66	22.84	17.47	9.64	91.61
7	28.2.13	111.0	12.52	8.13	3.65	3.56	27.85
8	29.3.04	110.5	45.33	27.61	16.30	13.38	102.61
9	25.4.13	100.5	30.13	18.29	10.63	10.53	69.58
10	28.9.12	98.0	21.33	11.08	6.65	4.37	43.42
	10 highest	**1389.3**	**479.33**	**284.1**	**183.0**	**138.0**	**1084.4**
11	9.11.06	89.9	34.69	17.85	13.57	6.24	72.34
12	14.9.06	88.0	15.70	12.33	14.25	6.65	48.92
13	24.3.11	83.5	6.99	4.79	2.55	1.35	15.68
14	26.1.07	80.0	24.38	20.16	13.89	8.39	66.81
15	30.11.14	72.9	8.41	4.33	2.56	1.52	16.82
16	25.4.11	70.0	2.55	0.76	0.89	0.53	4.73
17	20.3.12	70.0	14.22	8.13	3.14	1.60	27.08
18	29.8.13	70.0	8.55	4.33	2.40	0.89	16.16
19	18.10.07	68.0	30.25	20.18	11.34	3.74	65.52
20	10.5.08	66.0	5.13	2.72	2.66	0.98	11.49
	20 highest	**2147.60**	**630.17**	**379.72**	**250.24**	**169.86**	**1429.99**

Table 9. The rank of the runoff (20 most intense rainfall events) for the four plots and the total discharge (%).

nº	Runoff Date d.m.y	Plot Surface (%)	Plot 1 1 m^2 (%)	Plot 2 2 m^2 (%)	Pot 3 4 m^2 (%)	Plot 4 16 m^2 (%)	All plots 23 m^2 (%)
1	30.9.09	3.7	9.29	9.24	10.46	11.29	9.72
2	15.11.12	2.8	8.82	8.40	6.71	8.43	8.28
3	9.12.04	2.7	7.52	8.40	7.66	9.57	8.02
	3 highest	**9.1**	**25.63**	**26.03**	**24.83**	**29.30**	**26.02**
4	23.11.11	2.3	3.48	3.43	3.18	2.74	3.33
5	12.10.07	2.1	8.70	7.32	7.66	9.93	8.29
	5 highest	**13.5**	**37.81**	**36.79**	**35.67**	**41.97**	**37.63**
6	11.10.08	1.9	4.80	4.28	4.86	4.19	4.60
7	28.2.13	1.8	1.44	1.52	1.01	1.55	1.40
8	29.3.04	1.8	5.22	5.18	4.53	5.82	5.15
9	25.4.13	1.6	3.47	3.43	2.95	4.58	3.49
10	28.9.12	1.6	2.46	2.08	1.85	1.90	2.18
	10 highest	**22.1**	**55.19**	**53.28**	**50.88**	**60.01**	**54.46**
11	9.11.06	1.4	3.99	3.35	3.77	2.72	3.63
12	14.9.06	1.4	1.81	2.31	3.96	2.89	2.46
13	24.3.11	1.3	0.80	0.90	0.71	0.59	0.79
14	26.1.07	1.3	2.81	3.78	3.86	3.65	3.36
15	30.11.14	1.2	0.97	0.81	0.71	0.66	0.84
16	25.4.11	1.1	0.29	0.14	0.25	0.23	0.24
17	20.3.12	1.1	1.64	1.52	0.87	0.70	1.36
18	29.8.13	1.1	0.98	0.81	0.67	0.39	0.81
19	18.10.07	1.1	3.48	3.78	3.15	1.63	3.29
20	10.5.08	1.1	0.59	0.51	0.74	0.43	0.58
	20 highest	**34.19**	**72.56**	**71.20**	**69.57**	**73.88**	**71.81**

Table 10. Distribution of the runoff discharge per rainfall events.

Plot Surface	Plot 1 1 m² (l)	Plot 2 2 m² (l)	Pot 3 4 m² (l)	Plot 4 16 m² (l)	All plots 23 m² (l)
>100	458.00	273.07	176.35	133.60	**All plots**
>60	197.96	121.83	85.01	41.82	446.62
>30	145.41	92.98	63.77	36.73	338.90
>10	67.10	45.46	34.55	17.75	164.85
>5	0	0	0	0	0
>0	0	0	0	0	0
Total	868.47	533.34	359.68	229.90	1991.39

Plot Surface	Plot 1 1 m² (%)	Plot 2 2 m² (%)	Pot 3 4 m² (%)	Plot 4 16 m² (%)	Total 23 m² (%)
>100	52.74	51.20	49.03	58.11	52.28
>60	22.79	22.84	23.63	18.19	22.43
>30	16.74	17.43	17.73	15.98	17.02
>10	7.73	8.52	9.61	7.72	8.28
>5	0	0	0	0	0
>0	0	0	0	0	0
Total	100.00	100.00	100.00	100.00	100.00

3.4. Runoff generation and connectivity

The results of the 11 years of measurements at El Teularet research station demonstrate that the runoff at the plot scale (from 1 to 16 m^2) is highly determined by the size of the plot. As larger is the plot lower is the runoff discharge per unit, suggesting that the average duration of the runoff event – after the soil becomes saturated till the end of the rainfall event plus the duration of runoff-flow after ending precipitation– depends on the drainage area (López-Vicente and Navas, 2012). Another key information delivered in this research is that after 311 runoff events at the plot scale, 160 resulted in effective runoff at the plot scale, but only 1 delivered runoff to the stream (Barranco de Benacancil). A concept that can help to understand the hydrological behavior of the dry (ephemeral) rivers in the Mediterranean is the connectivity concept, as the loss of the overland flow discharge is due to how the flows are connected. The right term to be used under the Mediterranean karstic hydrological system is Dis-Connectivity, as it is rare that the runoff generated at pedon and slope scale will reach the stream. The use of the connectivity concept can help for the understanding of the geomorphic systems and the hydrological cycle in the continents (Bracken and Croke, 2007; Masselink *et al*., 2017).

The connectivity of the flows explains also the sediment reallocation along slopes and watersheds and affects the distribution of the vegetation (Keesstra *et al.,* 2018; Gerenmew and Triest, 2019). In El Teularet, the tilled plots induce higher connectivity than a forest due to the lack of vegetation that reduces the connectivity of the flows, and because agricultural land is better connected than the forest ones due to the high density of roads, drainages, and bare soil surfaces (Keesstra *et al.*, 2019). The smoothed topography of the agricultural land also contributes to high connectivity (Yu and Harbour, 2019) than can be only reduced by the ridges such as Rodrigo-Comino *et al.* (2018a) found in agricultural land cultivated with vineyards. The connectivity concept can also be used to investigate degradation thresholds in arid and semiarid ecosystems such as Saco *et al.* (2020) did.

In El Teularet experiment carried out along 11 years the connectivity of the flows was zero below 10 mm day^{-1} of rainfall following the measurements carried out on the four plots. Rainfall events higher than 10 mm day^{-1} contribute to runoff, and the discharge was higher as higher was the runoff. The largest runoff discharges were measured during the high rainfall events. We also demonstrated that the connectivity of the flows is determined by the length of the plots because as larger the plot lower the runoff discharge per unit area.

When the slope length increases, there is a reduction in the runoff discharge per unit area due to the loss of runoff as a consequence of the ponding developed as a consequence of the roughness of the tillage (Zhao *et al.,* 2018; Luo *et al.,* 2020). The loss of surface flow due to infiltration of runoff due to macropores (cracks or fauna and plant macropores) and due to the increase in the infiltration as the pressure of the ponds also explain that the runoff is reduced with the size of the plots (Cerdà and Rodrigo-Comino, 2020; Jourgholami and Labelle, 2020). The runoff coefficient in small plots increases more with increasing storm size than in large plots (Fig. 9 and 10). When this trend is extrapolated to the watershed it is found that only extreme events will generate hortonian overland flow that will reach the valley bottom and will create a flood event in the channel network, but this only took place along the study period once in eleven years.

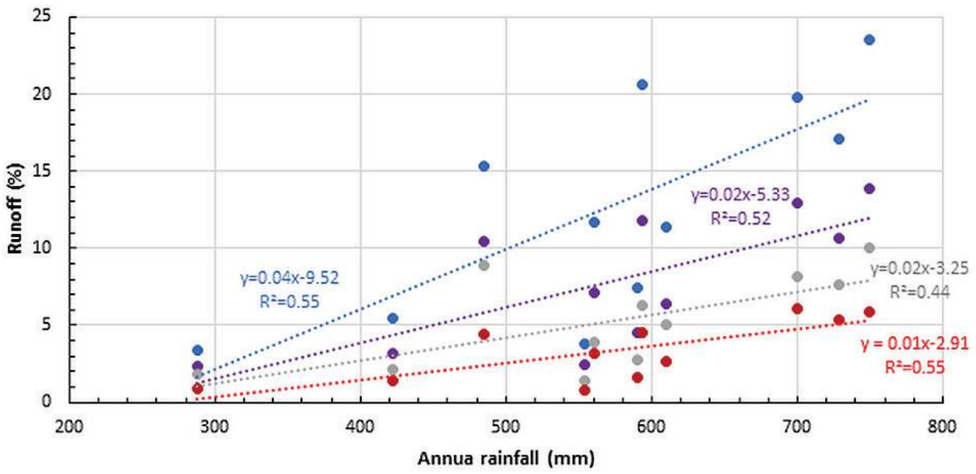

Figure 9. Runoff discharge (l) per year and plot per size of the plots (m²).

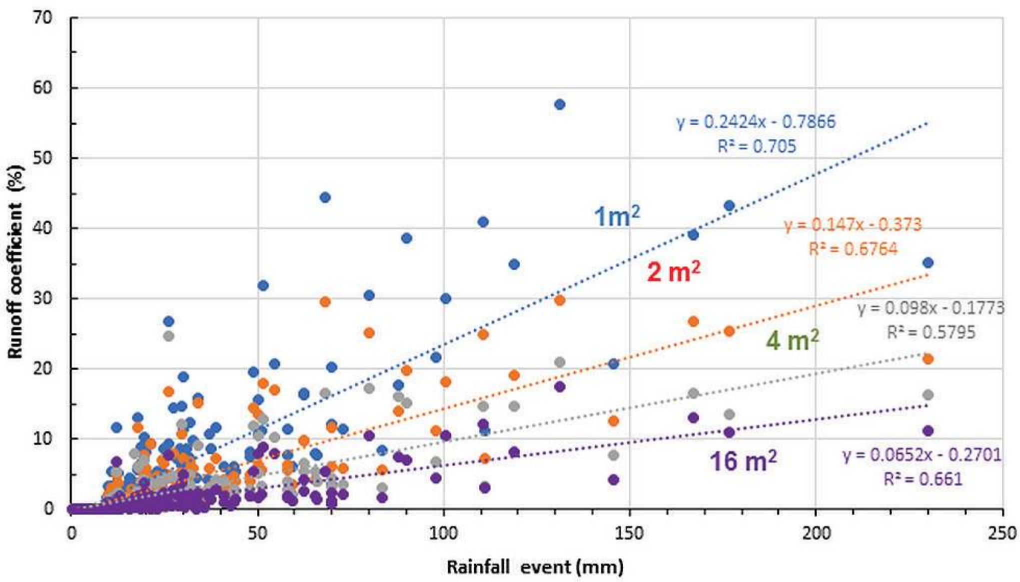

Figure 10. Relationship of annual rainfall on runoff discharge for the four plots (1, 2, 4, and 16 m²) from 2004 till 2014.

In other studies, it was identified that under Mediterranean climatic conditions the hydrological system is disconnected from the stream network (Masselink *et al.,* 2017). And the runoff in the channel used to originates from close areas to the channel network or from roads and degraded areas near the talweg. The contribution of the throughflow or groundwater flow at the study site is negligible due to the karstic system that allows the infiltrated water to deeply percolate in the aquifer. This behavior was found also on vineyards where the tillage induces the formation of ridges underneath the vines and reduces the runoff generated and the connectivity of the flows (Rodrigo-Comino *et al.,* 2018b) that only new plantations increase the flows.

During large events, the hydrological system becomes connected through overland flow, which is mainly hortonian overland flow, but this is very rare in the study area due to the low connectivity of the flows such as show the influence of the length of the plot. During these events also sediment is transported to the channel network, which means that the hydrological system also dis-connects the sediment transport system that is only active for a few days or even hours. This is relevant on agricultural land where soil erosion is very active due to the degradation of the soil organic matter and where land abandonment is relevant (Lasanta *et al.,* 2019). The runoff generated in the slopes is highly dependent on the weather types such as Rodrigo-Comino *et al.* (2020) demonstrated. Recently, approaches to show the spatio-temporal changes of floods generation confirms the relevance of the runoff generated at pedon and slope scale (Contreras *et al.,* 2021), and snow is relevant on mountainous areas (Pisabarro, 2020) and were the runoff connectivity and soil losses are encouraged by the trails (Salesa and Cerdà, 2019).

In the case of the study at hand, the dis-connectivity is an extreme case due to the local conditions. The limestone (karst) induces high percolation, the marly areas devoted to agriculture land are located in some patches that also show low connectivity within the slope and negligible with the river. The connection between the runoff producing hillslopes and the channel network is only established during an extreme event, such as the one measured in September 2009.

4. Conclusions

Eleven years of measurements employing plots of different sizes (1 to 16 m^2) and an assessment of the floods in the stream allow us to conclude that there is very deficient connectivity between the slope and the streams. Within the slope under tillage recurrent runoff events (160 in 11 years) were measured, but the runoff discharge is disconnected with the stream (1 runoff event in 11 years). The concentration of the runoff in a few rainfall events also contributes to the lack of connectivity in most of the rainfall events. The three most intense rainfall events contributed to 26 % of the runoff in 11 years. Ten rainfall events contributed to 55 % of the runoff at the plot scale. A 140 mm day^{-1} rainfall event connected the runoff from the plots to the Barranco de Benacancil creek. No other rainfall event contributed to a flood at a watershed scale.

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