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Changes of erosive rainfall for El Niño and La Niña years in the northern Andean highlands of Peru

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Abstract Information related to rainfall erosivity in the Andes is scarce. This study was carried out to determine the characteristics of rainfall events at the La Encañada watershed, northern Peru, using daily rainfall data from the 1995 to 2000 period that included all the El Niño and Southern Oscillation (ENSO) phases. Three weather stations were installed within the study area, at the top, middle and bottom of the watershed. We analysed the total amount, duration, intensity, kinetic energy and probability of return of rainfall events. In general, 80% of the rainfall events at watershed level had an average rainfall intensity lower than 2.5 mm h^{-1} and only 4% had an average intensity larger than 7.5 mm h^{-1}. Rainfall erosivity registered at the bottom of the watershed was slightly higher than in the rest of the area. The highest intensities were observed during an El Niño year whereas a La Niña year was characterized by the highest amount of total rainfall compared to the other ENSO phases and by the low intensity rain events. Simulations using the WEPP model estimated higher sediment yield and runoff for the bottom of the watershed during a La Niña year versus El Niño or Neutral years. Even when the analysed rainfall data was too limited to conclude erosion and runoff during any ENSO phase, the simulated results showed us the trend of the behaviour of rainfall erosivity under the ENSO phases at different locations.

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1 Introduction

Rainfall data are of interest for land use planning because rainfall characteristics such as duration, frequency and intensity affect the soil erosion process (Whiteman 2000; Schawb et al. 1993). The energy of raindrops help to detach soil particles, and by generating runoff the rain contributes to the transport of these particles (Morgan 1995). Rainfall can be characterised in many ways, varying from total precipitation in a year, season or other period, to daily rainfall or totals per rainfall event (Hoogmoed 1999). However, often a shortage of water for farming is not the consequence of low annual rainfall but of poor seasonal distribution (Sivakumar and Wallace 1991). The response of soil to rainfall in terms of soil loss can be variable, thus dramatic erosion processes can be observed during a rainy season, when heavy but not extreme precipitation intensities coincide with infrequent high soil moisture conditions in the watershed.

The study area, La Encañada watershed in the northern Peruvian Andes, receives between 500 and 1,000 mm/year, so the zone could be considered as relatively wet for the Andes. It is characterised by a hilly topography, with steep slopes constantly at risk of land degradation processes (Gonzales and Trivelli 1999). This research set out to characterise the rainfall in this watershed. The characteristics analysed were total amount, duration and intensity per rainfall event, kinetic energy and return period. This information is relevant since rainfall analysis studies are scarce in the Andes due to lack of data. From these analyses, the probability of a heavy rainfall reoccurring in this area can be estimated, although the high variability of the mountain climate makes it difficult to analyze the area's rainfall, especially in relation to the El Niño and La Niña phenomena (Baigorria et al. 2004). Additional objectives of this analysis were: (1) to predict the likelihood of an exceptionally heavy rainfall event reoccurring, and (2) to improve the quality of the information that prevails in hillsides watersheds.

The present paper is part of a multi-scale approach study for erosion assessment in the Andes (Romero 2005), where runoff and sediment yield data were obtained from runoff plots at the event-bases. These data were used to calibrate the Water Erosion Prediction Project – WEPP model (Flanagan and Nearing 1995). Soil loss estimations were first determined with the hillside version and then, by employing modelling techniques, to the watershed level. This paper tackles the effect of rainfall characteristics, focusing on rainfall erosivity, runoff, and sediment yield processes. In doing so, any relationship between the soil loss and runoff with climatic events, such as the El Niño and the South Oscillation – ENSO (Climate Prediction Center–National Oceanic and Atmospheric Administration; CPC–NOAA 2006), was considered.

2 Materials and methods

The research was carried out in the La Encañada watershed (approximately 160 km^2) within the northern Peruvian highlands (Cajamarca–Peru), between 7°00′ and 7°08′S latitude, 78° 11′ and 78°21′W longitude, ranging between 2,950 to 4,000 meters above sea level (m asl). There are three weather stations in the area: La Toma (3,590 m asl), Usnio (3,260 m asl) and Manzanas (3,020 m asl). The weather station at Usnio was set up in 1983; the other two were set up in 1995. The general climatic conditions are presented in Table 1; Fig. 1 shows the location of all weather stations.

The soils in La Encañada watershed belong to the following soil orders: Entisols, Vertisols, and Mollisols. The rainy season is from September to March. The cropping

Table 1 General climatic conditions (1995–2000) in La Encañada watershed, north Peru

Weather stations	Solar radiation (MJ m^{-2} day^{-1})	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)	Number of days with rainfall
La Toma	19.9	10.8	2.8	832	193
Usnio	19.2	14.2	6.1	720	152
Manzanas	18.3	16.2	5.9	633	177
Average La Encañada	19.1	13.7	4.9	767	174

season is determined more by the actual rainfall pattern than by the average rainfall, since farmers do not use weather data but instead rely on collective indigenous knowledge (Baigorria 2005).

In an earlier analysis (Stroosnijder and Hoogmoed 1984), it was found that events <10 mm do not have an important role in the water balance, events of 10–20 mm are most common, and rainfall events of >20 mm are rare but have a major impact on runoff and erosion. Since the present work will become the basis for a future erosion study in the area, a division into these classes was used. From the rainfall charts of the three weather stations for 1995–1998 period, rainfall amount, rainfall duration and rainfall intensity of each event was analyzed. With the rainfall intensity data, a cumulative probability curve was

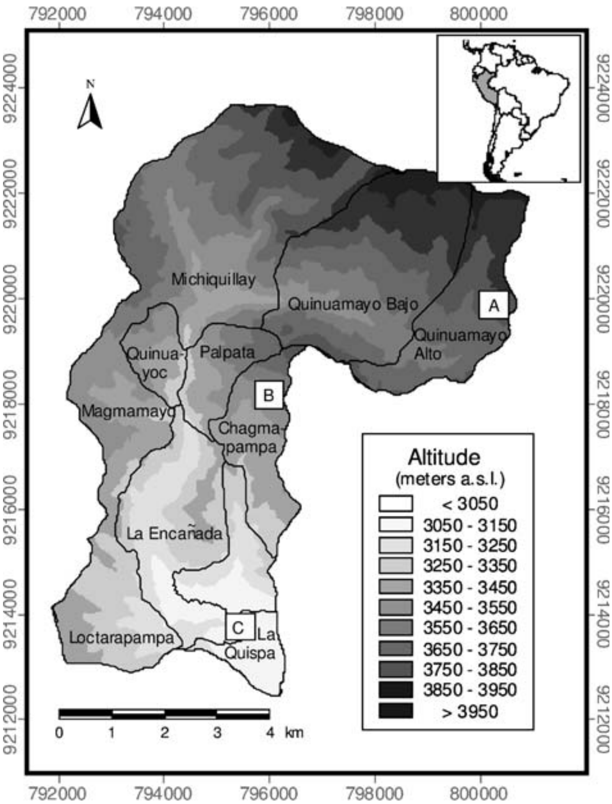

Fig. 1 Spatial distribution of weather stations of La Encañada watershed north Peru. *A* La Toma, *B* Usnio, *C* Manzanas

constructed. Though rain charts were not available for 1999 onwards, data from 1998 to 2000 were obtained from the automatic raingages.

The most suitable expression of the erosivity of rainfall is an index based on the kinetic energy of the rain (Morgan 1995). To calculate kinetic energy the Wischmeier and Smith (1958) equation was used:

$$\mathrm{KE} = 11.87 + 8.73 \log I \tag{1}$$

where I is the rainfall intensity (mm h^{-1}) and KE is the kinetic energy (J m^{-2} mm^{-1}). With these data, the probability of exceeding curves was performed.

We constructed the intensity–duration–frequency relationship curves for different return periods (estimate of the period between rainfall events of a given magnitude based on statistics; Oklahoma Climatological Survey 1996). They were designed to facilitate the description of the temporal variability of rainfall in a specific location (Linsley 1977). This type of analysis reveals the probability of occurrence for a rainfall event of a given magnitude. This is important since some events could be so heavy or so intense that they would likely produce 'exceptional' floods, increasing the risk of erosion downstream in the watershed.

In order to analyze the effect of rain erosivity of the events occurring in the La Encañada watershed the Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing 1995) was used. WEPP is a process-oriented model, based on modern hydrological and erosion science that estimates runoff and erosion on a daily basis (Nearing et al. 1994). The model was calibrated for the study area (Romero 2005). For the simulations, WEPP used daily climate data which included total rainfall amount, duration and intensity per rainfall event, maximum and minimum temperature and two factors, *ip* and *tp*, both defining the erosive behaviour of an event. The model was run considering an erodible soil of the same study area (Romero et al. 2007) whose characteristics were: 50% sand, 32% silt, 18% clay, an interrill erodibility factor (Ki) of 860,996 kg-s m^{-4}, a rill erodibility factor (Kr) of 0.0014 s m^{-1}, a critical shear stress of 3.5 Pa, and effective hydraulic conductivity of 3.4 mm h^{-1} under fallow conditions on a standard USLE plot (Wischmeier and Smith 1978). Estimated runoff was expressed as a percentage of total rainfall per year with the sediment yield in ton per hectare per year.

3 Results and discussion

3.1 Annual rainfall and temporal variability

Table 1 shows the average (1995–2000) annual rainfall at the three weather stations. The average for the whole watershed was calculated as 767 mm. On this basis, the area can be classified as Tropical Summer Rain High Mountain climate (HAw) according to Köppen's reformed classification (Rufloff 1981). However, analyses per year showed a wide range of total rainfall amounts (Table 2). The La Toma weather station ranged from 298 mm in 1996 to 1122 mm in 1997, the Usnio weather station ranged from 363 mm in 1996 to 1,054 mm in 1997, and the Manzanas weather station ranged from 526 mm in 1997 to 858 mm in 1998.

The temporal variability observed during these years is part of the information given by the Climate Prediction Center (CPC–NOAA 2006). This center has compiled the cold (La Niña) and the warm (El Niño) episodes to provide a season-by-season breakdown of

Table 2 Total amount of rainfall, maximum rainfall intensity and number of events with >25 mm h^{-1} per rainy season (1995–2000)

Rainy season	La Toma			Usnio			Manzanas			Weather anomalies
	Total rainfall (mm)	Max. intensity (mm h^{-1})	Number of events	Total rainfall (mm)	Max. intensity (mm h^{-1})	Number of events	Total rainfall (mm)	Max. intensity (mm h^{-1})	Number of events	
1995 (9/95–3/96)	408	40.0	2	629	156.3	5	531	70.0	1	Neutral
1996 (9/96–3/97)	298	55.0	2	363	11.0	0	512	147.3	3	Neutral
1997 (9/97–3/98)	1,122	130.0	3	1,054	17.7	0	526	82.5	11	El Niño
1998 (9/98–3/99)	1,252	7.4	0	826	16.8	0	858	82.4	1	La Niña
1999 (9/99–3/00)	1,081	5.0	–	728	4.5	–	736	4.4	–	La Niña

conditions in the Tropical Pacific. The Neutral years corresponded to the 1995–1996 period, with a weak incidence of La Niña at the end of 1995. From the end of 1997 to the beginning of 1998 a strong El Niño occurred, characterised by a major increase in the rainfall at the La Toma and Usnio weather stations, resulting in the totals exceeding 1,000 mm. At the Manzanas weather station, however, the rainfall was similar to that of Neutral years, 526 mm (Table 2). Weak and strong episodes of La Niña occurred during the1998–2000 period (CPC–NOAA 2006). At the three weather stations, total rainfall during the La Niña years was higher than compared to Neutral years.

3.2 Rainfall analyses

During the 1995–2000 period, rainfall events varied from 0.1 to 56 mm, the average being 3 mm. During a Neutral year, 90% events were lower than 10 mm with few of them higher than 20 mm (Table 3). During the El Niño year there was an increment, in percentage, of the number of events >10–20 mm at the La Toma and Usnio stations compared to a Neutral year. During La Niña years, events in all size classes increased at the Manzanas weather station. The percentage distribution was similar to that of an El Niño year at the La Toma and Usnio stations, but at the Manzanas station there were more events <1 mm and between 10–20 mm than in an El Niño/Neutral year. Because of this, the total amount of rainfall registered at the Manzanas station was higher during La Niña years.

From the frequency analysis of rainfall size classes according to the location (Table 4) it can be seen that during the 5 years (1995–2000) the distribution of the four size classes at the three weather stations was similar. Approximately 85% of the events were <10 mm, representing 51% of total rainfall. Although only 14% were larger than 10 mm, this percentage was responsible for 49% of the total rainfall. By contrast, events >20 mm were

Table 3 Frequency analysis of rainfall size classes for different altitudes and El Niño/La Niña years at La Encañada, north Peru

	<1 mm	1–10 mm	10–20 mm	>20 mm
Neutral years (1995 and 1996)				
La Toma				
No. of events	112	133	3	0
% of total	45.2	53.6	1.2	0
Usnio				
No. of events	72	121	26	4
% of total	32.3	54.3	11.7	1.8
Manzanas				
No. of events	101	134	22	5
% of total	38.5	51.1	8.4	1.9
El Niño year (1997)				
La Toma				
No. of events	69	104	32	8
% of total	32.4	48.8	15	3.8
Usnio				
No. of events	40	84	26	10
% of total	25	52.5	16.3	6.3
Manzanas				
No. of events	23	77	8	3
% of total	20.7	69.4	7.2	2.7
La Niña years (1998 and 1999)				
La Toma				
No. of events	147	216	64	15
% of total	33.3	48.9	14.5	3.4
Usnio				
No. of events	109	158	43	8
% of total	34.3	49.7	13.5	2.5
Manzanas				
No. of events	93	178	49	7
% of total	28.4	54.4	14.9	2.1

extremely rare, representing only 3% of the total events but providing up to 18% of total rainfall. Most of these larger events were reported during the El Niño year (1998).

According to the National Weather Service (2000) there are three categories of rainfall intensity: light (up to 2.5 mm h^{-1}), moderate (2.6 to 7.5 mm h^{-1}) and heavy (more than 7.5 mm h^{-1}). Our analysis of the rainfall intensity for rainfall events from 1995–2000 revealed that 71% of the events at the three weather stations were <2.5 mm h^{-1}, approximately 16% of events were moderate, and only a 4% of events were heavy (Fig. 2). The data given in Table 5 show that during the El Niño year 18% of events were >7.5 mm h^{-1} registered at the Manzanas weather station, at the bottom of the watershed. On the other hand, for low intensive rainfall events registered during the La Niña years, 91% of events were <2.5 mm h^{-1}. In the entire area 0.6% of the total events were >7.5 mm h^{-1}.

The maximum value of rainfall intensity for a Neutral year was 156 mm h^{-1}, recorded at the Usnio weather station, and 130 mm h^{-1} during El Niño year (Table 2). The difference between an El Niño year and a Neutral year was the total amount of rainfall and the highest number of intensive events >25 mm h^{-1}, reaching 14 events within the watershed compared to the other ENSO phases. During La Niña years there was only one

Table 4 Frequency analysis of rainfall size classes by location in north Peru (1995–2000)

	<1 mm	1–10 mm	10–20 mm	>20 mm	Total	Per year
La Toma						
No. of events	328	454	96	23	901	180
% of total	36	50	11	3	100	
Millimeters mm in class	137	2,035	1,365	622	4,159	832
% of total	3	49	33	15	100	
Usnio						
No. of events	221	363	93	22	699	140
% of total	32	52	13	3	100	
mm in class	91	1,542	1,300	668	3,601	720
% of total	3	43	36	18	100	
Manzanas						
No. of events	217	389	79	15	700	140
% of total	31	56	11	2	100	
mm in class	91	1,566	1,099	408	3,164	633
% of total	3	50	35	13	100	

heavy event with a rainfall intensity of 82.4 mm h^{-1}, whereas most events were lower than <2.5 mm h^{-1}.

Intensity analysis was performed to ascertain the kinetic energy of rainfalls. If, in accordance with Hudson (1981), 25 mm h^{-1} is considered to be the minimum intensity that will induce significant erosion, 28 events of this data set agreed with said criterion (Table 2). Fourteen events occurred during the El Niño year. Although not published, during this rainy season a landslide occurred in the watershed. From this information the risk of erosion could be higher during an El Niño year than Neutral or La Niña years, but more consistent relationships between rainfall and its effects on detaching soil particles must be established.

In runoff and soil erosion research it is crucial to determine the kinetic energy of rainfall, since this energy is what drives these processes. We determined the kinetic energy values for the data from the three weather stations using Eq. 1. The curves of probability for exceeding a certain kinetic energy value are shown in Fig. 3. At least 50% of the rainfall events had kinetic energy values below 12.5 J m^{-2} mm^{-1} and 90% did not exceed 16.6 J m^{-2} mm^{-1}. Maximum kinetic energy values reached 30.8 J m^{-2} mm^{-1}. According to our field measurements using runoff plots in this watershed, the minimum kinetic energy of a rainfall event producing soil loss was 14.1 J m^{-2} mm^{-1} for the highly erodible soil (Romero

Fig 2 Rainfall intensity probability of occurrence at three weather stations in north Peru

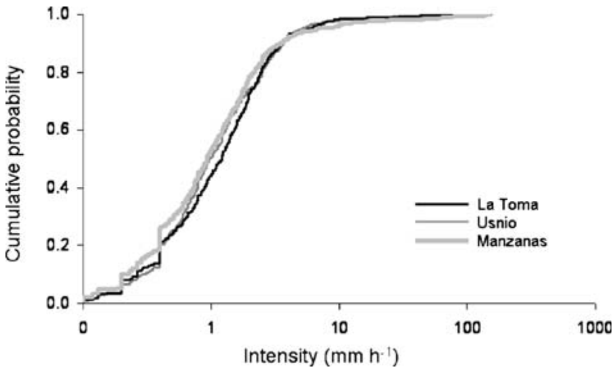

Table 5 Frequency analysis of rainfall intensity classes for neutral/El Niño/La Niña years at different locations in La Encañada watershed, north Peru

	<2.5 mm h^{-1}	2.5–7.5 mm h^{-1}	>7.5 mm h^{-1}
Neutral years (1995 and 1996)			
La Toma			
No. of events	163	63	23
% of total	65.5	25.3	9.2
Usnio			
No. of events	130	78	16
% of total	58.1	34.8	7.1
Manzanas			
No. of events	179	63	15
% of total	69.6	24.5	5.8
El Niño year (1997)			
La Toma			
No. of events	151	55	7
% of total	70.9	25.8	3.3
Usnio			
No. of events	99	42	2
% of total	69.2	29.4	1.4
Manzanas			
No. of events	72	19	20
% of total	64.8	17.1	18.0
La Niña years (1998 and 1999)			
La Toma			
No. of events	355	37	0
% of total	90.6	9.4	0
Usnio			
No. of events	289	21	2
% of total	92.6	6.7	0.6
Manzanas			
No. of events	370	27	5
% of total	92.0	6.7	1.2

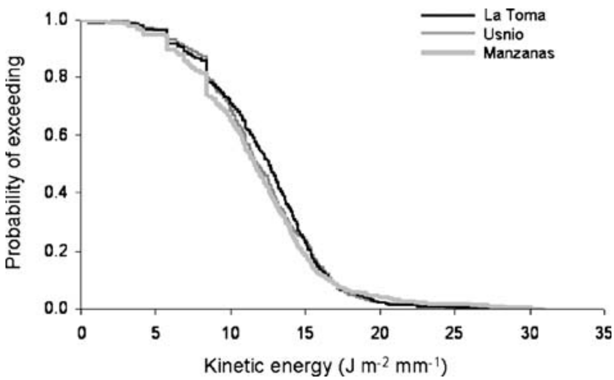

Fig. 3 Kinetic energy cumulative curves at three weather stations at La Encañada watershed, north Peru

2005). The results showed that most of the rainfall events with the highest kinetic energy were recorded in the lowest part of the watershed, at the Manzanas weather station.

Rainfall intensity analysis relates the total amount/total duration per rainfall event. Yet, within a rainfall event there are short periods when the intensity can be very high, and therefore very erosive. In order to determine this, the Wischmeier index (EI30) (Lal and Elliot 1994) was calculated from three random rain charts based on the principle that the erosivity of the chosen rainfalls is equal to that of all erosive rainfalls (Xie et al. 2001). Three examples of 2-h duration rainfalls were chosen (Table 6). According to the duration analysis, 50% of the total rainfall events in the watershed lasted less than 2 h. Like most of the events registered in the area, these were light intensity events where the amount of rainfall was <10 mm. The maximum individual EI30 value was registered at the Manzanas weather station, at the bottom of the watershed, with a value of 295.24 J-mm m^{-2} h^{-1}. The minimum individual EI30 value was registered at the La Toma weather station, at the top of the watershed, 28.42 J-mm m^{-2} h^{-1}. Hoyos et al. (2005) reported that individual storms in the Colombian Andes represented as much as 25% of the annual EI30 (1.04–1.59 MJ-mm m^{-2} h^{-1} $year^{-1}$) with a storm contribution of 0.2 MJ-mm m^{-2} h^{-1} at the Catalina weather station in 1992. Saavedra (2005) reported a maximum value of EI30 of 0.035 MJ-mm m^{-2} h^{-1} in a watershed of the Bolivian Andes, with an annual EI30 equal to 815 M J-mm m^{-2} h^{-1}. Other studies in tropical areas reported total annual EI30 values of 6,345–10,060 MJ-mm m^{-2} h^{-1} in southwest Colombia (Ruppenthal et al. 1996), 3,308–13,566 MJ-mm m^{-2} h^{-1} in Central Kenya (Angima et al. 2003) and 1,079–33,481 MJ-mm m^{-2} h^{-1} in Tropical Australia (Yu 1998). In temperate regions numbers are lower, as for example studies in Southern Australia, only reported 250–500 MJ-mm m^{-2} h^{-1} (Yu and Rosewell 1996) and Southeastern US, 4,680–10,212 MJ-mm m^{-2} h^{-1} (Renard et al. 1997). The difference in magnitude between our results (expressed in joules due to the low calculated values) and those described previously shows that our area has a semi-arid character in spite of its Köppen classification as Tropical Summer Rain High Mountain climate (Rufloff 1981). Low calculated EI30 values of individual rainfall events are in agreement with the low rainfall intensity values registered in the watershed.

Table 6 Three examples of 2-h rainfall events, showing the total kinetic energy and EI30 indexes

Interval (min)	Location (altitude)					
	La Toma (3,590 m asl)		Usnio (3,260 m asl)		Manzanas (3,020 m asl)	
	Intensity (mm h^{-1})	Δ E (J m^{-2})	Intensity (mm h^{-1})	Δ E (J m^{-2})	Intensity (mm h^{-1})	Δ E (J m^{-2})
30	1.2	7.5	2.0	14.5	0.2	0.6
30	0.6	2.9	0.5	2.3	2.8	22.1
30	1.4	9.2	0.3	1.1	1.0	5.9
30	0.2	0.6	0.8	4.4	4.4	38.5
Total E (J m^{-2})		20.3		22.31		67.1
Max. 30-min intensity (mm h^{-1})		1.4		2.0		4.4
EI30 (J mm m^{-2} h^{-1})		20.3×1.4= 28.42		22.3×2= 44.6		67.1×4.4= 295.24

3.3 Return period analysis

The curves for 25, 10 and 5-year return periods are shown in Fig. 4 for the three weather stations. The most intensive rainfall events were expected at the bottom of the watershed (Manzanas weather station) and the least intensive at the top of the watershed (La Toma weather station). At each location, the most intensive events had a long period of return (e.g. 25 years). For example, the return period for a 10-min rainfall with a 75 mm h^{-1} intensity in the La Encañada watershed is 25 years, at the Manzanas weather station. For the same period of time a 10-min rainfall with a 38 mm h^{-1} intensity could be expected at the La Toma weather station. Within a 5-year period of time, the maximum expected

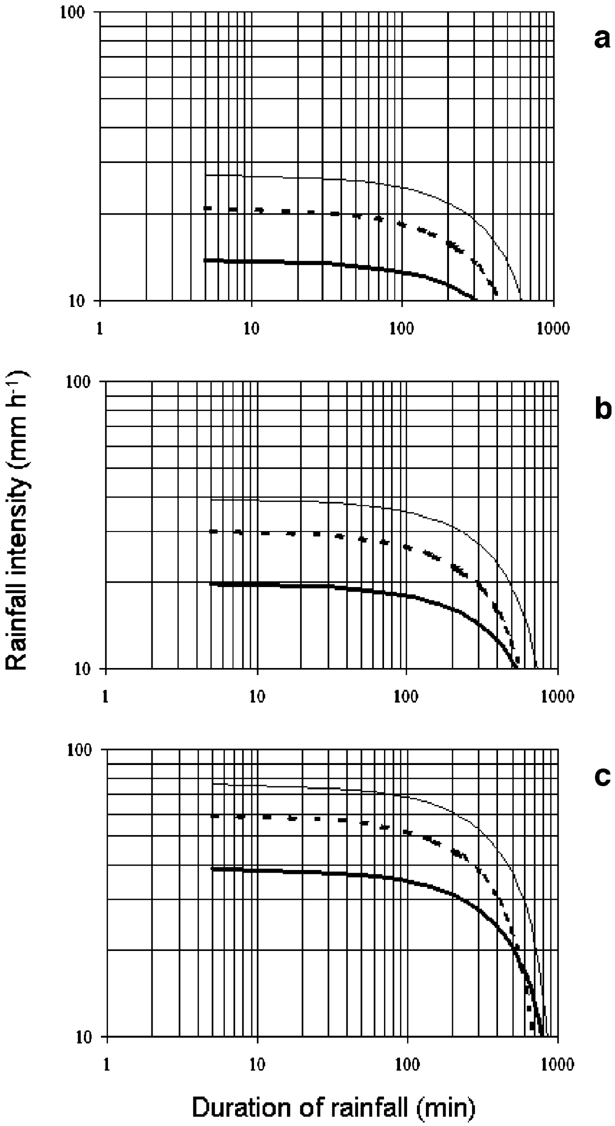

Fig. 4 Rainfall intensity–duration–frequency curves at three weather stations at La Encañada watershed, north Peru. **a** 5 years, **b** 10 years, and **c** 25 years. *Thick line* La Toma, *broken line* Usnio, *thin line* Manzanas

intensities for a 10-min rainfall event are between 12 and 28 mm h^{-1}. However, longer events with slightly lower intensities could also be expected (e.g. 100-min duration): these events would also increase the risk of erosion in the area.

The rainfall intensity analysis revealed that during the El Niño year there were more events with high intensities recorded at the bottom of the watershed and the return periods confirmed that this area was affected by the most intensive events. This was due to the marked warming of plane surfaces inducing convective rainfall events (Barry and Chorley 1980). The lower part of the La Encañada watershed is next to a plateau of approximately 60 km^2 called "Pampa de la Culebra", which is a large convective area. These analyses allowed us to determine where and when the most erosive events occurred, and although the response of soils to the rainfall erosivity depends on their own characteristics, factors like slope length, slope inclination and soil management must be taken into account.

3.4 Relating rainfall with soil loss and runoff

To establish the differences in erosivity at the three locations, the WEPP model was run for three scenarios: (1) Neutral year, (2) El Niño year and (3) La Niña year, where soil, slope and soil management were kept constant. Table 7 shows the simulated results which did not exceed 10 Mg ha^{-1} $year^{-1}$. In general, simulations under a La Niña year estimated the highest values of sediment yield as compared to El Niño and Neutral years for the three locations. These results can be more related to the soil characteristics (highly erodible soil) tested for the simulations, since during La Nina years rainfall intensity values were quite low. Yet, simulations considering an El Niño year estimated higher values of sediment yield than in Neutral years, specifically at the La Toma and Manzanas locations, probably due to the high number of intensive rainfall events (14) compared to the other years. Runoff estimations were also high for El Niño and La Niña years, compared to Neutral years, although the El Niño year had higher runoff estimations than the La Niña years at the Usnio and Manzanas locations.

Regarding locations, the highest estimated sediment yield was found at the Manzanas rainfall regime, followed by Usnio and then La Toma. These results can be related to the fact that there were 16 events registered at the Manzanas location with a rainfall intensity >25 mm h^{-1}. Five and seven events >25 mm h^{-1} were observed at the Usnio and La Toma locations, respectively (Table 2).

Runoff is the driving force for erosion. According to Horton (1945), if rainfall intensity is less than the infiltration capacity of the soil, no surface runoff occurs and no erosion is

Table 7 Simulated soil loss and runoff by the WEPP model according to the different ENSO phases for the evaluated location

Location	ENSO phase	Runoff (%)	Soil loss (Mg ha^{-1} $year^{-1}$)
La Toma	Neutral	13.8	0.5
	El Niño	25.0	1.7
	La Niña	28.7	7.5
Usnio	Neutral	25.5	5.5
	El Niño	40.3	3.6
	La Niña	27.4	9.3
Manzanas	Neutral	25.1	6.9
	El Niño	38.5	8.8
	La Niña	32.5	10.2

expected. However, if the rainfall intensity exceeds the infiltration capacity, the excess rainfall forms surface runoff. In the former case, the soil can get saturated and erosion can occur. In the latter case, high intensity events can promote the soil aggregates to break down quickly, producing a reduction in the infiltration capacity since the soil surface is "sealed" and runoff can occur immediately (Morgan 1995). Simulations of a La Niña year, with non-erosive events, estimated higher sediment yield and runoff values than other years. This phenomenon was observed in direct measurements of soil loss using runoff plots in this watershed, where low-intense but persistent rainfall events saturated the soil, especially in those soils with high infiltration capacity under low slope inclination, producing minimal runoff and soil loss. This process was captured by WEPP. Only when a highly erodible soil located on a steep slope was subjected to a heavy rainfall there were more runoff and soil loss generated, measuring a maximum of 2.9 Mg ha^{-1} per rainfall event under fallow conditions (Romero 2005). Uncertainty analyses performed using WEPP gave a maximum soil loss of 15.4 and 122.1 Mg ha $year^{-1}$ for two different soil management systems, fallow and potato respectively (Romero 2005). WEPP simulations at the watershed level showed 60% of the total area produced sediment yield in the order of <10 Mg ha^{-1} $year^{-1}$ and 30% produced >50 Mg ha^{-1} $year^{-1}$ (Baigorria and Romero 2007).

Even when the analysed rainfall data was too limited to conclude the actual results under any ENSO phase regarding erosion and runoff, the simulated results can give us a light tendency of the behaviour of rainfall erosivity under these ENSO phases for different years.

4 Conclusions

This study revealed that during Neutral years the mean annual rainfall was <600 mm. However, during El Niño and La Niña years the annual amount increased, with a maximum of 1,200 mm occurring during one of the La Niña years. In general, rainfall intensities were quite low, with 96% of events <7.5 mm h^{-1}, as this was reflected in the individual EI30 values, which were very low compared to other locations in the Andes. During the El Niño year, the number of high intensity events increased in the lower part of the watershed (18%) where normally only 4% of events were high intensity. The La Niña year was characterised by a large total rainfall, but with low intensities.

Our analysis showed that rainfall erosivity within La Encañada watershed is quite low. The lowest part of the watershed, the Manzanas location, showed a high number of erosive rainfall events, especially during the El Niño year. Proximity to a plateau of approximately 60 km^2 results in the high convectivity area. Therefore, this area is most likely to experience the most erosive rainfall events in subsequent years, whereas the lowest erosive events are more likely to be in the upper part of the watershed, the Usnio and La Toma locations. The Manzanas location also received the highest total annual rainfall.

Simulations using WEPP showed that under a La Niña year the estimated sediment yield was highest, followed by El Niño and Neutral years, respectively. Runoff and soil loss estimations were highest at the Manzanas, then Usnio and finally the La Toma locations.

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