Boletín de la Asociación de Geógrafos Españoles N.º 65 - 2014, págs. 463-468
I.S.S.N.: 0212-9426

DAILY PRECIPITATION CONCENTRATION AND THE RAINY SPELLS IN THE CANARY ISLANDS: TWO RISK FACTORS

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The analysis of rainfall, to characterize its danger to different spatial and temporal scales, is of interest due to its effects on geo-hydrological processes and on the analysis of erosion and soil loss. Many authors warn, in the current context of global warming, of a change in precipitation patterns towards a greater frequency of extreme weather events (Karl *et al*., 1998, Houghton et al., 2001, Zhai *et al.,* 2005, Zhang *et al*., 2009, Li et al. 2011; IPCC, 2012; Coscarelli and Caloiero, 2012). In this sense, the increase in days with heavy rains, which provide large amounts of water to the annual total, means an increase of risk to the local populations and their activities, especially in areas with steep slopes and little vegetation cover, such as those of the Atlantic archipelagos (Marzol *et al.,* 2006; Dorta, 2007).

It is therefore necessary to know the structure of the daily precipitation scale in these places. To do this, Martín Vide (2004) proposed a Daily Concentration precipitation Index (CI) which has been applied in different regions with very different results. Thus, in the case of the Iberian Peninsula CI spatial patterns show two clearly differentiated areas: a) the regions closest to the Mediterranean with higher concentration ratios, around 0.70, and b) inland regions of the peninsular and regions near the Atlantic coast with values of 0.55. In the first case, 25% of the rainiest days contribute almost 80% of the annual total, while in the second case this percentage drops to 65% (Martín Vide, 2004). The same differences in the CI values can be seen in other Mediterranean regions. Coscarelli and Caloiero (2012) obtained values between 0.62 and 0.45 in the region of Calabria in southern Italy. In the Canary Islands, where the irregularity and torrential nature of the rain are two of its main features, this type of analysis is critical because damage associated with rainfall has increased in recent decades due to increased levels of construction in vulnerable areas near to or in the same water channels of the ravines (Horcajada *et al.,* 2000; Romero *et al*., 2004; Marzol *et al*., 2006; Máyer and Pérez Chacón, 2006; Dorta, 2007; Mayer, 2011).

I. DATA AND METHODOLOGY USED

For the purposes of this paper, 91 series of daily precipitation were chosen from the period between 1970 and 2003. These series are from the Meteorological Agency (AEMET) and Hydraulic Service of Las Palmas. Each series has a minimum of 30 years. The application of CI requires the availability of reliable data, especially in the recordings of smaller amounts of rainfall with an intensity of less than 0.9 mm. Otherwise the value of the CI is considerably weakened. This necessitates the purging of data and the elimination of the meteorological stations that do not conform to a negative exponential distribution. An example of the different quality of the information can be seen by comparing the number of days with rain between 0.1 and 0.9 mm recorded in two nearby weather stations, Los Rodeos and Tegueste, located in the north of the island of Tenerife, during the same time period (34 years), 835 versus 37 days respectively. Sixty two of the ninety one series are removed because they did not record the daily precipitation correctly.

Their location in the territory of the series was an important factor when choosing the series, especially in relation to its altitude and orientation. The islands of higher elevation, all except for Lanzarote and Fuerteventura, traditionally differ in three main geo-ecological aspects in function of altitude: coastal, mountain slopes and summit. In general, there is no specific altitude threshold for each of them, although they do have some environmental features of their own. The most important factors in their differentiation are the topographical ones (altitude and direction), climate and soil which together determine the existence of a particular type of flora and even a historical preference in locating the settlements of the population (Ceballos y Ortuño, 1976; Sánchez *et al*., 1985; Marzol, 1988; Máyer, 2011; Martín *et al*., 2012).

The main objective of this work is to determine the concentration of daily rainfall by using the index proposed by Martín Vide (2004). This index is based on the percentages of the number of days with rainfall with respect to the annual total of days with precipitation (X), as well as on the percentages of the cumulative amounts of rainfall with respect to the annual total (Y). Subsequently, polygonal curves of precipitation concentration are generated in which the greatest distance to the distribution line means there is a greater concentration of daily rainfall according to equation (1)

$$Y = aXe^{bX} \qquad (1)$$

The constants a and b of the equation are obtained by the least squares method, as follows (2) and (3):

$$lna = \frac{\sum x_i^2 \sum \ln Y_i + \sum X_i \sum X_i \ln X_i - \sum X_i^2 \sum \ln X_i - \sum X_i \sum X_i \ln Y_i}{N \sum X_i^2 - N(\sum X_i)^2} \qquad (2)$$

$$b = \frac{N \sum X_i \ln Y_i + \sum X_i \sum \ln X_i - N \sum X_i \ln X_i - \sum X_i \sum \ln Y_i}{N \sum X_i^2 - (\sum X_i)^2} \qquad (3)$$

with N being the number of pairs of values.

Having determined the two constants, the calculation of the area between the line of equal distribution and the observed values at each station indicates the greatest or least daily rainfall concentration. In order to do this, it is necessary to calculate the integral defined by the exponential curve between 0 and 100 of the surface between each curve, the abscissa axis and the 100 ordinate by performing the following equation (4):

$$A' = \left[\frac{a}{b} e^{bx} \left(x - \frac{1}{b}\right)\right]_0^{100} \tag{4}$$

5000 is subtracted from the value obtained by this equation to determine the area between each curve, the line of equal distribution and the 100 ordinate (S'). Thus, the precipitation concentration index (CI) is obtained from the following formula (5):

$$CI = \frac{S'}{5.000} \tag{5}$$

The highest value of the index implies that there is greater irregularity of daily precipitation which, in the case of the Canary Islands, is related to the orientation and altitude of each locality.

Besides obtaining CI values, the distribution and frequency of rainfall events are analyzed, which refine the different behaviour of rainfall in the different islands and mountainsides, especially on islands where the water catchment areas have a surface area less than 71 km^2 and the conversion of rainfall into runoff occurs very quickly (Marzol *et al.,* 2006) causing serious problems in urban areas (Máyer and Pérez-Chacón, 2006).

II. RESULTS

Relationship between Ni (%) and Pi (%)

In general, the rains in the Canary Islands have a weak character as the range of 1.0 to 9.9 mm is the most prevalent and groups 55% of days with rain. However, the amount of water collected with these intensities varies significantly depending on the orientation. Thus, in the northern mountainsides those days with light rain accounted for up to 50% of annual rainfall, while in the southern mountainsides this only accounted for between 12% and 20% of the annual rainfall.

Considerably heavy rainfall, of over 50 mm, is associated with the passage of cold fronts coming from strong oceanic depressions, mainly during the winter, which affect this Atlantic region with winds from the third quadrant. By contrast, the high number of days with weak or very weak precipitation on the northern slopes provide significant volumes of water to the annual calculation and these are associated with both the stratiform cloudiness of the trade winds and the passage of fronts with a marked northeast- southwest disposition, which does not affect the southern slope.

On the other hand, the altitude also introduces significant changes in the rainfall concentration. Rainfall with intensities of less than 10.0 mm are especially common on the south coast (85%) and provide more than a third of the annual water volume, whereas on the *medianías* (the term *medianías* is a Canary term to describe the part of the mountainside which is neither the summit nor the coastal part, and is generally between 500 m an 100 m a.s.l.) of the same region these rains account for 65 % of days with rain and only provide 13% of the annual water. By contrast, the more intense rains -between 50 and 150 mm/24 h- are much more important in the latter than in the former, 9% of the days *versus* 1% respectively. And, the amount of water collected on these stormy days is half of the annual rainfall on the mountain slopes compared to only 13% on the coast. The most prominent example of this trait can be found on the islands of Lanzarote and Fuerteventura, due to their low altitude, where rainfall intensities of less than 10.0 mm account for up to 90% of rainy days and provide about half of the total annual water volume.

CI values

The spatial differences in the concentration of the precipitation are clearer when the CI values are calculated (Table 1). The values analysed in all the stations exceed 0.63 indicating a high precipitation concentration. This means that 25% of the rainiest days in the Canary Islands provide 77% of the annual rainfall. However, some spatial variations should be noted in the CI which are related to the role of the geographical conditioning played by the orientation of the relief.

The highest CI values, >0.70, corresponding to the eastern and southern slopes of the most mountainous islands, regardless of the altitude are similar to those obtained on the coast of the Valencian Community (De Luis *et al.,* 2011; Sánchez-Lorenzo and Martín Vide, 2006). This means that 80% of the rain comes from 25% of the rainiest days. This high concentration of rainfall has direct implications such as generating erosion, rivers bursting their banks and floods.

At the summits, the CI values are slightly lower, 0.66 to 0.67. Torrential rainfall is common at sites above 1000 m altitude, so that those of >50 mm in 24 hours account for only 9% of days with rain but contribute half of the total yearly rainfall. In view of the results and the low correlation between the CI and altitude, one can say that the latter is not a spatial differentiation factor, as both the coastal areas and the eastern and southern slopes have equally high values, an issue that has already been demonstrated by other authors (De Luis *et al*., 1997).

The more moderate CI values in the Canary Islands are from the slopes in N, NE and NW of the mountainous islands and from all the zones in Lanzarote and Fuerteventura, where the value does not exceed 0.66. In the first case, this is a consequence of the cloud type associated with the trade winds that stagnates in the northern slopes, while the second is due to the lower intensity of the fronts when they sweep across the most eastern islands of the archipelago, which are also those of lower altitude.

The duration and frequency of wet spells

Analysis of the duration of wet spells and the amount of water accumulated in each one, make it possible to refine the precipitation concentration. There are significant differences between the different islands and even between sites of the same island as a function of

Table 1

CONSTANT FEATURES A AND B OF THE EXPONENTIAL CURVES CO-EFFICIENT OF DETERMINATION (R2), CONCENTRATION INDEX (CI) AND PERCENTAGE OF TOTAL RAINFALL WHICH COMES FROM 25% OF THE RAINIEST DAYS IN 29 SITES IN THE CANARY ISLANDS (1970-2003)

Nº	Name	Island	Altitude	Orientation	a	b	R^2	CI	Rain (%)
1	Mazo airport	LP	40	E	0.01082	0.04320	0.976	0.71	80.9
2	Vellehermoso	LG	220	N	0.02646	0.03493	0.992	0.64	74.9
3	Cangrejos airport	EH	30	E	0.01364	0.04034	0.984	0.71	80.0
4	Sabinosa	EH	270	N	0.02041	0.03734	0.985	0.66	76.3
5	Los Rodeos airport	TF	617	N	0.02282	0.03674	0.995	0.64	74.7
6	Santa Cruz de Tenerife	TF	36	ESE	0.00824	0.04627	0.981	0.71	80.6
7	Arafo	TF	485	E	0.01631	0.03911	0.990	0.69	78.5
8	Izaña	TF	2371	summit	0.02470	0.03514	0.989	0.66	76.3
9	Vilaflor	TF	1435	S	0.01462	0.04048	0.995	0.70	80.4
10	Airport Reina Sofía	TF	59	S	0.01892	0.03780	0.994	0.67	77.0
11	Presa de Jimenez	GC	245	N	0.02679	0.03502	0.991	0.63	73.5
12	Arucas	GC	252	N	0.03073	0.03342	0.993	0.63	73.6
13	Tamaraceite	GC	210	N	0.02167	0.03701	0.990	0.65	75.1
14	Valleseco	GC	960	N	0.01629	0.04020	0.993	0.66	76.7
15	Lomo Aljorradero	GC	1075	NE	0.02514	0.03535	0.990	0.65	75.4
16	La Pardilla	GC	45	E	0.01338	0.04149	0.979	0.69	78.2
17	Cuevas Blancas	GC	1690	summit	0.02027	0.03725	0.991	0.67	77.0
18	Pinar de Pajonales	GC	1195	SW	0.01529	0.04010	0.993	0.68	78.3
19	San Bartolomé Tirajana	GC	887	S	0.01017	0.04408	0.995	0.71	80.4
20	Gando airport	GC	20	E	0.01697	0.03899	0.985	0.68	77.5
21	Barranquillo Andrés	GC	650	SW	0.01179	0.04306	0.996	0.69	78.8
22	Berriel	GC	30	SSE	0.02088	0.03711	0.992	0.66	76.3
23	Famara	LZ	15	NW	0.03101	0.03341	0.993	0.63	73.3
24	Yaiza	LZ	155	N	0.02881	0.03438	0.996	0.63	72.9
25	Puerto del Carmen	LZ	20	S	0.02003	0.03757	0.993	0.66	76.1
26	Guacimeta	LZ	23	E	0.01988	0.03782	0.989	0.66	75.4
27	Tindaya	FV	144	N	0.02863	0.03429	0.994	0.63	73.5
28	Matorral airport	FV	23	E	0.02257	0.03601	0.990	0.66	76.3
29	Puerto de la Peña	FV	19	W	0.02535	0.03521	0.986	0.65	75.6

La Palma (LP), La Gomera (LG), El Hierro (EH), Tenerife (TF), Gran Canaria (GC), Fuerteventura (FV) and Lanzarote (LZ).

longitude, altitude and orientation (Dávila and Romero, 1993; Marzol *et al*., 2006). Overall, between 40% and 70% of the rainy sequences occur in only one day, in which between 9% and 35% of the annual precipitation is recorded.

The sites where the sequences of a single rainy day are very important, not only because of their frequency but also because of the amount of water that they accumulate with respect to the annual total, are in the eastern islands, Lanzarote and Fuerteventura, and in coastal areas and on the lower slopes in the other islands. Thus, for example, in the Puerto de la Peña, in Fuerteventura, 70% of rainy spells are a single day and 34% of the annual precipitation is accumulated on these days. By contrast, the rainy sequences of a single day are rare in northern slopes and summits. This is the case of Los Rodeos, where rainy spells of a single day account for 39% and accumulate only 7% of the annual precipitation. The cloud form associated with the trade winds is responsible for the high number of days with drizzle which, nevertheless, provide much less water than the Atlantic storm fronts. These discharge precipitation over two or more days and considerable amounts of water are collected in these periods. It is precisely in these sites which are exposed to the fronts where there are the longest rainy spells, sometimes being more than 20 consecutive rainy days. Example of this are Sabinosa (23 days, from October 28 to November 19, 1983) and Los Rodeos (22 days, from December 30, 1977 to January 20, 1978), in both cases 228.6 mm and 226.9 mm of water were collected respectively.

As regards spells of two consecutive rainy days, the differences between the slopes are less, such that their frequency in the southern zones is 28% providing 25% of the total annual rainfall while the northern zones account for 22% of rainfall events and 20% of all the yearly rainfall.

In conclusion, the daily analysis of precipitation confirms that high irregularity and rainfall concentration are two very characteristic features of rainfall in the Canaries. Moderately high values of CI prove this and indicate that on a few rainy days, a significant percentage of all annual precipitation is accumulated. However, the irregularity of the rain is not the same in all the islands, not even in one island, therefore when any analysis performed with this climatic variable consideration of the factors of orientation and the altitude of the relief as well as the location of each island in the archipelago as a whole needs be taken into account.