ESTIMATION OF AREAL REDUCTION FACTORS IN THE PROVINCE OF CÓRDOBA (SOUTHERN SPAIN)

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ABSTRACT

There are many hydrological and meteorological applications requiring knowledge about spatial and temporal variability of rainfall over an area. The intensity of point precipitation is only applicable for relatively small areas, being necessary the use of empirical methods to estimate areal reduction factors (ARF). In some of them, ARF is unique for different recurrence intervals, while in others the ARF is a function of recurrence interval. These indices are used to transform point rainfall depths to an equivalent rainfall depth over an area. Generically, ARF is defined as the ratio between the average areal depth of precipitation and the average point depth.

In the present study, different methods of ARF calculations have been evaluated in the province of Córdoba, located in the centre of Andalusia region (Southern Spain). Andalusia is a Mediterranean region where rainfall generally decreases from West to East, characterized by high temporal variability (some extreme events) and high spatial variability as a consequence of rugged relief.

Keywords (3-6): *areal reduction factor, precipitation, rainfall, Southern Spain*

RESUMEN

Muchas aplicaciones hidrológicas y meteorológicas requieren un conocimiento de la variabilidad espacial y temporal de la lluvia en un área determinada. La intensidad de lluvia en un punto sólo puede extenderse a pequeñas áreas, por lo que se debe recurrir a métodos que emplean las alturas de lluvia registradas en un número de estaciones para calcular empíricamente el FRA (factor de reducción areal). En algunos de ellos el FRA es único para los distintos intervalos de recurrencia, mientras que en otros el FRA es función del intervalo de recurrencia. Estos índices se utilizan para transformar la altura de lluvia puntual en una altura de lluvia equivalente para un área determinada. El FRA se define como el factor que aplicado al valor de lluvia puntual para una duración y periodo de retorno especificado, se traduce en la lluvia espacial sobre un área para la misma duración y periodo de retorno.

En el presente estudio se han evaluado diferentes métodos de estimación de este índice en la provincia de Córdoba, situada en el centro de Andalucía (Sur de España). Una región mediterránea donde generalmente las precipitaciones disminuyen de Oeste a Este. Éstas se caracterizan por una marcada variabilidad temporal que permite la aparición de fenómenos extremos, y una fuerte variabilidad espacial como consecuencia del relieve accidentado.

Palabras clave (3-6): *factor de reducción areal, precipitación, lluvia, Sur de España*

1. INTRODUCTION

An areal reduction factor (ARF) is a value which can be applied to a point rainfall of a specified duration and return period to give the areal rainfall of the same duration and return period. Many hydrological and meteorological applications require knowledge about the temporal and spatial variability of average rainfall over an area (Allen and DeGaetano, 2005). Important applications of rainfall data occur when volumes or average depths of rainfall over various areas (usually river catchments) are required rather than individual point values (Omolayo, 1993). Intensity-duration-frequency (IDF) curves, which relate the intensity of point precipitation to its duration and frequency, can be used in such instances to estimate the depth of precipitation, but are only applicable for relatively small areas (< 4 km^2) (Srikanthan, 1995). For larger areas, design storms need to be converted to an average areal depth through the use of a depth-area correction, or an ARF. This is done by multiplying the average of the point depths for a given duration, frequency and area by the appropriate ARF. It is often assumed that the areal rainfall and the point rainfall have the same probability of exceedence. ARF ranges from 0 to 1 and is function of storm characteristics, such as intensity and duration, as well as basin characteristics, such as size, shape and geographic location (Asquith and Famiglietti, 2000).

Two types of areal reduction factors exist, storm centered and fixed area (Hershfield, 1962). For storm-centered ARF, the area in which the rain falls is not fixed but changes with each storm. The fixed-area reduction factor is used in order to derive critical storms which are estimated for planning and engineering design purposes. This study focuses on the analysis of fixed-area areal reduction factors. Geographically fixed-area reduction factors are, therefore, based on different parts of the different storms instead of on the highest point values at the respective storm centers, as is the case with the storm-centered reduction factors. The fixed-area reduction factors are not necessarily related to any individually recorded storm, they originate in rainfall statistics. This is why they could also be referred to as ‘statistical reduction factors’ (Omolayo, 1993).

The need for areal reduction factor in estimating catchment rainfall frequencies from point rainfall frequencies has long been recognized. Efforts to have the concept adopted for use in design flood estimation began in the United States (U.S. Weather Bureau, 1957). Similar efforts were made two decades later in the United of Kingdom (Natural Environmental Research Council (NERC), 1975). Bell (1976) developed another popular empirical approach that is similar to the NERC method, but accounts for return period. The Rodriguez-Iturbe and Mejia (1974) method is based on the spatial correlation of point rainfall and consistently leads to lower estimates of ARF than other methods as those reported by Omolayo (1992) or Asquith and Famigleitti (2000).

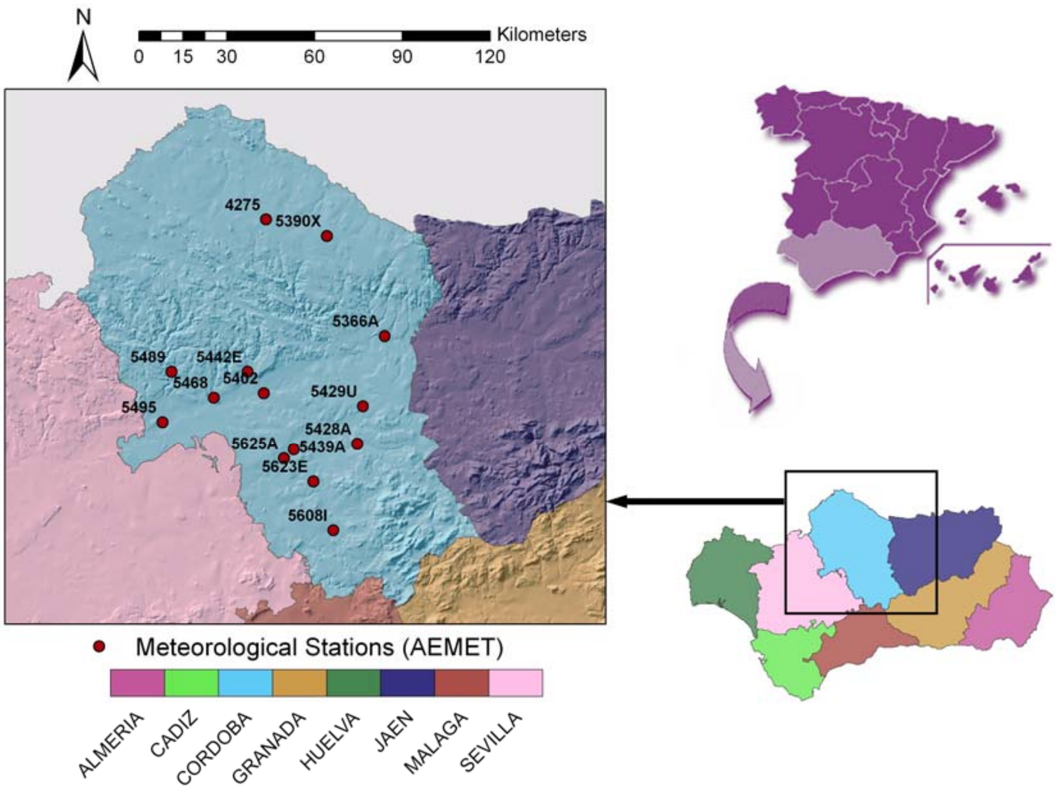
Not many works have been carried out to estimate values of areal reduction factors in countries other than USA, UK or Australia. In the present study, two of the most used methods of ARF calculations have been evaluated in Southern Spain.

2. MATERIALS AND METHODS

Study Area and Rainfall Data Source

Daily precipitation data from the Meteorological National Agency (AEMET, Agencia Estatal de Meteorología in Spanish) network in Andalusia region form the basis of this study. Córdoba is an inland province situated in the centre of Andalusia, in Southern Spain. Andalusia is a Mediterranean region located between the meridians 1° and 7 °W and the parallels 37° and 39°N and occupying an extension around 9 Mha. The climate is semiarid, with very hot and dry summers and rainfall generally decreases from West to East. Spatial distribution of meteorological stations used in the present study is represented in Figure 1.

Figure 1. Spatial distribution of the meteorological stations. Córdoba, province of Andalusía (Spain)



Stations included in the analysis were required to have precipitation daily records that at least spanned the period 1988-2006, with no more than five days missing per month during this interval. ARFs computations were made after a previous validation, following Estévez (2008) and Estévez and Gavilán (2006). These criteria eliminated a large number of candidate stations, leaving those shown in Figure 1. Coordinates, name of stations, and elevation are summarized in Table 1. Site elevations range from 70 to 740 m above mean sea level, longitude from 4.3838 to 5.2407 W and latitude, from 37.4222 to 38.37778 N. Fourteen stations were used in this analysis, all of them situated in Córdoba province.

Table 1. Coordinates, name and elevation of meteorological stations used in this study

id	Station Name	Province	Latitude (º)	Longitude (º)	Elevation (m)
5402	Córdoba Aeropuerto	Córdoba	37,8420	-4,8502	91
5442E	Córdoba La Jarosa	Córdoba	37,9069	-4,9143	340
5468	Pantano de Breña	Córdoba	37,8253	-5,0435	150
5439A	Fernán Núñez INM	Córdoba	37,6703	-4,7296	320
5625A	La Rambla Privilegio	Córdoba	37,6417	-4,7671	200
5489	Pantano Bembézar	Córdoba	37,9022	-5,2104	100

5429U	Córdoba Pradagna	Córdoba	37,8072	-4,4635	265
5623E	Montilla SEA	Córdoba	37,5717	-4,6518	340
5495	Hornachuelos El Carrascal	Córdoba	37,7458	-5,2407	70
5428A	Castro del Río SEA	Córdoba	37,6903	-4,4838	210
5366A	Montoro SMN	Córdoba	38,0250	-4,3838	200
5608I	Lucena Cerro de las Puertas	Córdoba	37,4222	-4,5712	410
5390X	Villanueva de Córdoba INM	Córdoba	38,3306	-4,6158	740
4275	Pozoblanco	Córdoba	38,3778	-4,8546	649

Areal Reduction Factor Computation Methods

ARF

One of the most common sources of ARF calculation is Technical Paper 29 (TP-29) (e.g., U.S. Weather Bureau 1957), defined as the following equation for TP-29 1-day:

$$ARF_{TP-29} = \frac{\frac{1}{n}\sum_{j=1}^{n}\hat{R}_j}{\frac{1}{k}\sum_{i=1}^{k}\left(\frac{1}{n}\sum_{j=1}^{n}R_{ij}\right)}, \qquad (1)$$

where R_{ij} = annual maximum point rainfall for year j at station i

= $\max(r_{i1}^{j}, r_{i2}^{j}, ..., r_{id}^{j})$

r_{iu}^{j} = daily point precipitation at station i in year j on day u

$\hat{R}_j$ = annual maximum areal rainfall for year j

= $\max(\hat{r}_1^{j}, \hat{r}_2^{j}, ..., \hat{r}_d^{j})$

$\hat{r}_u^{j}$ = daily areal precipitation on day u for year j

= $\frac{1}{k}\sum_{i=1}^{k} r_{iu}^{j}$

k = number of stations in the area

n = number of years

d = number of days in year j

The daily areal rainfall $\hat{r}_u^j$ is calculated as an unweighted average of each station's daily point rainfall r_{iu}^j. The highest of these in each year, $\hat{R}_j$, is selected and an annual mean is computed by averaging the maximum annual rainfall from each year. This average constitutes the numerator in Equation 1. The largest point measurement of precipitation at each station in each year, R_{ij} , is subsequently recorded. The grand mean over all stations and over all years is calculated and constitutes the denominator in Equation 1.

ARF$_{FSR}$

In many studies, the standard source of ARF is that found in the Flood Studies Report (FSR), Volume 2 (Natural Environment Research Council, 1975). ARF$_{FSR}$ is usually calculated for a wide variety of areas for durations of 1 minute to 25 days and for areas from 1 km^2 to 30,000 km^2. In this method, the maximum areal rainfall for year j is calculated and the corresponding station rainfalls $\tilde{R}_{ij}$ are noted. The maximum point values R_{ij} at each station in the same year are also recorded. The ratio of $\tilde{R}_{ij}$ to R_{ij} at each station in each year is calculated. The mean over all stations and all years defines ARF$_{FSR}$:

$$ARF_{FSR} = \frac{1}{nk} \sum_{j=1}^{n} \sum_{i=1}^{k} \left(\frac{\tilde{R}_{ij}}{R_{ij}} \right), \qquad (2)$$

where $\tilde{R}_{ij}$ = point rainfall for station i on the day the annual maximum areal rainfall occurs in year j

R_{ij} = annual maximum point rainfall for station i in year j

k = number of stations in the area

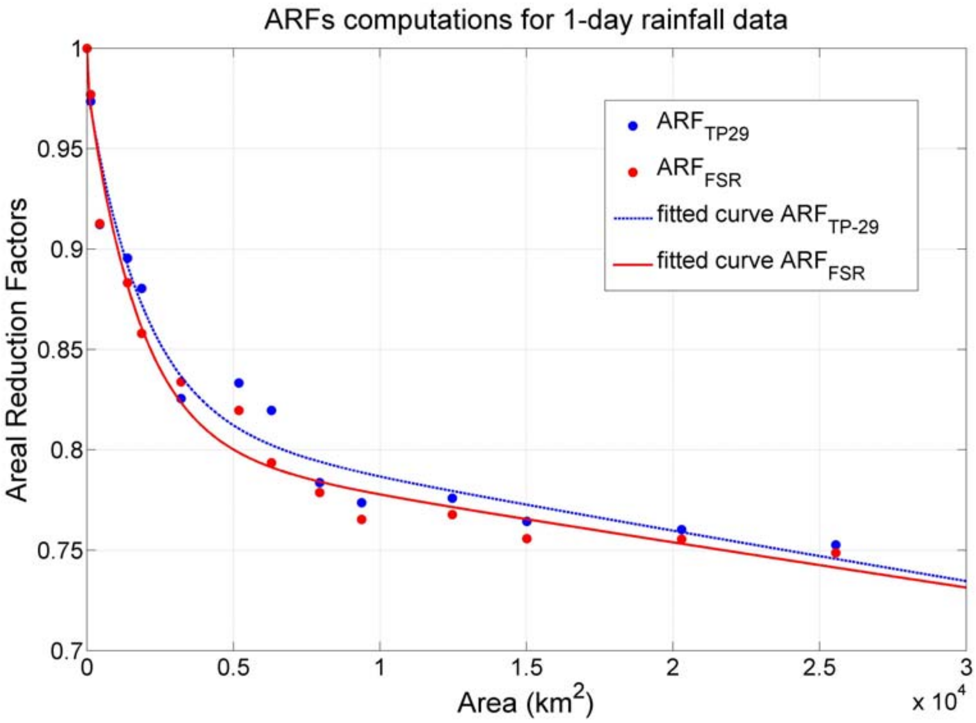
n = number of years

In both methods, the determination of the area of a watershed is somewhat arbitrary. The approach assumed in this work to estimate the area covered by k stations is that the area covered by k gauges is equal to k circles, each with a diameter equal to the average station spacing.

3. RESULTS AND DISCUSSION

The areal reduction factors estimated by the two methods were calculated for 1 day precipitation duration and are represented in Figure 2. Due to the relatively short record lengths of rainfall data available (19 years), frequency considerations could not be accurately determined (Allen and DeGaetano, 2005). Given the use of averages, the ARF curves correspond to events with return peiod of approximately two years, which is based on the mean of the Gumbel distribution (Wilks, 1995). For representing ARF values vs. Area, as explained in the methodology section, it is assumed that the area is equal to n circles with a diameter equal to the average station spacing, following TP-29 criteria. Many similarities exist between ARF_{TP-29} and ARF_{FSR}. Both ARFs estimations decrease with increasing area and the dependence of return period is assumed negligible with both methods. Since both types of computations are based on the mean annual maxima, it also corresponds to the about 2 years return period.

Figure 2. Areal reduction factors vs. Area (km^2)



The ARF estimations given by TP-29 method are generally higher than those obtained by FSR method. These results are in agreement to those reported by Omolayo (1993) for some Australian cities. Consequently, TP-29 fitted curve is slightly higher than FSR fitted curve, especially between the areas of 2000-25000 km^2. Out of this range, both fitted curves are nearly equal. The greatest differences in ARF values estimated by both methods were given for areas of about 63000 km^2. Values reported by Allen and DeGaetano (2005) for two-year return period and for areal sizes higher than 20000 km^2 in North Carolina are similar to ARF estimations represented in Figure 2. However, results discussed by Stewart (1989) for North West England and for an areal size of 10000 km^2 are slightly larger than corresponding ARF values obtained in this study. Regardless of these comparisons, caution is needed when interpreting them because the influence of station density related with the determination of network area is an important factor to be considered.

4. SUMMARY AND CONCLUSIONS

The adjustment of precipitation from a point depth to a mean areal depth is important for characterizing rainfall-runoff relations and for cost-effective designs of various hydraulic structures when design storms are considered. A design storm is defined as the precipitation depth at a point for a given duration and return period. An average areal depth is calculated by reducing these design storms via a depth area correction, or an areal reduction factor (ARF). The 24-hour areal reduction factor based on 19 years of AEMET network data has been estimated using different methods in Córdoba province (Southern Spain). The ARF values given by TP-29 method are very similar than those estimated by FSR method, for different areal sizes analyzed. The areal reduction factors presented in this study have been based on the assumption that areal reduction factor does not vary with return period. Due to the scarce availability of hourly rainfall data, ARF estimations for storm duration lower than 24 h cannot be studied in this region. Variation of ARF computations with return period and storm duration, and especially estimating this factor by other methods, needs to be investigated in order to make more valid conclusions. Although this work may be useful in understanding the meaning of areal reduction factors using precipitation data on a daily basis, being the most common time-period in any meteorological network. The extension of this preliminary work to a regional analysis across Andalusia region is the subject of a next study.

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