

COMPARISON OF DROUGHT INDICES FOR A TRANSBOUNDARY BASIN

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ABSTRACT

Guadiana River is a transboundary river flowing through Spain and Portugal. The basin area of Guadiana River amounts to 66 800 km², from which 55 200 km² belong to Spain and 11 580 km² belong to Portugal. Guadiana River basin represents a typical semi-arid area of southern Europe. The study region in this paper, from the point of view of drought, is that part of Guadiana River basin which belongs to Portugal. Daily rainfall data from 34 rainfall stations, for the time period 1931-2007, were available. The following quantitative drought indices were calculated in order to investigate if drought conditions took place during the time period 1931-2007 in the study region: (a) percent of normal, (b) deciles, (c) reconnaissance drought index, (d) annual deficit area – area drought, (e) drought duration, and (f) annual water shortage. The general conclusion drawn from the present study is that, in the time period considered (1971-2006) for the calculation of all the above indices, an increasing trend of drought risk exists in the study region, which is estimated quantitatively by means of the time variation of the drought indices.

1 INTRODUCTION

Guadiana River is a transboundary basin flowing through Spain and Portugal. The basin area of Guadiana River amounts to 66 800 km², from which 55 200 km² (83%) belong to Spain and 11 580 km² (17%) belong to Portugal. The length of Guadiana River in Spain is 550 km, while the river length in Portugal is 260 km. Many kilometers of total river length constitute natural borders of both countries (Figure 1).

Guadiana River basin represents a typical semi-arid area of southern Europe. The study region in this paper, from the point of view of drought, is that part of Guadiana River basin which belongs to Portugal. Daily rainfall data from 34 rainfall stations, for the time period 1931-2007, were available. 13 stations are situated in the study region, while 21 stations are situated around the study region (Figure 2).

In order to investigate if drought conditions took place during the time period 1931-2007 in the study region, the quantitative drought indices described in the following

sections were calculated.



Figure 1. Location of Guadiana River basin.



Figure 2. Rainfall stations in Guadiana River basin.

Regarding the literature about drought indices, the following bibliographic sources are indicatively given: Rossi et al. (1992) have reviewed different methodologies for the estimation and analysis of regional drought. Tsakiris et al. (2007) have proposed the Reconnaissance Drought Index (RDI) and have applied RDI, as well as two other indices (Standardized Precipitation Index, SPI, and deciles) to the basins of Nestos River and Mornos River (Greece). Kanellou et al. (2008) have applied three drought indices, the deciles, the Palmer index and the Reconnaissance Drought Index, to four study areas, in Greece. Mishra and Singh (2010) have provided a review of fundamental concepts of drought, classification of droughts and drought indices. Additionally, Mishra and Singh (2011) review different methodologies used for drought modelling, which include drought forecasting, probability based modelling, spatio-temporal analysis, use of Global Climate Models (GCMs) for drought scenarios, land data assimilation systems for drought modelling, and drought planning.

2 PERCENT OF NORMAL (PN)

In the present case study, the drought index “percent of normal” is defined as follows (Rossi et al., 1992):

$$PN = \frac{P}{P_m} \times 100 \quad (1)$$

where

PN: percent of normal (%)

P: annual rainfall

P_m: mean annual rainfall

By means of this index, the trend of the annual rainfall depth can be estimated. In Figure 3 (Balanis, 2007), the time evolution of the index “percent of normal”, as well as the trend line for the years 1931-2007, for the rainfall station Amareleja (Figure 2) is indicatively given.

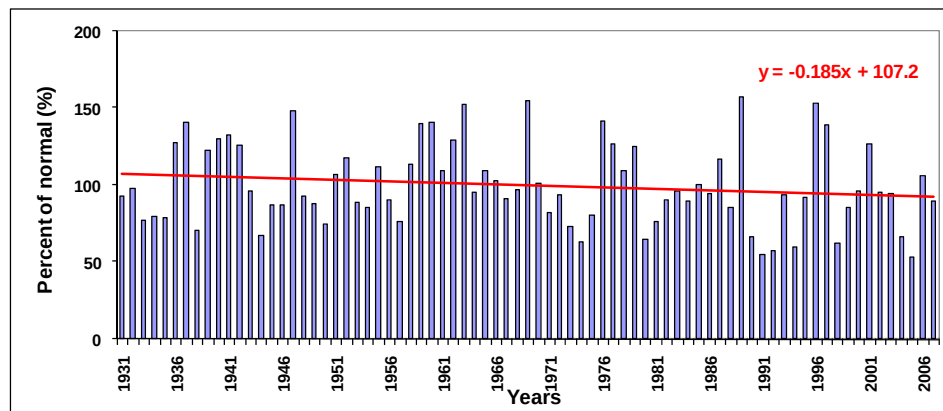


Figure 3. Time evolution and trend line of the drought index “percent of normal” for the rainfall station Amareleja.

In Figure 3, a decreasing trend of the annual rainfall depth in relation to the mean annual rainfall depth for the station Amareleja is observed. Generally, in the 30 from the 34 rainfall stations considered, a decreasing trend of the drought index “percent of time” with time (years) is observed.

3 DECILES

The monthly values of the rainfall depth of the years 1931-2007 are written in an increasing order and are divided into five categories: very dry period – dry period – normal period – humid period – very humid period. Totally, 908 values of monthly rainfall depth were divided into the above five categories. Each category contains 182 values. Corresponding to the five categories, five intervals of cumulative probability, called deciles, were defined: 0.0 - 0.2 / 0.2 – 0.4 / 0.4 – 0.6 / 0.6 – 0.8 / 0.8 – 1.0.

Arranging monthly precipitation data into deciles is another drought-monitoring technique, that was developed by Gibbs and Maher (1967) to avoid some of the weaknesses within the “percent of normal” approach.

In Figure 4 (Balanis, 2007), the diagram of the cumulative probability for the monthly rainfall depth of the rainfall station Amareleja is indicatively given.

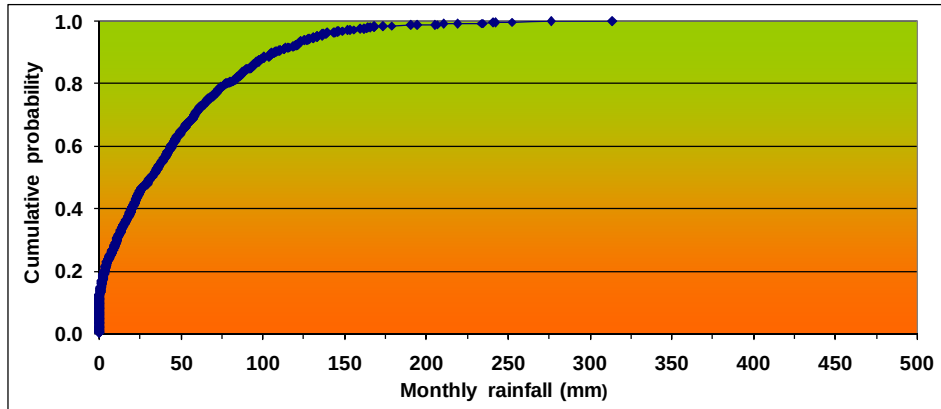


Figure 4. Diagram of cumulative probability for the monthly rainfall depth of the rainfall station Amareleja (years 1931-2007).

Future rainfalls at the station Amareleja can be classified into one of the five categories mentioned above, because the rainfall bounds of each category can be determined by means of the diagram of Figure 4.

4 RECONNAISSANCE DROUGHT INDEX (RDI)

The Reconnaissance Drought Index (RDI) was proposed by Tsakiris et al. (2007). It is mathematically defined as follows:

$$RDI(k) = \frac{a_k}{\bar{a}_m} - 1 \quad (2)$$

$$a_k = \frac{\sum_{j=1}^k P_j}{\sum_{j=1}^k PET_j} \quad (3)$$

where

P_j : rainfall of the month j (for a station)

PET_j : potential evapotranspiration of the month j (for a station)

$\bar{a}_m$: mean annual value of a_k (for a station)

The monthly potential evapotranspiration PET was calculated by means of the following relationships of Thornthwaite:

$$PET = 16\lambda \left(\frac{10T}{J} \right)^a \quad (4)$$

$$J = \sum_{i=1}^{12} J_i \quad J_i = \left(\frac{T}{5} \right)^{1.514} \quad (5)$$

$$a = 0.016J + 0.5 \quad (6)$$

where

T : mean monthly temperature

λ : percentage of sunlight hours on a monthly time basis (from tables)

According to Equation (2), if $RDI < 0$, then there is drought risk.

In Figure 5 (Balanis, 2007), the time evolution of RDI for the years 1971-2006 is given indicatively for the rainfall station Amareleja. According to Figure 5, there is drought risk in most of the considered years. In the last years of the time period 1971-2006, the drought risk becomes higher. This remark is valid also for the other rainfall stations of the study area.

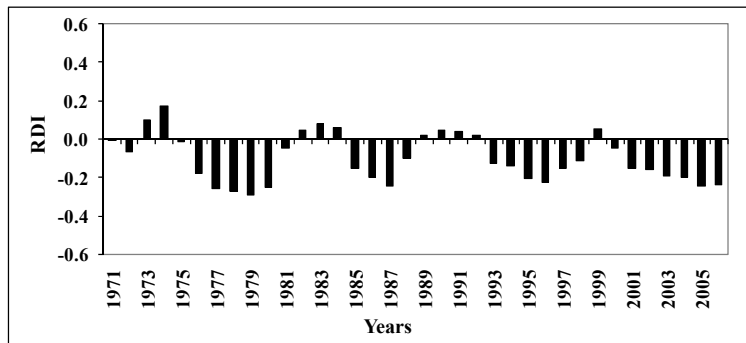


Figure 5. Time evolution of RDI for the rainfall station Amareleja (years 1971-2006).

5 ANNUAL DEFICIT AREA

The annual deficit area is calculated by the following relationships (Rossi et al., 1992):

$$A_s(i) = \sum a_k I[h(i, k)] \quad a_k = \frac{S_k}{S} \quad (7)$$

where

$A_s(i)$: deficit area for the year i

a_k : impact factor of the rainfall station k ($0 < a_k < 1$)

S_k : area corresponding to the rainfall station k

S : total study area

$h(i, k)$: annual rainfall depth for the year i , at the rainfall station k

$I[h(i, k)]$: function obtaining the values 0 or 1

If $h(i, k) < CL$, then $I[h(i, k)] = 1$

If $h(i, k) > CL$, then $I[h(i, k)] = 0$

CL : threshold rainfall value (critical rainfall depth)

Twelve (12) rainfall stations in the study area were taken into account for the calculation of the annual deficit area. The mean annual rainfall of the years 1931-2007 is 540 mm. For the threshold value CL , the assumption $CL = 0.90 \times 540 = 480$ mm was made.

In Figure 6 (Balanis, 2007), the variation of the annual deficit area with time (years) for the study area is shown.

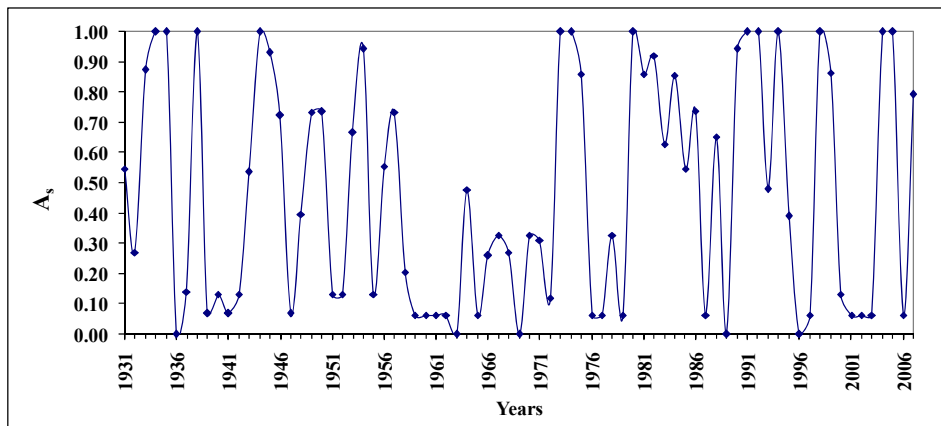


Figure 6. Time variation of the annual deficit area for the study area (years 1931-2007).

If the annual deficit area A_s exceeds a critical value CA (threshold value), then an area drought prevails. In this study, the assumption $CA=0.5$ was made. In the diagram of Figure 7 (Balani, 2007), only the years of the time period 1931-2007 with area drought for the whole study region are shown.

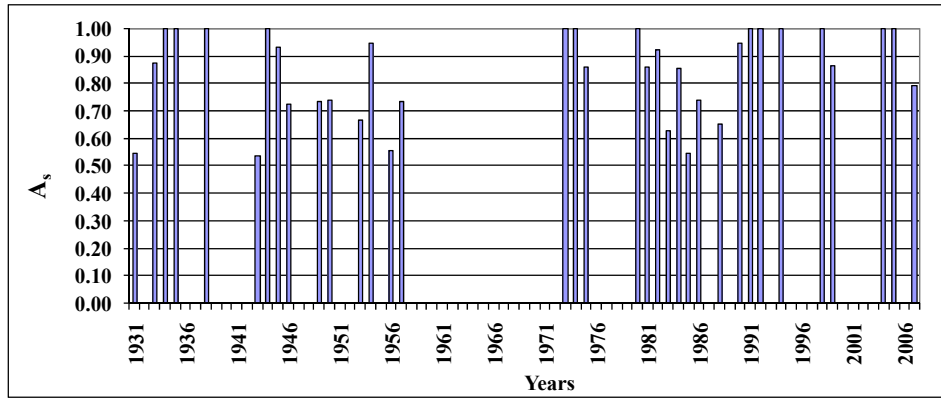


Figure 7. Years of the time period 1931-2007 with area drought for the whole study region.

According to Figure 7, there is an increasing trend for area drought after the year 1980.

6 DROUGHT DURATION

The drought duration L for a study area is defined as follows (Rossi et al., 1992):

$$L = t_e - t_o + 1 \quad (8)$$

where

t_o : beginning of the drought (certain year)

t_e : end of the drought (certain year)

Additionally, the following relationships are valid:

$$A_s(t_o) > CA \quad A_s(t_o - 1) < CA \quad (9)$$

$$A_s(t_e) > CA \quad A_s(t_e + 1) < CA \quad (10)$$

In Figure 8 (Balani, 2007), the drought duration for certain years, for the study area, is shown.

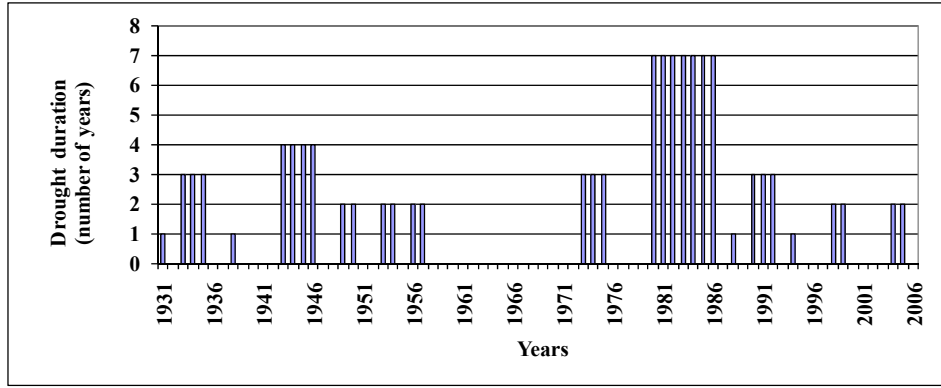


Figure 8. Drought duration for certain years.

According to Figure 8, during the last years of the time period considered (1931-2006), an increase of drought duration is observed.

7 ANNUAL WATER SHORTAGE

The annual water shortage, which designates the drought intensity, is mathematically defined as follows (Tase, 1976):

$$D_s(i) = \sum_{k=1}^n a_k [CL - h(i, k)] I[h(i, k)] \quad (11)$$

where $D_s(i)$ is the annual water shortage for the year i . The other symbols of Equation (11) were defined previously.

In Figure 9 (Balanis, 2007), the time variation of the annual water shortage for the study area is graphically represented.

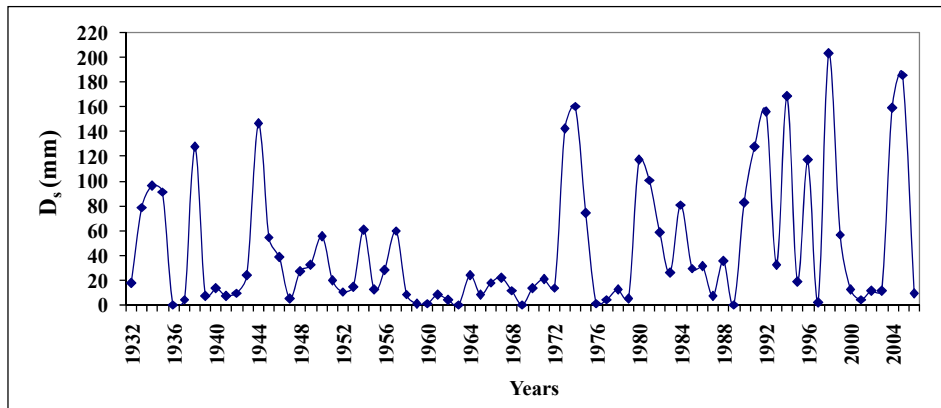


Figure 9. Time variation of the annual water shortage for the study area.

According to Figure 9, in the last years of the time period considered (1932-2006), an increasing trend of drought intensity is observed.

8 CONCLUSION

The general conclusion drawn from the present study is that, in the time period considered (1971-2006) for the calculation of the drought indices “percent of normal”, deciles, reconnaissance drought index, annual deficit area – area drought, drought duration, and annual water shortage, an increasing trend of drought risk exists in the study region, which is estimated quantitatively by means of the time variation of the drought indices.

ACKNOWLEDGEMENTS

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