A peaks over threshold approach for hydrological drought severity assessment.

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Abstract

Information on hydrological drought characteristics is very important for the design and operation of hydrotechnical projects (e.g. water reservoirs, water transfer works etc.). In this study, streamflow drought characteristics of the river at Yermasoyia catchment, Cyprus, were analyzed based on 30 year daily runoff data, using the threshold level method. Fixed and variable thresholds (seasonal, monthly and daily) were employed for this purpose. The 50th percentile values of the flow duration curve were used as suitable thresholds for the semi-arid catchment of the study area. Drought severities, as estimated by the four thresholds, were used to perform statistical frequency analysis in order to estimate appropriate design levels and derive Severity-Duration-Frequency (SDF) curves. Peaks-Over-Threshold analysis (POT) was used for this purpose and the application showed that monthly and daily varying thresholds have similar patterns estimating more severe drought events as the return period increases. The other two thresholds are not able to incorporate the effect of drought duration appropriately; therefore, the estimated severities are lower and the return period has almost no effect.

Keywords: Streamflow droughts, Threshold level method, Peaks over threshold, Severity-Duration-Frequency curves, Cyprus

1. Introduction

Droughts are extreme water related hazards with severe consequences on the environment, societies and economy. It is a periodic phenomenon which appears in a local as well as in a global scale and threatens many aspects of life in both developed and undeveloped countries. It is probably the least understood of all the weather phenomena and therefore it is difficult to define droughts in a single universal manner. According to the American Meteorological Society (1997) four types of droughts can be distinguished; meteorological, agricultural, hydrological and socio-economic. Hydrological drought refers to a shortage of water in the hydrological cycle, which results in abnormally low streamflow in rivers and abnormally low levels in lakes, reservoirs, and groundwater (Tallaksen and van Lanen, 2004).;Hydrological droughts have been commonly analyzed by the scientific community (van Loon, 2015; Ye *et al*., 2016). However, their complex structure hinders the identification of key drought characteristics such as duration, severity, intensity etc. The threshold level method has been frequently used for this purpose in several studies (Tigkas *et al*., 2012; Sung and Chung, 2014; Sarailidis *et al*., 2015; Heudorfer and Stahl, 2016). This method is attractive in hydrological drought studies because it is possible to define drought characteristics in a uniform manner (Tallaksen and van Lanen, 2004; WMO, 2008; Nalbantis and Tsakiris, 2009; van Loon, 2015). Knowledge on drought characteristics is essential in order to perform statistical frequency analysis and estimate appropriate design levels. A commonly used method for this purpose is the Peaks-Over-Threshold (POT) method. In this study, the hydrological drought characteristics were analyzed using the threshold level method and maximum drought severities for various return periods for all thresholds were estimated. Moreover, Severity-Duration-Frequency (SDF) curves were constructed using the POT method.

2. Study Area – Data

Yermasoyia river basin, in Cyprus, is the study area of the project (Figure 1). It is located on the south-west side of the island covering an area of 157 km^2. The altitude reaches 1400 m above mean sea level. The most important part of the runoff is observed during the wet season (October – March) and the mean annual runoff is 150 mm. The catchment belongs to the CSa climatic division of Koppen Geiger climate classification system according to Peel *et al*. (2007). Therefore, hot and dry summers and mild and wet winters dominate in the catchment. Precipitation is highly variable and the mean annual precipitation is 638 mm. The data are 30 year daily river discharge covering a historical period from 1969-70 till 1998-99.

3. Methodology

3.1 Threshold level method - Hydrological Drought Characteristics.

Hydrological drought characteristics were estimated using the threshold level method. According to this method a drought event occurs when the discharge is below a predefined level. In this way, the drought duration is defined as the period during which the discharge remains below the predefined level. The severity is the

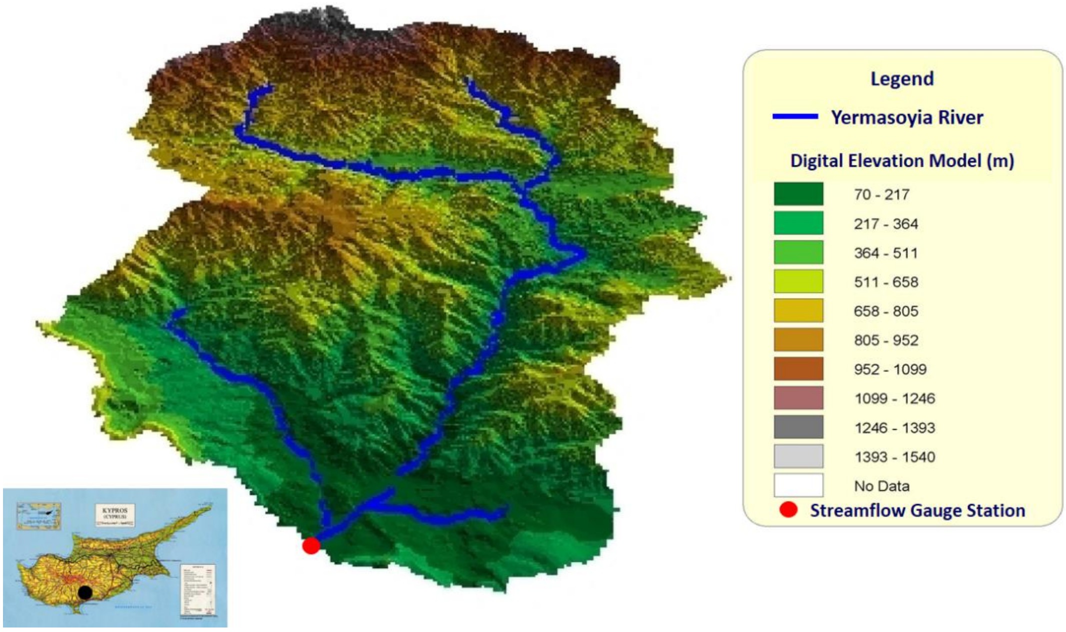


Figure 1 Study Area.

accumulation of the single deficits that occur during the corresponding drought duration and the intensity is defined as the ratio between severity and duration. More details about the threshold level method could be found in recent studies (Smakhtin, 2001; Tallaksen and van Lanen, 2004; WMO, 2008). A fixed or a variable (seasonal, monthly, or daily) threshold could be used. A variable threshold could be chosen when seasonal patterns need to be then taken into account. Fleig *et al*., (2006) demonstrated in their study that there is no single threshold level that is preferable and the selection of a specific threshold level remains a subjective decision. Hence, four (4) different thresholds (fixed, seasonal, monthly and daily) are used in this study for the derivation of the drought characteristics. Ideally the threshold level should be related to the drought impact system at operational water resources management (i.e. irrigation, reservoir operation, environmental flows). However, this information is not available and percentiles of the flow duration curve have been used to overcome this problem. The selection of flow quantile threshold (i.e. Q_{50}) has been tested and selected in a recent study at the same watershed by the authors (Sarailidis *et al*., 2015). Based on the latter study the 50^{th} percentile is selected for reservoir management due to drought conditions at Yermasoyia watershed. Hence, estimated thresholds from Q_{50} percentiles of flow duration curve are 1, 2, 12 and 365 threshold values for the fixed, seasonal, monthly and daily varying thresholds, respectively.

3.2 Peaks-Over-Threshold Analysis.

Each drought event after application of the threshold level method is characterized by its duration and severity or deficit volume calculated by summing up the differences between the actual flux and the threshold level over the drought period. The appropriate design levels in terms of severity were estimated for various return periods (e.g. 10, 20, 30, 50, 100, 250 and 500 years) based on POT approach. In this method, a limit u is defined and the extreme value analysis is performed with the values of discharges that exceed this limit. More specifically, the Generalized Pareto distribution (GP) (Equation 1) is fitted to the excesses;

$$G_{\xi,\sigma}(\chi) = \begin{cases} 1-(1+\xi\chi/\sigma)^{\frac{-1}{\xi}} & if\ \xi \neq 0 \\ 1-exp(-\chi/\sigma) & if\ \xi = 0 \end{cases} \qquad (1)$$

Where ξ and σ are the shape and scale parameter respectively. The evaluation of the fitting was based on diagnostic plots. The limit u should be high enough in order to keep the extreme events and avoid bias in the estimations but it should also give an appropriate number of excesses in order to avoid uncertainty. Therefore, in this study, the selection of an appropriate limit u was based on two plots; The Mean Residual Life plot (MRL) and the parameters (shape and scale) stability plot. An appropriate limit u according to the MRL plot is the value above which there is an evident linearity in the plot. On the other hand, in the parameters stability plots, the appropriate limit u is the value where the shape and scale parameters remain constant or the value before which the plot starts to become imbalanced. More details about the plots and POT analysis can be found in Coles (2001).

4. Results

4.1 Drought Characteristics – Threshold level method

In Table 1 the statistics of the derived drought characteristics for the four different thresholds are summarized. The results show that the fixed and seasonal varying thresholds produce fewer events which however are more severe and last longer. This means that these two thresholds are able to capture only the severe seasonal drought events that occur during the hydrological year. On the other hand, the monthly and daily varying thresholds are able to capture less severe events which may occur.

Table 1. Statistics of drought duration and severity for the four different thresholds

Thresholds	**Fixed**		**Seasonal**		**Monthly**		**Daily**	
Characteristics	Duration (days)	Severity (m^3)	Duration (days)	Severity (m^3)	Duration (days)	Severity (m^3)	Duration (days)	Severity (m^3)
Events	85		76		208		186	
Average	65.54	3.83E+05	72.95	3.94E+05	27.98	2.26E+05	30.17	2.52E+05

Table 2. Selected limits for the POT method and the number of excesses for the four different thresholds.

	Fixed	**Seasonal**	**Monthly**	**Daily**
Limit u (m^3)	930,769.2	959,183.7	755,102	830,612
No of excesses	21	16	15	15

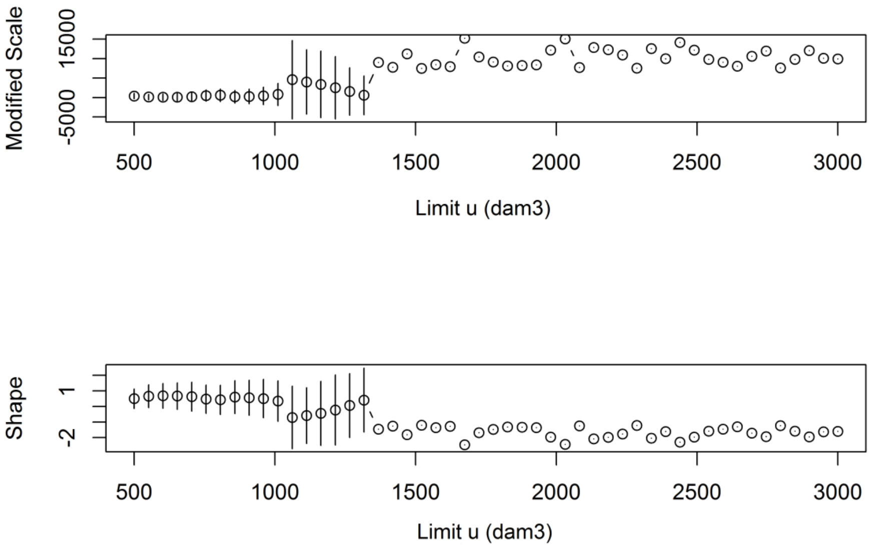
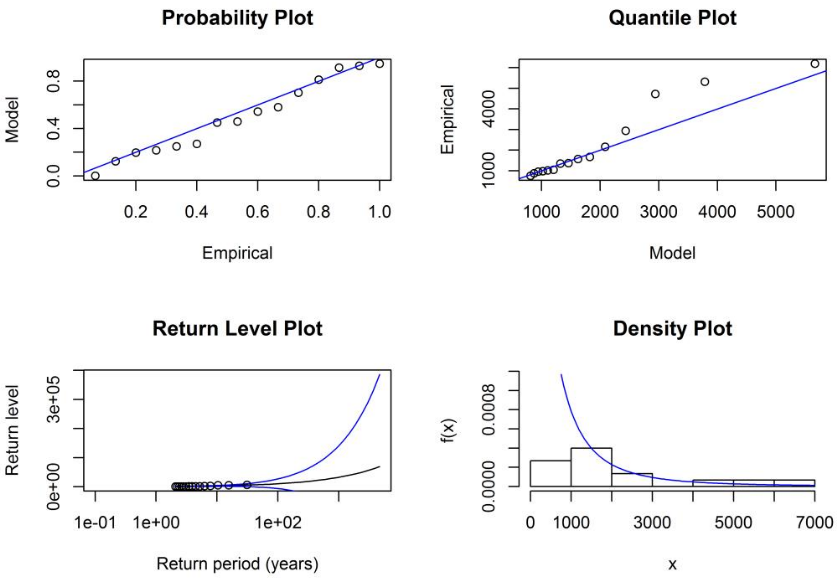


Figure 2 Parameters stability plot for the monthly varying threshold. The units of the limit u are in dam^3.



($1dam^3=1000m^3$).

Figure 3 Diagnostic plots for the case of monthly varying threshold.

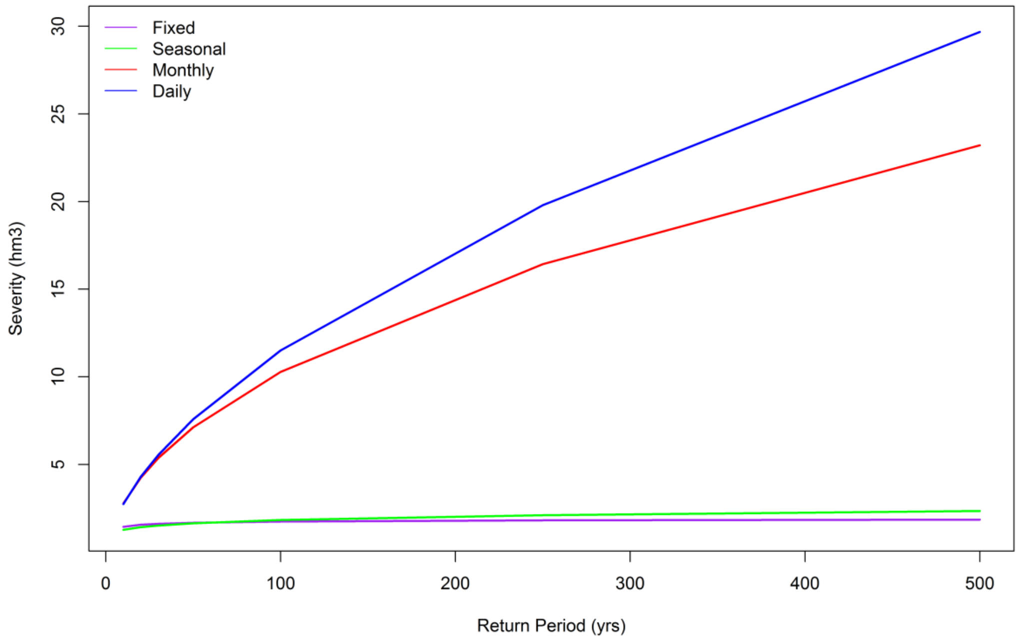


Figure 4 Return level estimates for the four different threshold

during the wet period something which is abnormal and should be prevented. Sarailidis *et al*. (2015) showed that the majority of the events derived by the monthly and daily varying thresholds start to occur during the wet period

4.2 Peaks over threshold analysis.

An important step in POT analysis is to select the appropriate limit u. In Table 2 the limits as well as the number of the excesses for the four different thresholds are summarized. Due to the fact that the MRL plots were tricky to interpret and select the limits u, the selection was based mainly on the parameters stability plots. Indicatively, the parameters stability plot is shown in Figure 2 for the case of the monthly varying threshold. According to the methodology an appropriate limit for this case would be 755,102 m^3 where the shape and scale parameters remain constant as it can be seen in the plot. It should be mentioned that the fitting was acceptable for all the thresholds. Indicatively, the diagnostic plots for the monthly varying threshold are shown in Figure 3. Since the fitting of the GP distribution was acceptable for all the cases, maximum severities were estimated for various return periods and the results are shown graphically in Figure 4. Monthly and daily varying thresholds follow a similar pattern and the estimated severities increase as the return period increases as expected. However, this is not the case for the fixed and the seasonal varying thresholds where the estimated severities are much lower than those of the other two thresholds and the return period has almost no effect. This is probably due to the fact that in the fixed and seasonal varying thresholds the severe seasonal drought events are mainly captured and therefore the slope of the distribution of the excesses is smaller leading to the estimation of less severe events for long return periods.

5. Conclusions

In this study an analysis of streamflow drought characteristics using the threshold level method was performed. A comparison between fixed and variable thresholds showed that the fixed and seasonal varying thresholds were able to capture mainly the severe seasonal drought events that occur during the year while the monthly and daily varying thresholds were able to capture more events that occur also during the wet period. Moreover, maximum drought severities for various return periods were estimated and the corresponding SDF curves were constructed. The analysis was based on POT approach and the results show that the monthly and daily varying thresholds estimate more severe events than the other two thresholds and the estimated severities increase as the return period increases. On the other hand, it seems that the return period on the other two thresholds has almost no effect in the estimated severities, probably due to the fact that only the seasonal drought events were captured with these two thresholds.

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