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REGIONAL FLOOD FREQUENCY ANALYSIS IN THE RIVERS OF THE SOUTH EASTERN PART OF BULGARIA

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Keywords: *L-moments, generalized logistic distribution, south Black sea basin*

Research area: *hydraulics and hydrology*

ABSTRACT

Research on the maximum river flow and the development of methods for estimating probabilities of occurrence are of great economic and environmental importance, especially for regions with scarce hydrological information such as Southeastern Bulgaria. The aim of this study is based on multiannual data for rivers of the Black sea southern coast to develop a model for regional flood frequency analysis by the method of L-moments. Using the statistical criteria for discordance and heterogeneity was found that the rivers of the Black Sea Southern coast are formed as a possible homogeneous region. As suitable to describe the maximum flows in study area was determined the generalized logistic distribution.

1. Introduction

Flood is one of the worst natural disasters that sometimes cause adverse effects on humans, the environment and infrastructure. Planning and development of water resources often demands one to cope with the problem of scarce data. The reasonable estimation of flood has been remained one of the main problematic issues where hydrological data and information are limited. This is typical case in many basins of Bulgaria, where quite rivers are ungauged. This problem is intensified due to shortness of records and incomplete records. In such cases, regionalization can be very helpful in pooling flood data such that design flood estimations can be made at ungauged basins. This same problem now increasingly receives

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attention from the river conservation and restoration community because establishment of management criteria and assessment of hydrologic impacts rely heavily on sufficient records of flow. This situation has led engineers or hydrologists to look for alternative ways to augment the limited flow information at the design location by using the data available at neighbouring rivers, or from a so called homogeneous hydrologic region (Dalrymple, 1960; Cunnane, 1988). An approach to tackle such a problem is pooling at-site information within a hydrologically similar region and scaling the derived regional model to the ungauged sites (Wallis et. al., 2007; Norbiato et. al., 2007; Lizama & Koleva-Lizama, 2011). Among the existing regionalization approaches, the index flood method, proposed by Dalrymple (1960), has become particularly popular for the flood frequency analyses since Hosking and Wallis (1993) presented the L-moment-based measures for evaluating the fitness of the model. Hosking & Wallis (1993) suggested an index flood procedure by assuming that the flood distributions at all sites within a homogeneous region are identical except for a scale or index-flood parameter and using L-moments to undertake regional flood frequency analysis. This study applies the methodology proposed by Hosking and Wallis (1997) to annual maximum series (AMS) flood data from the Bulgarian South Black Sea river basins. The purposes of the study are to identify whether the study region is homogeneous region based on L-moments and to identify the suitable regional frequency distributions for the catchments of the basin using L-moment ratios.

2. Description of study area and data used

The South Black Sea basin covers an area of 5457 km^2. It is bordered by the Black Sea to the east, by the catchments of the Kamchia River and Dvoynitsa River to the north, by the Turkish border to the south, and by the Tundzha River catchment to the west. Small and independent rivers with small catchment areas debouch to the Black Sea. The bigger rivers in this region are the Veleka River (995 km^2) and Sredetska River with (985 km^2). The Sredetska River has 19 tributaries. The remaining rivers cover an area of between 133 km^2(Diavolska River) and 641 km^2 (Fakiyska River). The longer river is the Veleka (147 km); the stream length of the rest of the rivers varies between 32 km (Aytoska River) and 69 km (Sredetska River). The more important rivers in this region between the Kamchia River and the Turkish border are the Dvoynitsa, Hadzhiyska, Aheloy, Aytoska, Rusokastrenska. Sredetska, Fakiyska, Ropotamo, Diavolska, Veleka and Rezovska rivers.

The topography is characterized by lowlands (0–100 m a.s.l.) which cover the eastern and middle parts of the region and the coast, low plains and low mountainous area. The higher parts are in the north and south; Strandja Mountain (up to 600–700 m a.s.l.) and the western regions are low (up to 400 m a.s.l.). The streams that discharge to the Black Sea have rather diverse forest vegetation. According to the climatic classification of the country, the study region belongs to the Black Sea climate sub-type of the Continental Mediterranean climate. The weather generated from the west and north has an influence; the Black Sea influences weather from the east and the Mediterranean influences weather from the south. The southeastern region climate is mainly transitional Mediterranean climate. The considerable values of the radiation balance, positive for all months, fix the high thermal level. The average temperatures for all months are positive. The highest average monthly temperatures in winter, in Bulgaria, are observed here (along the southern Black Sea coast, 3–4 °C in January). Local climatic differences are due, above all, to the proximity of the Black Sea, which warms up the coastal zone in winter, and cools it, especially in spring. The topography, particularly the mountains to the south (Strandja Mountain), plays an important role in the distribution of precipitation.

The runoff regime in the studied catchments is characterized by considerable variability caused by precipitation fluctuations and other landscape elements. In respect of the within-the-year distribution of runoff the following four periods are observed: The high flows are typical of inconstant runoff regime with good noticeable maximum in February. The duration is from the beginning of January to the end of April. Spring runoff decrease covers May and June. The low flows occur from July to October. The autumn runoff increase begins from November to the end of year. The cause of high runoff in autumn and winter is due to the distribution of precipitation in the studied region. On rare occasions and for short duration the feeding of floods is the snowmelt (Lizama Rivas and Koleva-Lizama, 2002).

The annual maximum peak flood data of 9 streamflow gauging sites (Razhitsa, Kameno, Prohod, Svetlina, Fakiya, Zidarevo, Veselie, Zvezdets and Gramatikovo) are used. They are located in the study catchments and ranging over 28–44 years in record length. The catchment areas of these sites vary from 50.1 to 995 km^2 and mean annual peak floods of these sites vary between 5.147 and 141.231 m^3/s. Before use, the streamflow data was carefully reviewed and adjusted. The study region corresponds to a basin where the human activity is minimal. The alterations on the natural flow regime (storage, withdrawals, diversions etc.) in the rivers due to construction of hydro-technical installations, agricultural development and growing urbanization are not significant.

3. Methodology

Regionalization enables a frequency analysis of short records of annual floods to be performed by assisting with the identification of the shape of the parent distribution and leaving the measure of scale to be estimated from the at-site data. In the context of flood frequency analysis, regionalization refers to the identification of homogeneous flood response regions and the selection of an appropriate frequency distribution for the selected regions (Kachroo et al., 2000). Methodology for the flood frequency analysis include testing of homogeneity, development of relationship between mean annual peak flood and catchment characteristics, determination of regional parameters for various distributions, selection of the best-fit distribution and lastly the development of flood frequency curve for the region. Within a homogeneous region, historical data can be pooled to obtain efficient estimates of the parameters of the distribution and hence robust quantile estimates with smaller standard errors (Mkhandi et al., 2000). Thus, the concept of regional analysis is to supplement the time limited sampling record by the incorporation of spatial randomness using data from different sites in a region. These analyses provide a procedure for utilizing the obvious spatial coherence of hydrological variables and thus all available relevant information is incorporated in the flood estimate. A well conducted regional frequency analysis involves objective and subjective techniques for defining homogeneous regions, assigning of sites to regions, identifying and fitting regional probability distribution to data, and testing hypotheses about distributions.

In the present study, standardized L-moments have been used to identify the probability distributions of flood peak flows for the South Black Sea basin in Bulgaria, which are represented by annual maximum daily streamflows. The main advantage of L-moments is that, being a linear combination of data, they are less influenced by outliers whereas the ordinary moments require squaring and cubing of the observed data L-moments can be defined for any random variable whose mean exists. They form the basis of a general theory which covers the summarization and description of theoretical probability distributions and observed data samples, and the estimation of parameters and quantiles of probability distributions. The method of L-moments is analogous to the method of ordinary moments. The L-moments are linear combinations of probability weighted moments (PWMs) and can be estimated directly from them. However, the L-moments are more convenient, as they are directly interpretable as measures of the scale and shape of probability distributions. Parameter estimation with L-moments has been found more accurate than even the maximum likelihood estimate, in case of small sample. The approach based on the theory of L-moments developed by Hosking and Wallis (1997) is a very reliable method for assessing excess probabilities of extreme environmental events when data is available from more than one site.

The Hosking and Wallis regional frequency analysis includes screening of the data, testing of regional homogeneity, identification of the regional distribution, and development of regional storm frequency relationships for gauged and ungauged sites. According this studies, if a proposed region has *N* basins, the measure of discordancy, *Di*, for basin *i* is defined as:

$$D_i = \frac{1}{3} N \left(u_i - \bar{u}\right)^T A^{-1} \left(u_i - \bar{u}\right) \tag{1}$$

where u_i is a vector containing the L-moment ratios for basin *i*, namely the L-CV(*t*), L-skewness (t_2), and L-kurtosis (t_3), $\bar{u}$ is the unweighted regional average for u_i and *A* is the matrix of sums of squares and cross products.

Homogeneity checks using the L-moment approach as proposed by Hosking & Wallis (1993), which were also adopted by Burn & Goel (2000), are based on Monte Carlo simulation. The L-moment ratios t^R , t_3^R and t_4^R for the proposed region are calculated as the sample means weighted proportionally to the record length, *l*, of *i* sites. It follows that *V*, the weighted standard deviation of the at-site sample L-CVs (t_i), is given by:

$$V = \left[\sum_{i=1}^{N} l_i \left(t_i - t^R\right)^2 / \sum_{i=1}^{N} l_i \right]^{1/2} . \tag{2}$$

A homogeneity statistic, *H* is obtained from the simulation of a large number of realizations for a region with *N* sites, with μ_V and σ_V as the mean and standard deviation, respectively, of simulated *V*s:

$$H = \frac{\left(V - \mu_V\right)}{\sigma_V} . \tag{3}$$

Hosking & Wallis (1997) suggested that a region is considered to be "acceptably homogeneous" if $H<1$, "possibly heterogeneous" if $1 \leq H \leq 2$, and "definitely heterogeneous" if $H \geq 2$. For each of the proposed regions, a Kappa distribution with its parameters derived from the fitting of the distribution to the regional average L-moment ratios is used to simulate some large number N_{sim} of realisations for the same region. For each *m*-th simulated region, the regional average L-kurtosis t_4^m is calculated. Typical three parameter distributions are fitted to the sample regional L-moment ratios. For each fitted distribution, the corresponding L-kurtosis, τ_4^{Dist} , is found. The goodness-of-fit measure for each distribution is given by:

$$Z^{Dist} = \left(\tau_4^{Dist} - t_4^R + B_4\right) / \sigma_4 \tag{4}$$

where B_4 is the bias of t_4^R and σ_4 is the standard deviation of t_4^R . A distribution could be declared as fitting satisfactorily if $|z^{Dist}| \leq 1.64$ (Hosking & Wallis, 1993).

4. Results and discussion

In this study, regional frequency estimation was made by considering all of the stations in the region. The annual maximum peak flood data of the 9 gauging stations are available. The first step of the regional frequency analysis was the identification of the homogeneous regions. Initially the Bulgarian South Black Sea basin as a whole was assumed as a hydrometric homogeneous region. Screening of the data has been carried out using the discordance measure, D_i. Homogeneity of the region has been tested using the heterogeneity measure, *H*. Goodness of fit has been tested using the L-moment ratio diagram (*LMRs*) as well as Z^{Dist} statistic for identifying the robust distribution.

The objective of the discordance measure (D_i) test is to identify those sites from a group of given sites that are grossly discordant with the group as a whole. Discordance measure has been computed in terms of the L-moments of the data for all the 9 gauging stations of the study basin and the same are given in Table 1. Generally any site with $D_i>3$ can be regarded as discordant. It is observed from Table 1 that the D_i values for all the 9 sites are less than the critical value. Hence, as per the discordance measure test, none of the 9 sites is regarded as a discordant site.

Table 1. D_i values for the gauging stations of the South Black Sea basin in Bulgaria

Gauging stations	Sample size (years)	D_i value
Kameno	39	0.97
Prohod	41	0.61
Fakiya	42	1.12
Zidarovo	42	1.05
Veselie	41	1.23
Zvezdets	41	0.80
Gramatikovo	42	0.28
Svetlina	44	0.92
Razhitsa	28	2.02

The heterogeneity measure (*H*) estimate the degree of heterogeneity in a group of sites and to determine whether or not it is reasonable to treat the sites as a homogeneous region. Three heterogeneity statistics can be employed to test the variability of three different *L*-statistics: *H* for *L-cv*; H_2 for the combination of *L-cv* and *L-skewness*, and H_3 for the combination of *L-kurtosis* and *L-skewness*. To establish what would be the expected inter-site variation of L-moment ratios for a homogeneous region, 500 simulations were carried out for computing the heterogeneity measure *H*, using the four parameter Kappa distribution.

Kappa distribution includes as special cases the GLO, GEV and GPA distributions and it is capable of representing many of the distributions. A region is suggested to be "acceptably homogeneous" if $H<1$, "possibly heterogeneous" if $1\leq H<2$, and "definitely heterogeneous" if $H\geq 2$. A group of sites must therefore have $H<2$ to be considered as a possibly homogeneous region. The values of heterogeneity measure computed for the South Black Sea basin in Bulgaria using the data of 9 sites are given in Table 2. As can be seen from the table, the study region was identified as homogenous region.

After confirming the homogeneity of the study region, an appropriate distribution needs to be selected for the regional frequency analysis. In other words, in a homogeneous region all sites should have the same population L-moments. The selection was carried out by comparing the moments of the candidate distributions to the average moments statistics derived from the regional data. All distributions whose absolute Z^{Dist} value is less than 1.64 qualified as a possible candidate, with the lowest value qualifying for the best fit distribution.

The findings of the goodness-of-fit measures for 500 simulation times are given in Table 3. It can be seen that the generalized logistic, generalized extreme value, generalized normal distributions providing the bound $|Z^{Dist}|\leq 1.64$. Because Z^{Dist} value of the generalized logistic

Table 2. The Processes of Heterogeneity Measures for 500 Simulation Times

Heterogeneity Measures	Values
Observed S.D. of Group *L*-Cv	0.0672
Simulated Mean of S.D. of Group *L*-Cv	0.0630
Simulated S.D. of S.D. of Group *L*-Cv	0.0195
Standardized Test Value H (1)	0.2100
Observed Ave. of *L*-Cv/*L*-skewness Distance	0.1457
Simulated Mean of Ave. *L*-Cv/*L*-skewness Distance	0.1063
Simulated S.D. of Ave. *L*-Cv/*L*-skewness Distance	0.0279
Standardized Test Value H (2)	1.4100
Observed Ave. of *L*-skewness / *L*-kurtosis Distance	0.2023
Simulated Mean of Ave. *L*-skewness / *L*-kurtosis Distance	0.1341
Simulated S.D. of Ave. *L*-skewness / *L*-kurtosis Distance	0.0368
Standardized Test Value H (3)	1.8500

distribution is -0.29 and this is quite close to zero, it can be said that generalized logistic is the most suitable distribution for annual maximum discharges of the South Black Sea basin.

Table 3. Goodness-of-fit Measures for 500 Simulation Times

Distribution	L-Kurtosis	Z^{Dist}
Generalized logistic	0.344	-0.29 **
Generalized extreme value	0.332	-0.57 **
Generalized normal	0.293	-1.48 **
Pearson type III	0.225	-3.02
Generalized pareto	0.280	-1.77

** Suitable distributions.

The Generalized Logistic distribution (GLO) was selected as appropriate for the entire Bulgarian South Black Sea basin. The form of the regional frequency relationship for GLO distribution is expressed as:

$$Q_T / Q_m = \xi + \alpha y_T \quad (5)$$

where $$y_T = [1 - \{(1-F)/F\}^{\kappa}]/\kappa . \quad (6)$$

Here, Q_T is T-year return period flood estimate, Q_m is the mean maximum discharge, ζ, α and κ are the parameters of the GLO distribution, F is the annual nonexceedance probability, 1 –exceedance probability, or [1–(1/T)], where T is recurrence interval and Y_T is the GLO reduced variate corresponding to T-year return period. The parameter estimation for suitable distributions and Wakeby distribution which is independent of the goodness-of-fit measure was given in Table 4.

Table 4. Regional parameters for the various distributions

Distribution	Regional Weighted Parameters				
	ζ	α	κ	γ	δ
Generalized logistic distribution	0.639	0.361	-0.462		
Generalized extreme value distribution	0.456	0.435	-0.410		
Generalized normal distribution	0.602	0.615	-0.998		
Wakeby distribution	0.024	0.662	2.032	0.455	0.399

The next step in regional flood frequency is to estimate flood quantiles in the region. In this paper flood quantiles for each distribution is presented at the 90 percent level (Table. 5).

Table 5. Values of growth factors for Bulgarian South Black Sea basin

Distribution	Return period (years)				
	2	10	20	100	1000
	Growth factors/Quantile estimates				
Generalized logistic	0.639	2.014	2.902	6.383	18.836
Generalized extreme value	0.628	2.065	2.981	6.388	17.386
Generalized normal	0.602	2.201	3.170	6.275	13.471
Wakeby	0.634	2.065	2.979	6.379	17.195

For estimation of T-year return period flood at a site, the estimate for mean annual peak flood is required. For ungauged catchments at-site mean can not be computed in absence of .the observed flow data. In such a situation, a relationship between the mean annual peak flood of gauged catchments in the region and their pertinent physiographic and climatic characteristics is needed for estimation of the mean annual peak flood.

5. Conclusion

Using the method of L-moments was established the following: as per the discordance measure test, none of the 9 sites is regarded as a discordant site; the study region was identified as homogenous region; the possible distribution types identified by the Z-statistic are Generalized Logistic, Generalized Extreme Value and Generalized Normal; the most suitable distribution for annual maximum flood discharges of the Bulgarian South Black Sea basin is the generalized logistic; the regional parameters for suitable distributions were estimated; the flood quantiles for different return periods were obtained which is especially useful for water resources planning, design, and management in ungauged watersheds.

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РЕГИОНАЛЕН ЧЕСТОТЕН АНАЛИЗ НА МАКСИМАЛНИЯ ОТТОК В РЕКИТЕ НА ЮГОИЗТОЧНА ЧАСТ НА БЪЛГАРИЯ

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Ключови думи: *L-моменти, обобщено логистично разпределение*

Научна област: *хидравлика и хидрология*

РЕЗЮМЕ

Максималният отток е екстремно състояние на речните течения, което е резултат от протичащите процеси във водосборните басейни при проявата на съответни валежни обстановки. Поради естеството на формиране и развитие на максималния отток се прилагат вероятностни подходи, които позволяват оценка на ефектите на явленията и вземане на решения. Един от тези подходи е регионалният честотен анализ, който в последните години се прилага интензивно в много страни по света. Предимството му се състои в това, че в повечето случаи решава проблема с оценката на честотата на редки явления при липсата на достатъчно дълга редица и позволява получаването на надеждни резултати, необходими при изграждането на хидротехнически съоръжения. Изследванията върху максималния речен отток и разработването на методи за оценки на вероятностите за възникването му имат голямото икономическо и екологично значение, особено за райони с оскъдна хидроложка информация, какъвто е районът на югоизточна България. Целта на настоящото изследване е на базата на многогодишни данни за поречията от Южното Черноморие да се разработи модел за регионален честотен анализ на максималния отток по метода на L-моментите. С помощта на статистическите критерии за несъответствие и хетерогенност е установено, че поречията на Южното Черноморие формират възможно хомогенен район. Като подходящо за описване на максималните водни количества в изследвания район е определено обобщеното логистично разпределение.

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