

## Statistical analysis of excess water on drainage systems in the northern part of Serbia

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**Abstract:** Drainage systems in Serbia are mainly designed to evacuate excess water generated in the winter-spring period, which occurs as a result of snow accumulation during the long and wet winter and its sudden melting with the parallel appearance of spring rains. Dimensioning of the drainage system is done in such a way as to satisfy the needs of draining the design excess water, which is usually calculated using the water balance. Applying statistical analysis based on distributions of probability, the results of the future occurrence of excess water can be predicted. The paper tests the distribution that best corresponds to the empirical distribution of excess water obtained by applying the water balance. The Kolmogorov-Smirnov, Anderson-Darling, and  $\chi^2$  tests were used to test a number of theoretical distributions, and basis on those tests Generalized Extreme Value (GEV) distribution was selected, which is often used in hydrological analyzes. The probabilities of excess water on drainage systems for the return period of 5, 10, 50, and 100 years were obtained. The results of the calculations can be used in the reconstruction of existing drainage systems, since most of them were designed more than 50 years ago, or in the planning and design of new drainage systems.

**Keywords:** Excess water, drainage systems, statistical analysis

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### Introduction

Drainage systems in the northern part of Serbia, Vojvodina were in most cases designed or revitalized in the 70s and 80s of the XX century. Even though the systems were designed to evacuate excess water with an occurrence probability once every 5 to 20 years, it has often been the case lately that systems were unable to respond effectively to excess water that has been occurring. According to previous research by Belić and Savić (2005), on an area of 77% of drained areas, excess water, which is being evacuated by pumping stations into the recipient, comes from climatic factors. In Vojvodina, the systems are mainly designed to evacuate excess water generated during the winter-spring period, which occurs as a result of

snow accumulation during the long, cold and wet winter, and its sudden melting, with the parallel appearance of spring rains. The dimensioning of the drainage system is performed in such a way that the need of draining the design excess water is satisfied. It should be emphasized that the average excess water that occurs in a certain area in the winter-spring period is not an appropriate value for dimensioning, but the systems are dimensioned based on the design excess water that occurs in that period and must be evacuated in optimal time frames to avoid the delay in agricultural production (Helmert et al., 2012). This design excess water is usually calculated using the water balance. In water balancing, i.e. when the excess water in an area is being estimated, the most commonly used form of the water balance equa-

tion is the simplest one, in which the revenue component is precipitation and the expenditure evapotranspiration (Thornthwaite, 1948). As an indicator of soil moisture conditions, reserves in the soil depend on the water-physical properties of the soil and are determined for specific conditions, usually taking into account a layer 1 m deep; however, the maximum water reserves should be determined for a certain land, in order to obtain realistic values that we strive for when designing a drainage system. In order for statistical analyzes of the excess water occurrence on drainage systems to be relevant, it is necessary for the sequence to be at least 30 years long, after which a certain conclusion is reached (Gregorić, 2009). Probability distributions can also be the basis of statistical inference. The conditions in which excess water is formed are covered by the laws of theoretical distribution itself, which adapts to the nature and character of the observed phenomenon. When data representing the empirical distribution are available, it is not possible to assume with which theoretical probability distribution a random variable could correlate. The aim of this research is to be able to reliably predict the results of future events based on empirical probability distributions, which can be achieved by "distribution fitting," that is by finding a theoretical distribution function that corresponds to the sample data, then testing the selected theoretical distribution, on the basis of which the probabilities of events that are not otherwise represented in the sample can be determined (Adams et al., 1986). In this way, we can obtain the probabilities of the occurrence of the relevant excess water on the drainage systems for different return periods.

### Materials and Methods

In order for drainage systems to be reliable (well designed) and for exploitation to be efficient, it is necessary to precisely define the

relevant amount of water that is evacuated from the drainage system. Excess water is calculated using water balance factors (precipitation, evapotranspiration, and soil water reserves) of a certain occurrence's frequency. The proposed methodology for determining the relevant excess water is shown in Figure 1.

The precipitation used was taken from the meteorological yearbooks of the Hydrometeorological Institute of the Republic of Serbia for the period from 1971 to 2021 for eight climatological observation stations (Belgrade, Rimski Šančevi, Palić, Sombor, Sremska Mitrovica, Vršac and Zrenjanin). Evapotranspiration was calculated according to the Thornthwaite method. The fields of influence of climatological stations by area were determined via Thiessen polygons and it has been adopted that the data valid on them were calculated for the water balance of the soil for each polygon of the pedological map, based on data from the corresponding meteorological station, for the multianual period from 1971 to 2021. The water reserve in the soil was calculated for each polygon of the digital pedological map, and it was obtained as a product of the depth of the solum and available water. Available water is the difference between the field water capacity and the wilting point. In the area of Vojvodina, the quantities of potential water reserves in the soil range from 10 mm to 150 mm, which is why the water balance is calculated with 10, 50, 100, and 150 mm as critical values.

Following the proposed methodology for determining the design excess water, the next step involves statistical analysis, i.e. calculating the empirical probabilities of the certain excess water occurrence in the non-vegetation period. The non-vegetation period was adopted as the period in which the winter-spring excess water should be evacuated in order for the optimal time frames required by agricultural production to be met.

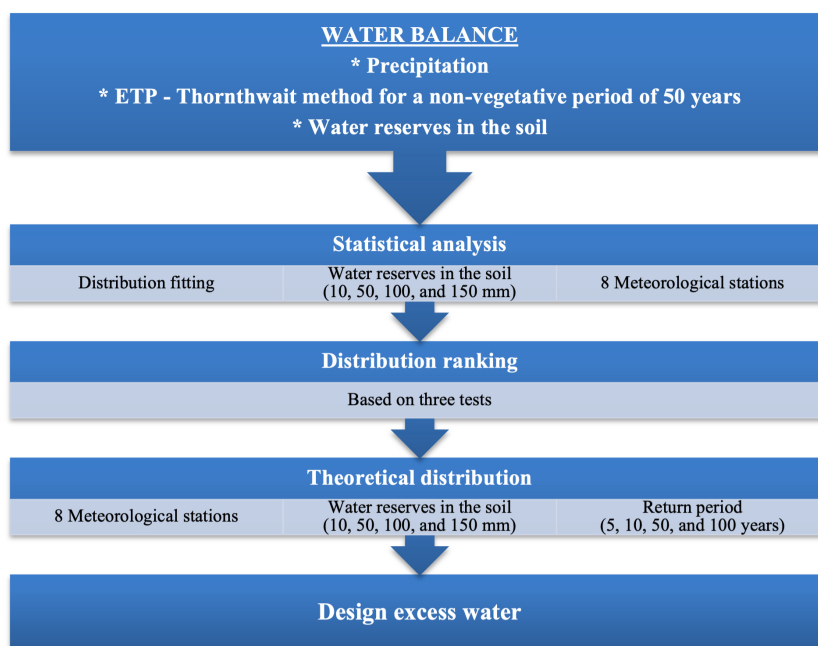


Figure 1: Methodology for determining the design excess water for certain return periods

Table 1: Testing theoretical distribution

Theoretical distributions		
Beta	Gumbel Max	Pareto 2
Burr	Gumbel Min	Pearson 5
Cauchy	Hypersecant	Pearson 6
Chi-Squared	Inv. Gaussian	Pert
Dagum	Johnson SB	Phased Bi-Exponential
Erlang	Johnson SU	Phased Bi-Weibull
Error	Kumaraswamy	Power Function
Error Function	Laplace	Rayleigh
Exponential	Levy	Reciprocal
Exponential (2P)	Log-Gamma	Rice
Fatigue Life	Logistic	Student's t
Frechet	Log-Logistic	Triangular/
Gamma	Lognormal	Uniform
Gen. Extreme Value	Log-Pearson 3	Wakeby
Gen. Gamma	Nakagami	Weibull
Gen. Logistic	Normal	
Gen. Pareto	Pareto	

In order to find the theoretical distribution that most closely matches the calculated values of excess water, the correlation of empirical distributions with the theoretical ones was tested. Table 1 show the 49 theoretical distributions used in this analysis for all values of soil water reserves (from 10 to 150 mm) and eight meteorological stations (Bel-

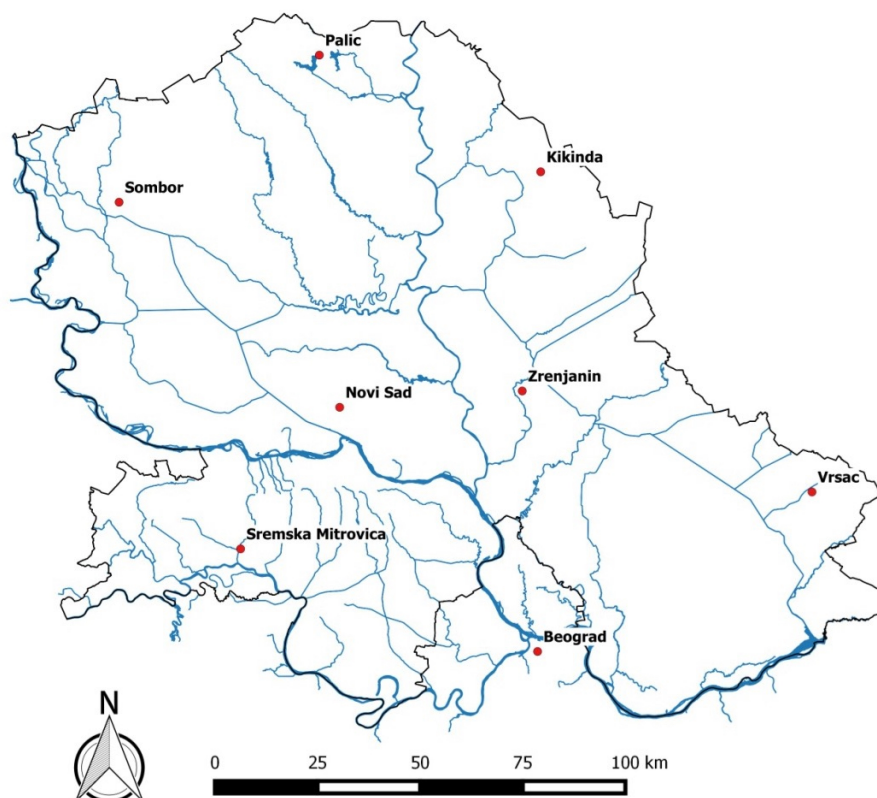


Figure 2: Meteorological stations in Vojvodina, Serbia

grade, Rimski Šančevi, Palić, Sombor, Sremska Mitrovica, Vršac, and Zrenjanin) which are presented in Figure 2.

Finding the theoretical distribution function, which corresponds to the data from the sample, was tested using Chi-square ( $\chi^2$ ) test, Kolmogorov-Smirnov test, and Anderson-Darling test. For the significance threshold  $\alpha = 0.05$ , there is correspondence for 25 theoretical distributions with empirical values. Other distributions did not show satisfactory correspondence. Based on the three tests, for each solum depth and for each meteorological station, the theoretical distributions were ranked according to the corresponding match with the empirical distribution. According to all three tests, the ranks were summarized and the theoretical distribution with the lowest sum of ranks should be selected because it represents the distribution that most closely matches the empirical distributions of excess water values.

After the selected theoretical distribution, for all values of water reserves in the soil and all eight meteorological stations, the relevant excess water is determined. This excess water is directly related to the dimensions of all facilities on the drainage system. The dimensioning of the system is then reduced to determining the relevant length of the return period. The length of the return period is expressed by the amount of water that needs to be removed from the system and is determined by the time in which the excess is removed from the system. When calculating any part of the system, "economic values" are taken into account, i.e. a solution is sought that would minimize damage or optimize flooding time. The technical optimization implies the selection of the minimum capacity for evacuation of the design excess water, which is a prerequisite for minimizing investments, as well as maintenance and operation costs. In this research, the calculation

Table 2: Example of the performed water balance for the hydrological year 2009/2010 for meteorological station Rimski Šančevi

09/10	10	11	12	1	2	3	4	5	6	7	8	9
P	82	63	97	76	66	39	64	114	172	99	169	68
ETP	41	21	6	0	3	23	56	98	126	152	130	75
P-ETP	41	42	91	76	62	15	7	15	46	-53	38	-7
Reserve	41	82	100	100	100	100	100	100	100	47	85	78
ETR	41	21	6	0	3	23	56	98	126	152	130	75
Deficit	0	0	0	0	0	0	0	0	0	0	0	0
Excess water	0	0	74	76	62	15	7	15	46	0	0	0
	Non-vegetation period						Vegetation period					
Deficit sum	0						0					
Excess w. sum	227						69					

of the design excess water was conducted for a return period of 5, 10, 50, and 100 years.

## Results

The calculated water balance for the period from 1971 to 2021 for eight observation climatological stations is divided in order to obtain winter-spring excess water for the non-vegetation period and the vegetation period. The example presented in Table 2 shows the procedure for obtaining excess water. The amounts of excess water in the non-vegetation period for the observed period represented the empirical distribution, which was then "fitted" with 49 theoretical distributions used in this analysis for all values of soil water reserves (from 10 to 150 mm) and eight meteorological stations.

In order to examine the extent to which the group of observed frequencies coincides with the theoretical distribution, matching tests are performed between the theoretical distribution in the general population and the empirical frequency distribution in the sample extracted from that general population. The tests most commonly used to test the good fit between the theoretical and empirical frequency distribution in a sample are

the Chi-square ( $\chi^2$ ) test, the Kolmogorov-Smirnov test, and the Anderson-Darling test, which were used in this paper as well.

The three first-ranked distributions that best correspond to the empirical distributions of excess water values in Vojvodina are the four-parameter Johnson SB distribution, the three-parameter Generalized Extreme-Value distribution (GEV), and the two-parameter normal distribution (Normal). The Generalized Extreme-Value distribution, although ranked second, was selected as the theoretical distribution for calculating the probability of the occurrence of corresponding excess water in the non-vegetation period, due to its application in hydrology and simpler calculation compared to Johnson's SB distribution (has fewer parameters). GEV distribution has great application in hydrology, especially in the analysis of extreme hydrological phenomena such as floods, high water levels, annual flows, annual precipitation amounts, etc. (Martins & Stedinger, 2000; Li & Chen, 1990).

Bearing in mind that the return period is directly related to the economic power of land users, realized yields and revenues, defining it is a technical problem chosen based on the economic criteria. Therefore, using three-parameter GEV distribution, excess water

Table 3: Five-year excess water in the non-vegetation period

Meteorological Station	Water reserves in the soil (mm)			
	10	50	100	150
	Excess water (mm)			
Beograd	258	218	163	103
Kikinda	190	150	93	30
Palić	199	159	103	44
Rimski Šančevi	225	185	130	69
Sombor	215	175	121	60
Sremska Mitrovica	211	171	117	57
Vršac	227	186	130	67
Zrenjanin	204	163	105	42

Table 4: Ten-year excess water in the non-vegetation period

Meteorological Station	Water reserves in the soil (mm)			
	10	50	100	150
	Excess water (mm)			
Beograd	293	253	201	143
Kikinda	219	178	124	53
Palić	231	191	137	71
Rimski Šančevi	255	215	163	102
Sombor	243	203	152	90
Sremska Mitrovica	233	193	142	83
Vršac	265	224	170	105
Zrenjanin	241	200	144	71

Table 5: Fifty-year excess water in the non-vegetation period

Meteorological Station	Water reserves in the soil (mm)			
	10	50	100	150
	Excess water (mm)			
Beograd	349	309	272	244
Kikinda	268	228	195	146
Palić	289	249	213	167
Rimski Šančevi	303	263	227	196
Sombor	288	248	209	177
Sremska Mitrovica	267	227	185	154
Vršac	334	295	259	226
Zrenjanin	312	274	242	191

was calculated separately for five-year, ten-year, fifty-year, and hundred-year return pe-

riods, for all analyzed meteorological stations, and for all values of soil water reserves

Table 6: Hundred-year excess water in the non-vegetation period

Meteorological Station	Water reserves in the soil (mm)			
	10	50	100	150
	Excess water (mm)			
Beograd	366	326	297	293
Kikinda	284	245	227	215
Palić	310	270	246	230
Rimski Šančevi	318	278	250	247
Sombor	302	262	230	224
Sremska Mitrovica	276	236	200	190
Vršac	358	321	297	299
Zrenjanin	339	303	288	280

in the analyzed area ranging from 10 to 150 mm. The results are shown in Tables 3, 4, 5, and 6.

Existing drainage systems are mainly sized to meet the needs of draining the design excess water in the non-vegetation period, 10% frequency or a 10 years return period, and for this excess water the operation of the aggregates in pumping stations is 35–40 days or 840–960 hours (Belić & Stojšić, 1985). This data is of key importance in sizing new or reconstructing and adapting existing drainage systems, because it indicates a tendency of an increased frequency of years with extreme values of excess water in the non-vegetation period and in the vegetation period.

## Discussion

After water balancing in the forty-year period, statistical data processing was performed to determine the theoretical distribution of the probability of occurrence. The testing of theoretical and empirical distributions of excess water based on soil water reserve (from 10 to 150 mm) and eight meteorological stations was performed. The adopted three-parameter Generalized Extreme-Value distribution (GEV) was used to obtain relevant excess water for the prob-

ability of occurrence of 20%, 10%, 2%, and 1%, i.e. for return periods of 5, 10, 50, and 100 years. The obtained excess water ranged from 30–258 mm for a return period of 5 years, 53–293 mm for a return period of 10 years, 146–349 mm for a return period of 50 years, and 190–366 mm for a return period of 100 years. These results indicate that the zone of aeration can receive wide ranges of excess water of different frequency occurrences depending on the type of soil and its water-air characteristics.

The global analysis that has been conducted can serve as a basis, not only for detailed analyzes of increasing the efficiency of individual drainage systems but also for solving many other problems that overlap with the problem of creating, draining, and evacuating excess water. All this points to the fact, that a seemingly complex methodology can be easily applied in engineering practice to drainage systems that require increased efficiency.

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