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# 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 (Helmers 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 equation 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 multiannual 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.


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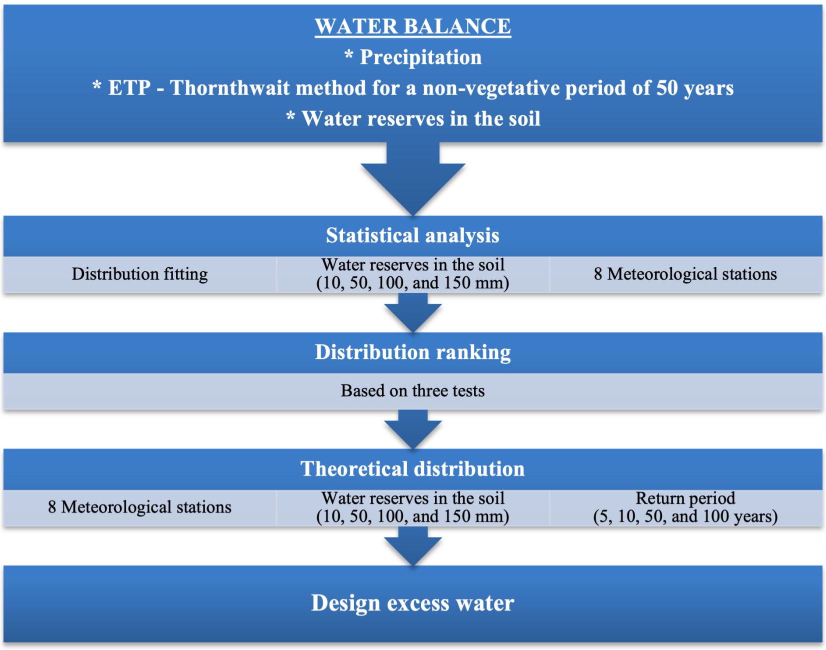


Figure 1: Methodology for determining the design excess water for certain return periods

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-

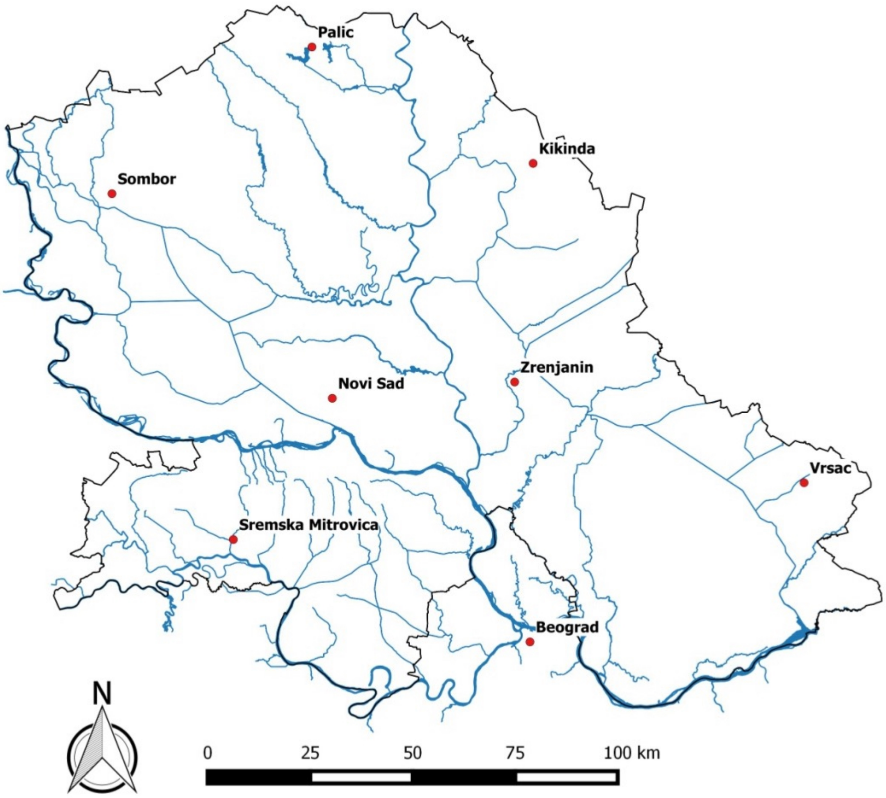


Figure 2: Meteorological stations in Vojvodina, Serbia

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, ie. 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


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

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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 probability 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.

## Acknowledgements

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Gallo-Roman harvesting machine, called Vallus. Source: U. Troitzsch - W. Weber (1987): Die Technik : Von den Anfangen bis zur Gegenwart

*Rear cover:*
Portrait of Columella, in Jean de Tournes, Insignium aliquot virorum icones. Lugduni: Apud Ioan. Tornaesium 1559. Centre d'Études Supérieures de la Renaissance - Tours

### HORVÁTH Ákos, editor-in-chief

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### Lucius Junius Moderatus Columella

(AD 4 – 70) is the most important writer on agriculture of the Roman empire. His De Re Rustica in twelve volumes has been completely preserved and forms an important source on agriculture. This book was translated to many languages and used as a basic work in agricultural education until the end of the 19$^{th}$ Century.