Hydrological forecasts of average, low and high waters in the Gaberska River Basin

Mrđan Đokić[1], Nenad Živković[2], Ninoslav Golubović[1], Milena Nikolić[1], Ranko Dragović[1]

[1] *University of Niš, Faculty of Sciences and Mathematics, Department of Geography*
[2] *University of Belgrade, Faculty of Geography*

Abstract: Gaberska River is distinguished by its torrential character, which is conditioned by the geological structure of the basin, degraded forest cover, unregulated course of the main river and its tributaries and others. In this paper, the quantification of the average, minimal and maximal annual discharges was done, as well as the forecast of the probability of their occurrence based on forty-four-year measurements. The Log Pearson III distribution method was used, and the return period of the occurrence of discharges expressed in years was determined, i.e., the probability of occurrence was expressed in percentages. The results confirmed the torrential character of the Gaberska River and great fluctuations in discharges during the research period. The measures for mitigation of high and low waters have been proposed.

Key words: Gaberska River, discharge, hydrological forecasts, Log-Pearson III

1. Introduction

The Gaberska River Basin covers the border area of the Republic of Serbia and the Republic of Bulgaria, limited by the basins of the Jerma River in the west, Ežovica River in the east and the Slivniška River in the southeast. The Gaberska River is the left tributary of the Nišava River, and by the length of 40.51 km, the basin area of 249.2 km^2, is its most important tributary upstream from the confluence of the Jerma River.

Average discharge of the Gaberska River in the period from 1964 to 2007 was 1.06 m^3/s, which gave the runoff of 4.25 l/s/km^2. This value is the lowest compared to other major tributaries of the Nišava River, including the Nišava River itself, which has an average runoff of 7.09 l/s/ km^2 (Djokić, 2015). Such low value is more surprising considering that the water richness, expressed through runoff, generally increases upstream (Dukić, Gavrilović, 2008). In the case of the Gaberska River, the runoff is low considering the low average altitude of the basin area of 742 m (which is lower value even compared to the average altitude of the Nišava River Basin - 813 m), and in this regard, also the small amount of precipitation. Eastern position of the Gaberska River Basin within the Nišava River Basin also affects the reduced amount of precipitation, and the human impact through irrigation should not be ignored.

Few authors have done the research of the hydrological characteristics of this river basin so far. The torrential character of the Gaberska River was pointed out by Djokić M. (2015) and explained, before all, by a geological assembly of the terrain that was composed mainly of impermeable rocks and which was characterized by low capacity of groundwater, mainly degraded forest cover, unregulated river courses and steep inclines of the tributaries.

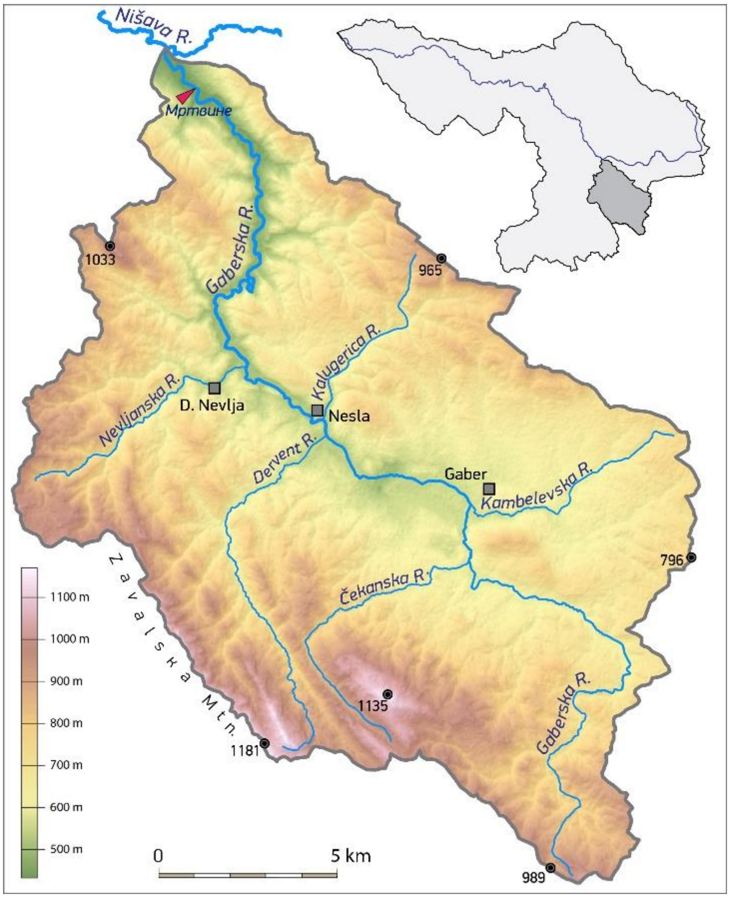

Figure 1 – Gaberska River Basin and its location within the Nišava River Basin

The aim of this paper will be the quantification of the average, minimal and maximal annual discharges and the forecast of the probability of their occurrence, which will facilitate the water management planning in the Gaberska River Basin.

2. Material and method

River discharges depend on a huge number of various factors and are subject to the laws of coincidences, so they can be studied by the use of the statistical methods (Gavrilović, 1988). Assessment of the size of discharges which can be expected in the future on a certain hydrological profile, can be given on the basis of the value of the discharges that have already occurred. In other words, it is necessary to determine the return period of occurrence of a discharge, expressed in years, i.e., the probability of its occurrence, expressed as a percentage.

In order to make a reliable estimate of the discharges, it is necessary to take into account a longer series of data. This paper analyses the data on the average annual, minimal and maximal annual discharges for the period from 1964 to 2007, which were measured at the hydrological station of Mrtvine, near the confluence of the Gaberska River in the Nišava River. Among many statistical methods for forecasting the size of the discharges, the Log Pearson III distribution is often used. This distribution is widely applied and used in a number of hydrological studies (Bob, 1975; Wallis, Wood 1985, Gavrilović, 1988; Milanović, 2006; Griffis, Stedinger, 2007; Djokić, 2010; Bolgov, Korobkina, 2013; Vasilevski, Radevski 2014). It was even recommended by the US Water Resources Council (WRC).

The process of the discharge forecasting firstly involves the calculation of the average value of the discharges for the given period, or Q_{av}. After that, the module coefficient *k* is calculated for each value of the annual discharge, by dividing with the average value of the entire series, or $k = \frac{Q}{Q_{sr}}$.

The coefficient of variation of the discharges which places in relation the average deviation and the arithmetical mean of the series of measurements, as well as asymmetry coefficient are calculated in further method procedure.

To avoid getting negative values of the discharges, it is often assumed that $C_s=2C_v$, which is applied on this occasion as well. In the table of Ribikin (Gavrilović, 1988), for each value of the asymmetry coefficient is given a deviation of the ordinate of the binominal asymmetric curve of provision from the average at C_v=1 (ø), and the parameters for design of the curve of provision from the average annual discharges are calculated (Gavrilović, 1988). The result is the estimation of the probability of the discharge occurrence, expressed as a percentage from 0.01% to 99.9%, as well as an assessment of the discharge occurrence expressed in years, from one year (discharge can be expected each year) to 10,000 (discharge is expected once in 10,000 years).

Table 1 – Parameters for calculating the curve of provision of the average annual discharges and the probability of the occurrence of the average annual discharges of the Gaberska River in Mrtvine

Probability (%)	Probability (years)	ø	ø·C_v	K_s = ø·C_v+1	$Q_{av.}$ (m^3/s)
0.01	10,000	5.62	2.44	3.44	3.64
0.1	1,000	4.31	1.87	2.87	3.04
1	100	2.92	1.27	2.27	2.40
3	33.3	2.2	0.95	1.95	2.07
5	20	1.85	0.80	1.80	1.91
10	10	1.34	0.58	1.58	1.68
20	5	0.78	0.34	1.34	1.42
25	4	0.58	0.25	1.25	1.33
30	3.3	0.4	0.17	1.17	1.24
40	2.5	0.12	0.05	1.05	1.12
50	2	-0.14	-0.06	0.94	1.00
60	1.67	-0.38	-0.16	0.84	0.89
70	1.42	-0.6	-0.26	0.74	0.78
75	1.33	-0.73	-0.32	0.68	0.72
80	1.25	-0.86	-0.37	0.63	0.66
90	1.11	-1.16	-0.50	0.50	0.53
95	1.05	-1.35	-0.59	0.41	0.44
99	1.01	-1.7	-0.74	0.26	0.28
99.9	1,001	-1.96	-0.85	0.16	0.16

ø – deviation of the ordinate of the binominal asymmetric curve of provision from the average at C_v=1, $\mathbf{C_v}$ – coefficient of variation of the average annual discharges, $\mathbf{K_s}$ – module coefficient of the ordinate, $\mathbf{Q_{av.}}$ **–** average discharge for the given occurrence probability

As an example for the procedure, Table 1 shows all the parameters for the estimation of the average annual discharges of the Gaberska River in Mrtvine. Table 2 shows only the estimated minimal and maximal discharges. The presented method can be also applied to determine the probability of a discharge occurrence on a monthly basis.

3. Results

Once every 10,000 years, the average annual discharge of 3.64 m^3/s of the Gaberska River can be expected, once in 1,000 years of 3.04 m^3/s and once in 100 years of 2.4 m^3/. Only once in 10,000 years, the average annual discharge could be below 0.16 m^3/s. The lowest measured value of the average annual discharge was 0.33 m^3/s, and was recorded during the least water richness year of 1993. The highest average annual discharge was recorded in 1976 and amounted to 2.03 m^3/s, and the probability of its occurrence is slightly higher than 3%, or once in 33 years.

The average annual discharge of the Gaberska River at Mrtvine is 1.06 m^3/s, and at least that same discharge can be expected, with a probability of about 48%, which is exactly what happened for twenty two of the forty-four-year study period. The coefficient of variation of the average annual discharges of the Gaberska River at Mrtvine is 0.43.

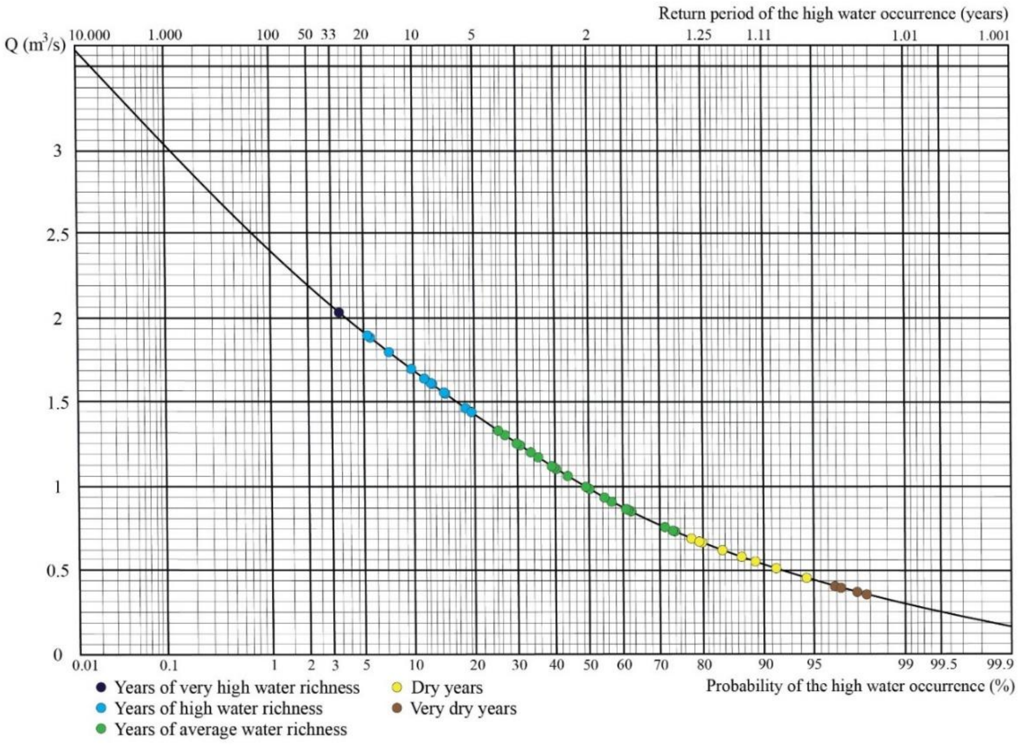

Figure 2 – Curve of the occurrence probability of the average annual discharges of the Gaberska River in Mrtvine

In the period from 1964 to 2007, the average value of the minimal annual discharges of the Gaberska River at Mrtvine amounted to 0.21 m^3/s. Every year we can expect a discharge of at least 0.005 m^3/s, and every other year of at least 0.14 m^3/s. The highest minimal discharge was recorded in 1981, the fourth year in regard to water richness in the research period, and amounted to 1.18 m^3/s. The lowest recorded discharge during the period covered by the researches is 0.023 m^3/s, during the least water richness year of 1993 (July 21st).

Table 2 – Occurrence probability of the minimal and maximal discharges of the Gaberska River in Mrtvine, in m^3/s

Probability (%)	Probability (years)	$Q_{min.}$	$Q_{max.}$
0.01	10,000	1.97	229.9
0.1	1,000	1.51	176.0
1	100	0.99	119.5
3	33.3	0.75	92.6
5	20	0.64	79.6
10	10	0.49	62.5
20	5	0.34	44.9
25	4	0.29	38.9
30	3.3	0.25	34.3
40	2.5	0.19	26.7
50	2	0.14	21.0
60	1.67	0.10	15.9
70	1.42	0.07	11.7
75	1.33	0.06	9.6
80	1.25	0.05	7.6
90	1.11	0.02	4.2
95	1.05	0.014	2.4
99	1.01	0.007	0.8
99.9	1	0.005	0.3

Coefficient of variation of the minimal annual discharges of the Gaberska River at Mrtvine is 1.02, which is very high value.

The average value of maximal annual discharges of the Gaberska River in Mrtvine is of 28.3 m^3/s. In the period covered by the research, the maximal discharge was recorded on July 1st, 1983. This year is otherwise characterized by an average water richness. At that time, through a riverbed of the Gaberska River, 104 m^3/s was discharged. The probability of the occurrence of so much discharge is about once in 60 years.

The minimal value of the maximal annual discharge is 3.19 m^3/s and was recorded in a dry year of 1990. Once every 10,000 years a discharge of 229.9 m^3/s can be expected at Mrtvine, and every other year, the maximal discharge of at least 21 m^3/s. The coefficient of variation of the maximal annual discharges of the Gaberska River in Mrtvine is high - 0.92.

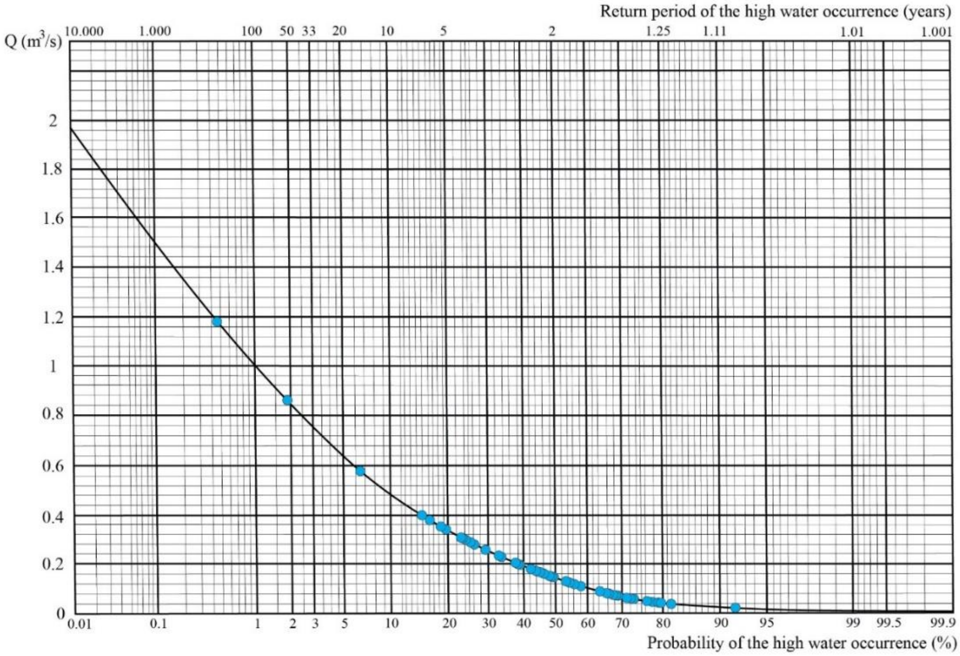

Figure 3 – Curve of the occurrence probability of the minimal annual discharges of the Gaberska River in Mrtvine

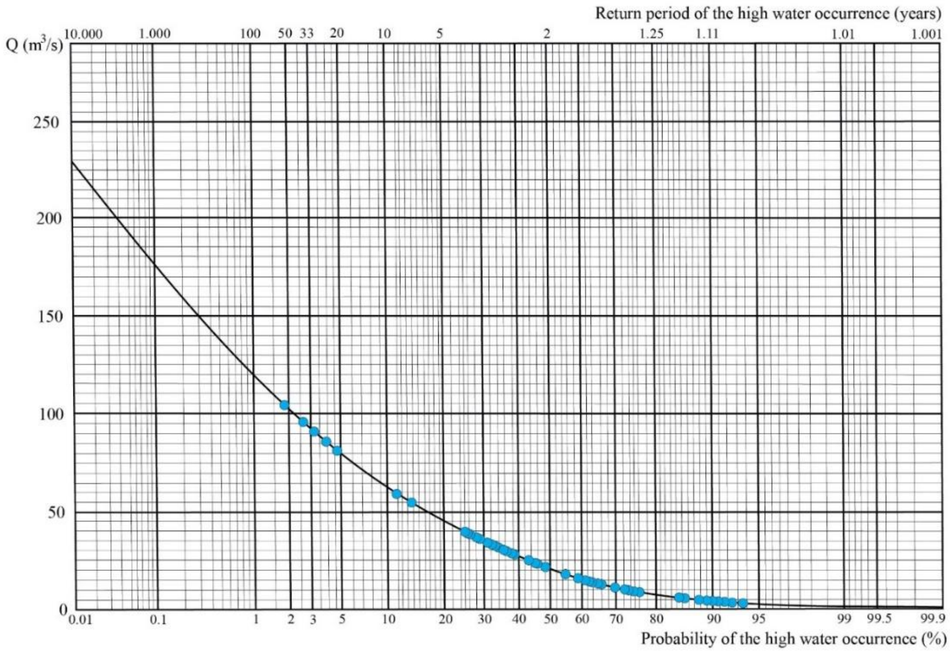

Figure 4 – Curve of the occurrence probability of the maximal annual discharges of the Gaberska River in Mrtvine

4. Discussion

Gaberska river is of a torrential river course, as confirmed by the Log-Pearson III distribution. The coefficient of variation of the average annual discharges is 0.43, which is a value that indicates significant fluctuations in discharges. This value is higher than those recorded in the downstream profiles of the Nišava River (0.33 in Pirot, 0.31 Bela Palanka and 0.31 in Niš), but is in accordance with the values of the neighbouring hydrological station in Dimitrovgrad - also 0.43 (Djokić, 2015). There are large fluctuations in discharges are on a monthly basis as well. The highest coefficients of variation are during the cold moths of January (1.08) and February (0.94) because, on the one hand, the precipitation often linger in the form of snow cover and in that way reduce discharges, while on the other hand, sudden warming cause snow to melt, what leads to increasing discharges. Also, a large coefficients of variation in discharges are recorded in July (C_v=1.05), August (C_v=1.03), September (C_v=0.95) and October (Cv=1), when the normally low discharges sometimes increase because of heavy precipitation.

The coefficient of variation of the minimal annual discharges is expectedly even higher, and amounts to 1.02, indicating extreme fluctuation. The ratio of the highest and the lowest recorded minimal annual discharges is 1:51.3. In the observed forty-four-year period, the minimal discharges are usually recorded in August (18 times) and September (11 times) as a result of high temperatures and lesser amount of precipitation.

The coefficient of variation of the maximal annual discharges is 0.92, that is, the fluctuations are extreme. The ratio of the highest and the lowest recorded maximal annual discharges amount to 1:32.6. The maximal annual discharges are more regularly distributed throughout the year than the minimal ones. The most common are recorded in March (8 times), April and February (7 times) and in May and June (5), which was caused by a period of heavy precipitation, rapid snowmelt period, or the overlapping of these two periods.

The Gaberska River discharges are characterized by large fluctuations. The ratio of the absolute maximal and absolute minimal discharge, during the period of observation covered by this study, amounts to 1:4522. Extremely large discharges in relation to its average value can be expected. Thus, once in 1,000 years, a discharge that is even 166 times higher than the average can be expected. On the other hand, once in 1,000 years, a discharge can fall to the value of 151 times lower than the average annual value.

Extreme fluctuation in discharges of the Gaberska River complicates the water management planning. In order to mitigate the effects of high waters, it is necessary to take measures which would include planning of the reforestation of the basin area, regulation of the river course in the form of its straightening, widening of the riverbed and cleaning of sediments, the construction of reservoirs for high waters. Low waters, among other things, are a consequence of the relatively high population density by rural population, who, by using both groundwater, and river water for irrigation, can easily reduce the already low discharges during the dry period of the year. It is necessary to legally regulate this area and exercise control of individual irrigation. Reservoirs can also be used to mitigate the effects of low waters.

References

Bobée B. The Log Pearson Type 3 Distribution and Its Application in Hydrology, Water Resources Research 1975, Vol. 11, No. 5

Bolgov M, Korobkina E. Applying the Log Pearson Type 3 Distribution for Modeling Annual Inflow to the Closed Lake, Water & Environmental Dynamics, 6th International Conference on Water Resources and Environment Research, Koblenz, Germany, 2013

Gavrilović Lj. Hydrology in Spatial Planning, Department of Geography and Regional Planning of the Faculty of Science and Mathematics 1988

Griffis V. Stedinger J. Log-Pearson Type 3 Distribution and Its Application in Flood Frequency Analysis. I: Distribution Characteristics, Journal of Hydrologic Engineering 2007, Volume 12, Issue 5

Dukić D. Gavrilović Lj. Hydrology, Textbook Institute, Belgrade 2008

Đokić M. The Nišava River – Potamology Study, Doctoral Dissertation. Faculty of Science and Mathematics, University of Niš 2015

Đokić M. Hydrogeographical Study of the Jerma River, Master's Thesis. Faculty of Geography, Belgrade 2010

Milanović A. Hydrological Forecast of High Waters in the Lepenica River Basin and Flood Protection, Bulletin of the Serbian Geographical Society 2006, 1:47-54

Vasilevski D, Radevski I. Analysis of High Waters on the Kriva reka River, Macedonia. Acta geographica Slovenica 2014, 54-2

Wallis J. Wood E. Relative Accuracy of Log Pearson III Procedures, Journal of Hydraulic Engineering 1985, Volume 111, Issue 7