Supporting the Development of an Irrigation Strategy for Serbia

Brief on Irrigation Water Availability (IWA) and Irrigation Water Requirements (IWR)

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Terms of Reference

Prepare a brief on water resources availability, distribution and accessibility in the Republic of Serbia. The brief will be based on locally available data and will include a SWOT analysis of the irrigation development potential compared to available water resources, considering the need for sustainable abstraction levels and the climate change impact on water resources and the irrigation system overall.

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1 Introduction

The aim of this brief is to determine the irrigation development prospects in the Republic of Serbia taken into consideration natural water related factors, namely the Irrigation Water Requirements (IWR) and the Irrigation Water Availability (IWA).

The Republic of Serbia as such is not classified as a country with a lack of water resources. However, it faces a predicament of unfavourable temporal and spatial distribution of available water.

Unlike the water abstracted for water supply and industrial purposes, the majority of irrigation water cannot be reused, as it is actually consumed by the flora, while only a small percentage gets returned to the streams. Having in mind that irrigation consumes a lot of water (70% of global water withdrawal is used for irrigation), it is necessary to make detailed water balance calculations that include the spatial and temporal distribution of IWR and IWA for all major catchment areas in Serbia with irrigation potential.

Section 2 of the present brief deals with Irrigation Water Requirements (IWR), while Section 3 is dedicated to the Irrigation Water Availability (IWA) estimation of water that could be directly abstracted from rivers, groundwater sources, a single-purpose or multipurpose reservoirs.

2 Irrigation Water Requirements in the Republic of Serbia

2.1 Methodology and Data Sources

Irrigation Water Requirements (IWR) are calculated using the data from meteorological stations covering the entire territory of the Republic of Serbia.

The sources of meteorological data are:

- Annual reports issued by the Republic Hydrometeorology Service of Serbia; and,
- "The Water Management Master Plan - Hydrometeorology Data" from 2009.

In the present analysis, data from 437 meteorological stations was used. Twenty-six (26) of them possessed detailed monthly meteorological data necessary for calculating the reference evapotranspiration (ET_0) using the Penman-Monteith Method, while the rest only had the monthly precipitation data.

2.1.1 Reference Evapotranspiration – ET_0

Reference evapotranspiration is calculated on monthly bases using the following monthly meteorological data:

- The average of daily minimum (T_{min}) and maximum temperatures (T_{max}) (°C);
- The average relative humidity – *RH* (%);
- Insolation – *n* (h/month); and,
- The average wind velocity at 2 meters above ground - U_2 (m/s).

The following Penman-Monteith equation (FAO 56) was used to calculate the reference evapotranspiration ET_0 (mm/day) for each of the 437 meteorological stations:

$$\lambda ET_0 = \frac{\Delta(R_n - G) + \gamma\lambda \frac{187250}{T+273}\frac{(e_s - e_a)}{r_a}}{\Delta + \gamma(1 + \frac{r_s}{r_a})} \qquad (1)$$

As complete sets of meteorological data necessary for ET_0 calculations were available only for the 26 main meteorological stations, it was imperative to recalculate ET_0 for the remaining 411 stations measuring only precipitation. For those stations, ET_0 was calculated using the interpolation method that takes into account meteorological data from the 26 main meteorological stations, as well as the weighting factors for the 4 nearest main stations in 4 quadrants, selected through the inverse distance method.

Having in mind that the temperature data has the strongest impact on ET_0 and that it changes with altitude, the data was rescaled in relation to the elevation of the actual precipitation station, using the standard factor -0.65 °C / 100 m of altitude increase.

2.1.2 Crop Potential Evapotranspiration – ET_c

Crop potential evapotranspiration (ET_c) is calculated using the average estimated cropping pattern embodied in the calculated crop coefficient K_c:

$$ET_c = K_c ET_0 \tag{2}$$

For the purposes of preliminary analysis aiming to provide insight into the country-wide spatial and temporal IWR distributions, uniform cropping pattern was adopted: 25% wheat, 30% maize, 15% vegetables, 15% fruits, 15% industrial crops and 10% second harvest. The average crop coefficients K_c, calculated using the aforementioned assumptions, are shown in Figure 1.

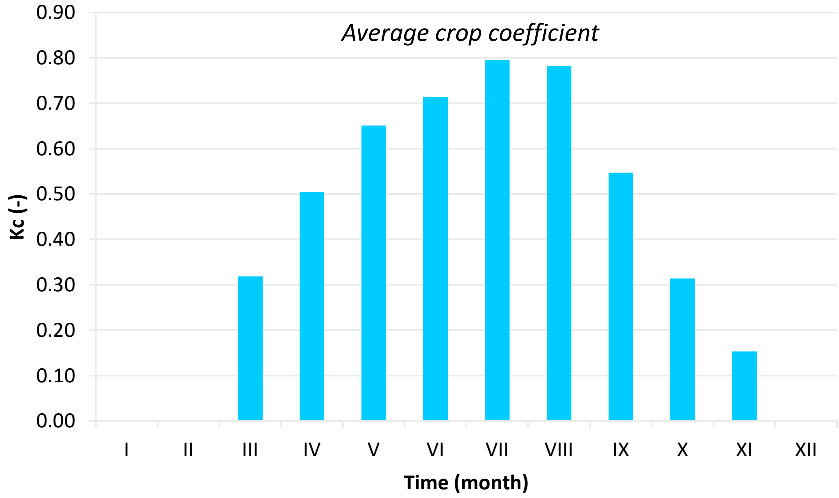


Figure 1. Adopted Average Crop Coefficients - K_c

2.1.3 Irrigation Water Requirement (IWR)

Irrigation Water Requirement (IWR) was calculated for all 437 meteorological stations. For that purpose, a simplified water balance equation was used:

$$IWR = ET_c - P_e \tag{3}$$

where P_e was the effective monthly rainfall, calculated by applying the following USDA methodology [USDA (1993) National Engineering Handbook, Part 623, Irrigation Water Requirements]:

$$P_e = 1.2525(P^{0.82416} - 2.3435)e^{0.0022ET_c}\delta \tag{4}$$

Here, P is a monthly cumulative precipitation, while δ is the soil factor of 1. Please note that equation no. 3 does not account for the changes in the soil moisture content, and, therefore, the simplified approach utilized in the said equation yields results that err on the side of caution, which is more than adequate for the present analysis.

Irrigation Water Requirement is calculated utilizing:

- The monthly average for each station ($IWR_{i,j};\ i = 1$ to $437;\ j = 1$ to 12);
- The annual sum for each station ($IWR_i = \sum_j IWR_{i,j}$);
- Monthly values for a fictitious drought year with selected Recurrence Interval of RI = 5, meaning drought occurring once in 5 years [$IWR_{i,j}(RI = 5)$]; and,

- The annual sum for a fictitious drought year for each station $[IWR_i(RI=5) = \sum_j IWR_{i,j}(RI=5)]$.

The fictitious drought year data is the result of statistical analysis that uses the assumption that monthly IWR values for the period of 71 years (from 1949 to 2019) follow the normal distribution patterns.

The calculated IWR are the net ("on the ground") Irrigation Water Requirements, while the Gross Irrigation Water Requirements (GIWR) are the actual water quantities withdrawn from different water sources (rivers, reservoirs and/or groundwater). GIWR depends on the distribution systems and the irrigation methods, where the impacts of both are included in the efficiency coefficient (n). Having in mind the assumption that the future development of irrigation in Serbia will be based mostly on sprinkler and drip irrigation methods, since they are the most water efficient, it is reasonable to adopt *n* = 0.85. Finally, the GIWR can be expressed as the following:

$$GIWR = IWR/n \tag{5}$$

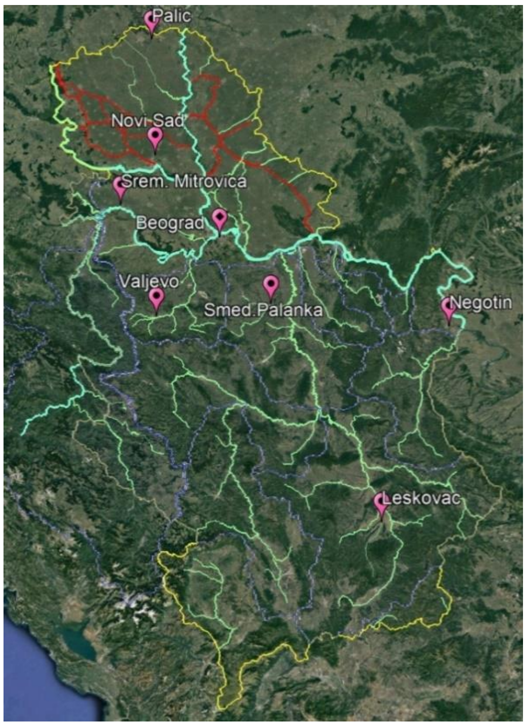
2.2 Results for Selected Meteorological Stations

Detailed results are presented for 8 out of 26 main meteorological stations listed in Table **1** with their locations indicated in Figure 2. Results pertain to the 71-year period, between 1949 and 2019.

Table 1. Geographical Data for Eight Meteorological Stations Analysed

Meteorological stations	**ℓ (°)**	**λ (°)**	**Z (m.a.s.)**
Beograd	44.80	20.47	132
Leskovac	42.98	21.95	230
Negotin	44.23	22.55	42
Rimski Šančevi	45.33	19.85	86
Palić	46.10	19.77	102
Smed.Palanka	44.37	20.95	121
Srem. Mitrovica	45.00	19.55	82
Valjevo	44.28	19.92	176

Figure 2. Locations of the Eight Meteorological Stations Listed in Table 1



For the period in question, the calculated average monthly ET_0 values for selected meteorological stations are presented in Figure 3. Clearly, results are similar for most stations, except for Valjevo, where ET_0 peak occurring in August has an approximately 15% lower value. Distribution of monthly ET_0 values over a year-long period follows mostly the same pattern: about 80% of ET_0 is related to the vegetative period of 6 months from April to September, while about 50% of the annual sum is pertains to summer months (June, July and August).

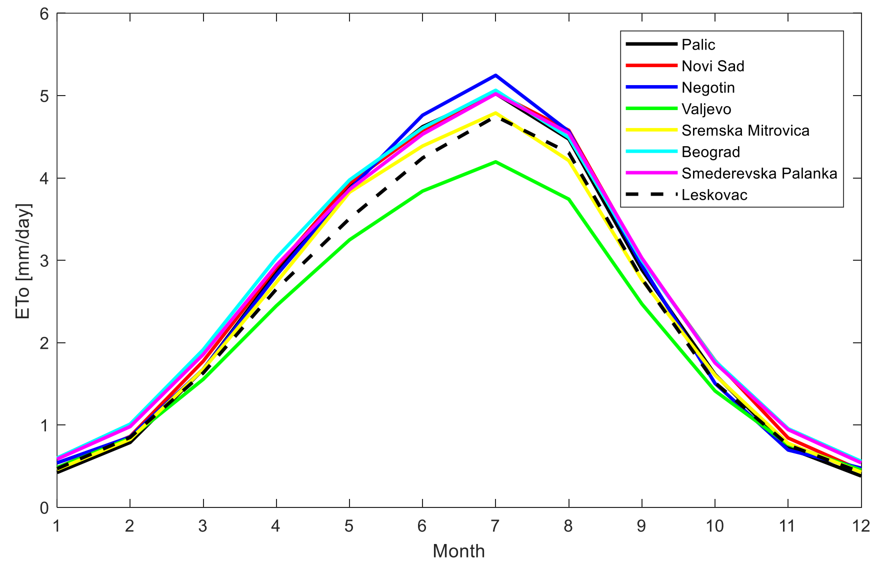


Figure 3. Average Monthly ET_0 Values for Eight Meteorological Stations from Figure 2

The results, including ET_0, ET_c, IWR, GIWR and the irrigation design module q (l/(s ha)), have been plotted in the forthcoming sections for each of the selected meteorological stations (Figures 4 to 11). The design module is calculated using the maximum monthly GIWR value during a drought year with a recurrence interval of RI = 5 years:

$$q = 0.116 \times max\{GIWR(RI = 5)\}/30 \quad (6)$$

where 0.116 is the factor transforming [mm/day] into the $l/(s \times h_a)$.

2.2.1 Results for Belgrade Meteorological Station

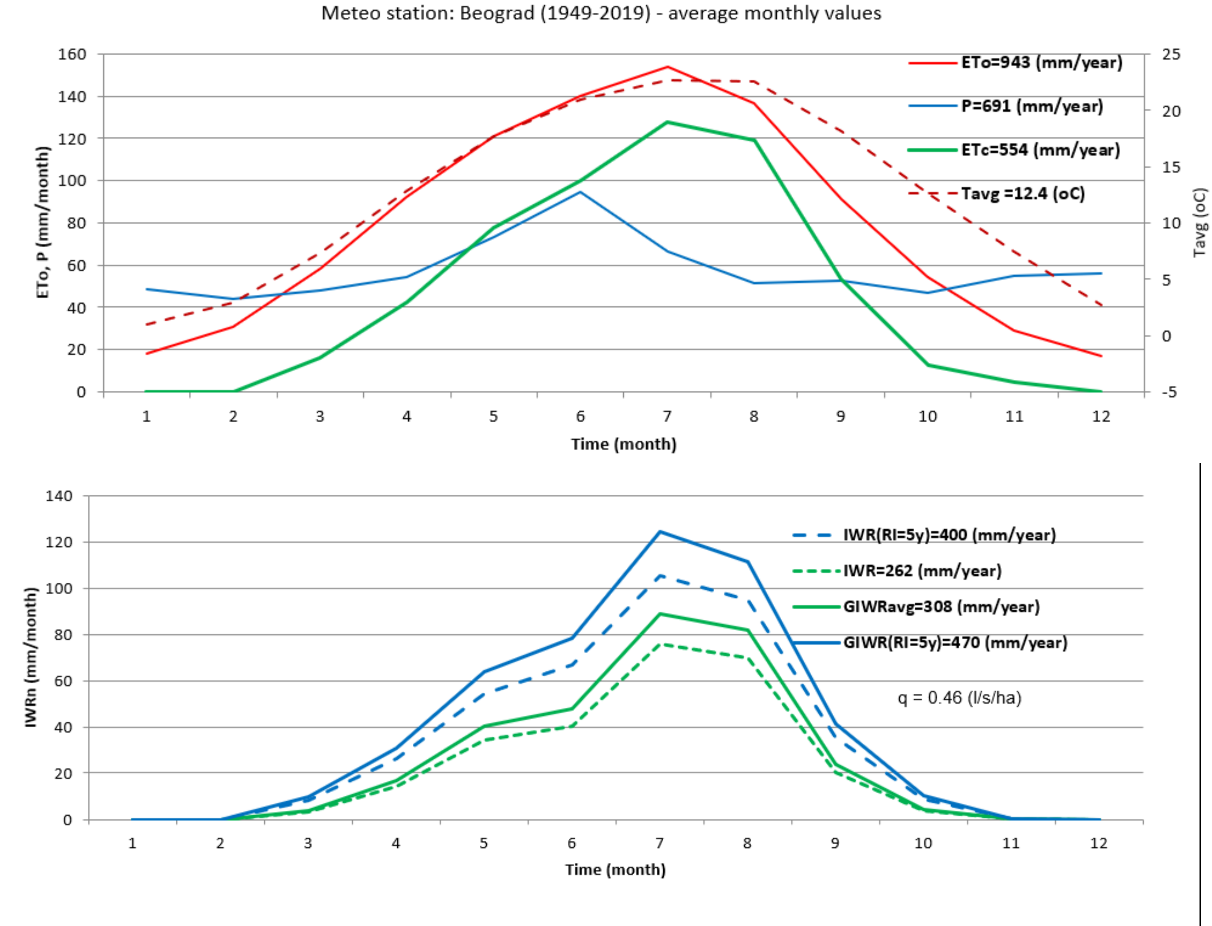


Figure 4.

Top graph – average monthly values of ET_0 (solid red line), ET_c (solid green line), *P* (solid blue line), presented to the left-side *y* axis, and of *T* (dashed line), presented on the right-side *y* axis;

Bottom graph – average monthly values of *IWR* (dashed green line), GIWR (solid green line), *IWR* (*RI* = 5) (dashed blue line) and *GIWR* (*RI* = 5) (solid blue line). The corresponding value of *q* is also indicated in the bottom graph.

2.2.2 Results for Leskovac Meteorological Station

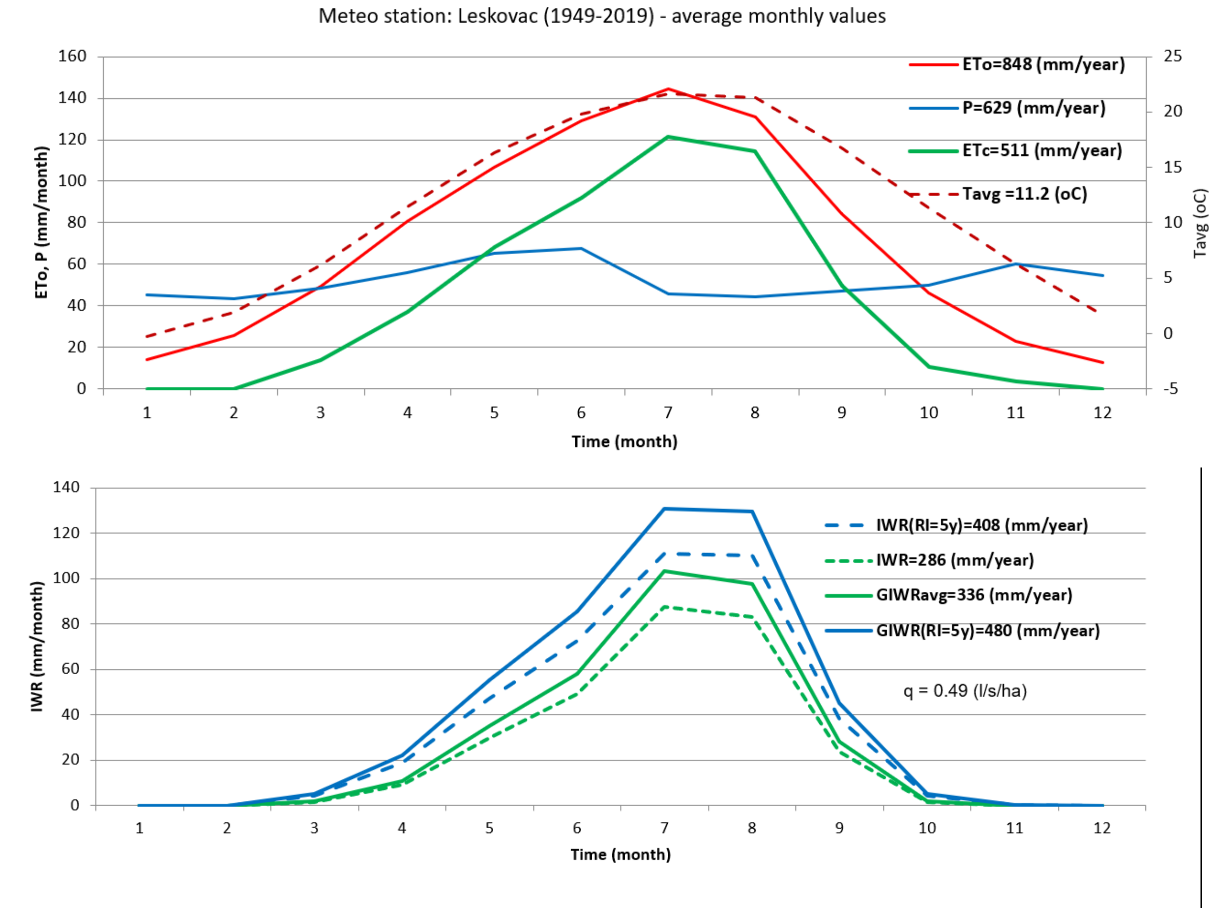


Figure 5.

Top graph – average monthly values of ET_0 (solid red line), ET_c (solid green line), P (solid blue line), presented on the left-side y axis, and of T (dashed line), presented on the right-side y axis;

Bottom graph – average monthly values of *IWR* (dashed green line), GIWR (solid green line), *IWR* (*RI* = 5) (dashed blue line) and *GIWR* (*RI* = 5) (solid blue line). The corresponding value of q is also indicated in the bottom graph.

2.2.3 Results for Negotin Meteorological Station

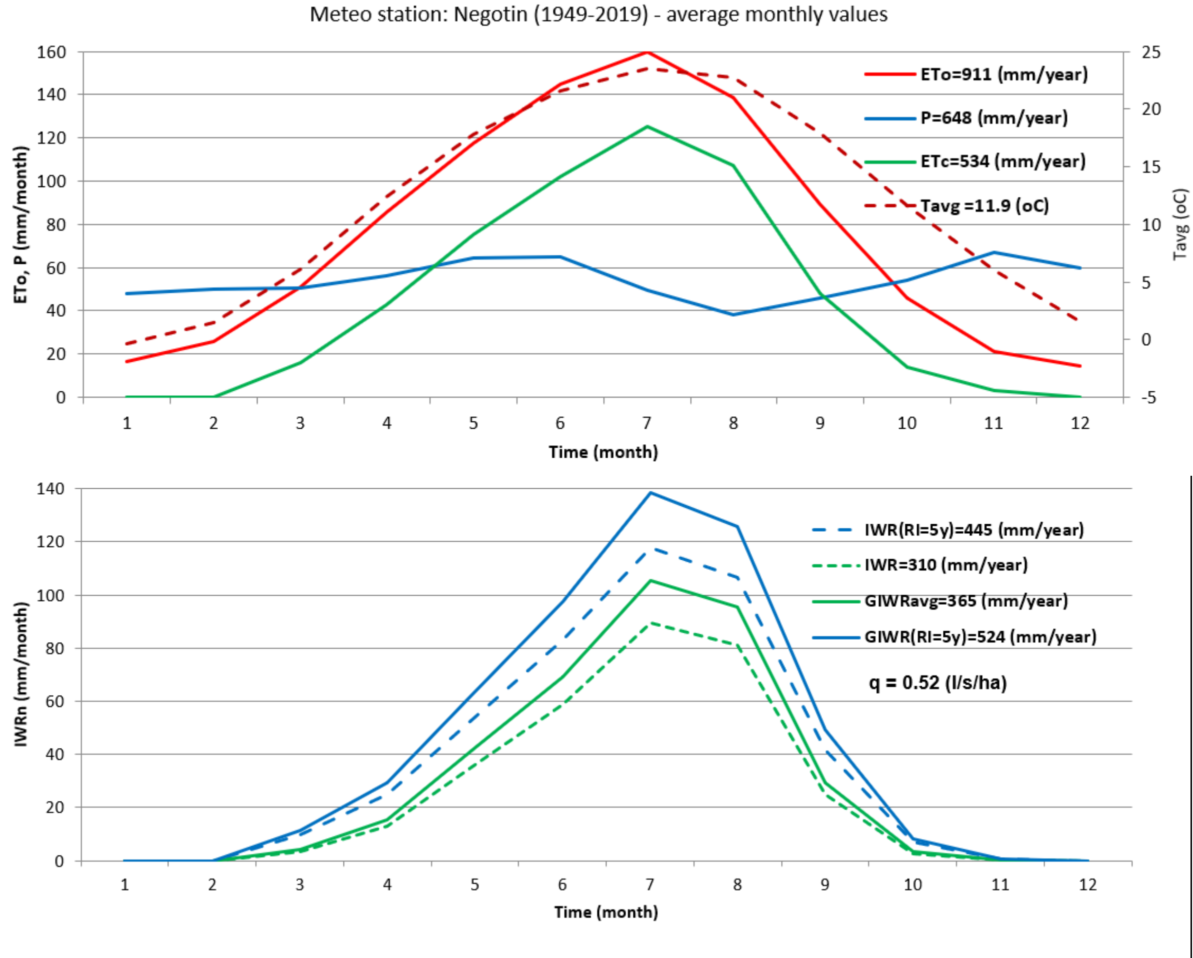
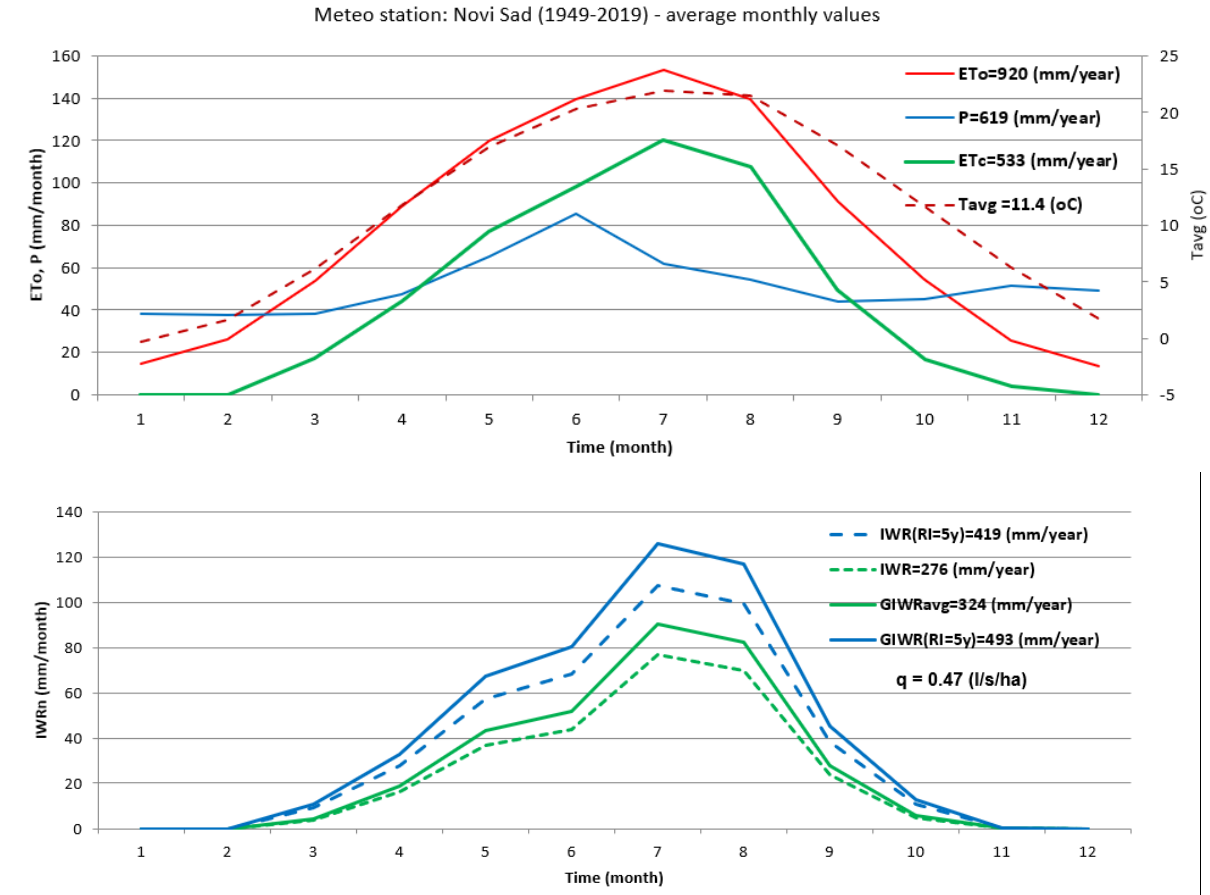


Figure 6.

Top graph – average monthly values of ET_0 (solid red line), ET_c (solid green line), P (solid blue line), presented on the left-side y axis, and of T (dashed line), presented on the right-side y axis;

Bottom graph – average monthly values of *IWR* (dashed green line), GIWR (solid green line), *IWR* (*RI* = 5) (dashed blue line) and *GIWR* (*RI* = 5) (solid blue line). The corresponding value of q is also indicated in the bottom graph.

2.2.4 Results for Novi Sad Meteorological Station



<u>Figure 7.</u>

Top graph – average monthly values of ET_0 (solid red line), ET_c (solid green line), *P* (solid blue line), presented on the left-side *y* axis, and of *T* (dashed line), presented on the right-side *y* axis;

Bottom graph – average monthly values of *IWR* (dashed green line), GIWR (solid green line), *IWR* (*RI* = 5) (dashed blue line) and *GIWR* (*RI* = 5) (solid blue line). The corresponding value of *q* is also indicated in the bottom graph.

2.2.5 Results for Palić Meteorological Station

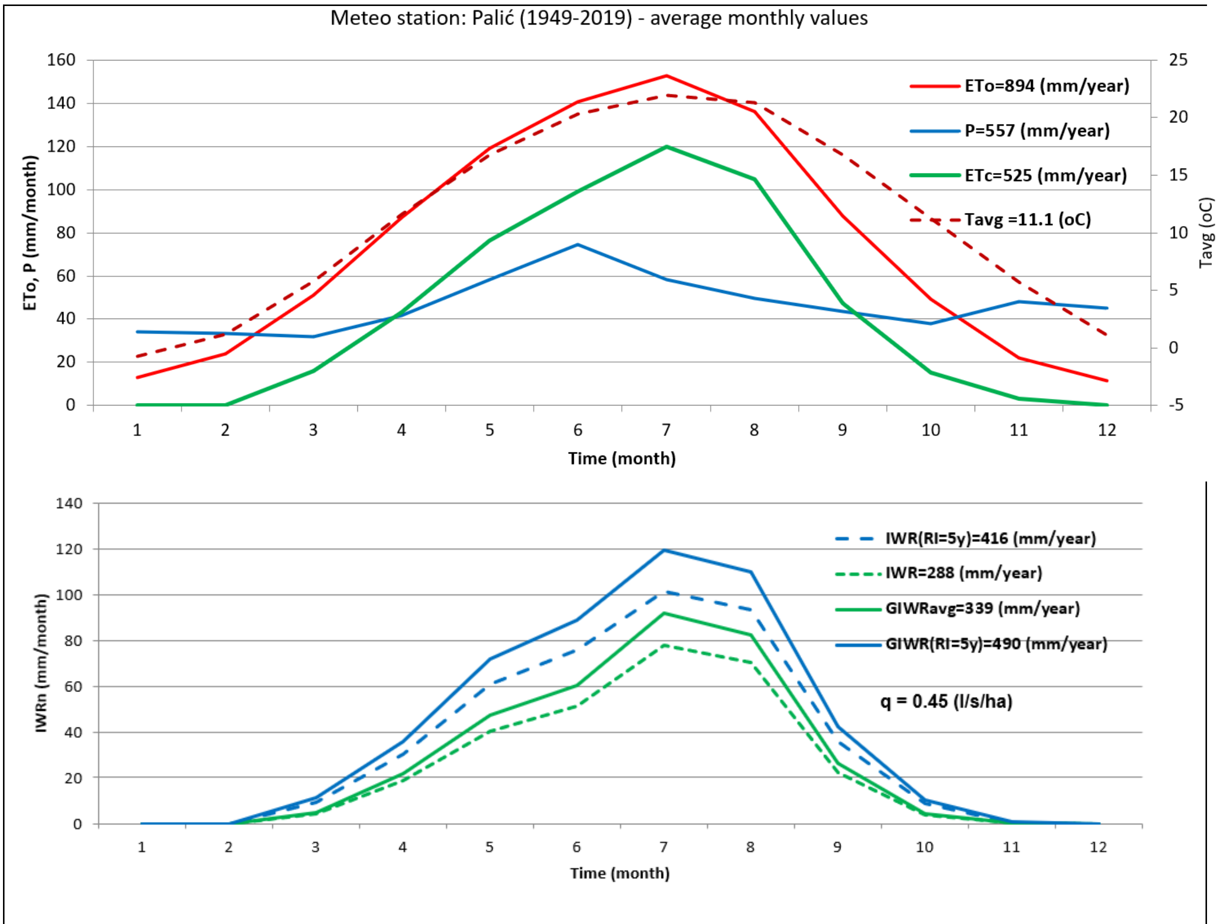


Figure 8.

Top graph – average monthly values of ET_0 (solid red line), ET_c (solid green line), *P* (solid blue line), presented on the left-side *y* axis, and of *T* (dashed line), presented on the right-side *y* axis;

Bottom graph – average monthly values of *IWR* (dashed green line), GIWR (solid green line), *IWR* (*RI* = 5) (dashed blue line) and *GIWR* (*RI* = 5) (solid blue line).

The corresponding value of *q* is also indicated in the bottom graph.

2.2.6 Results for Smederevska Palanka Meteorological Station

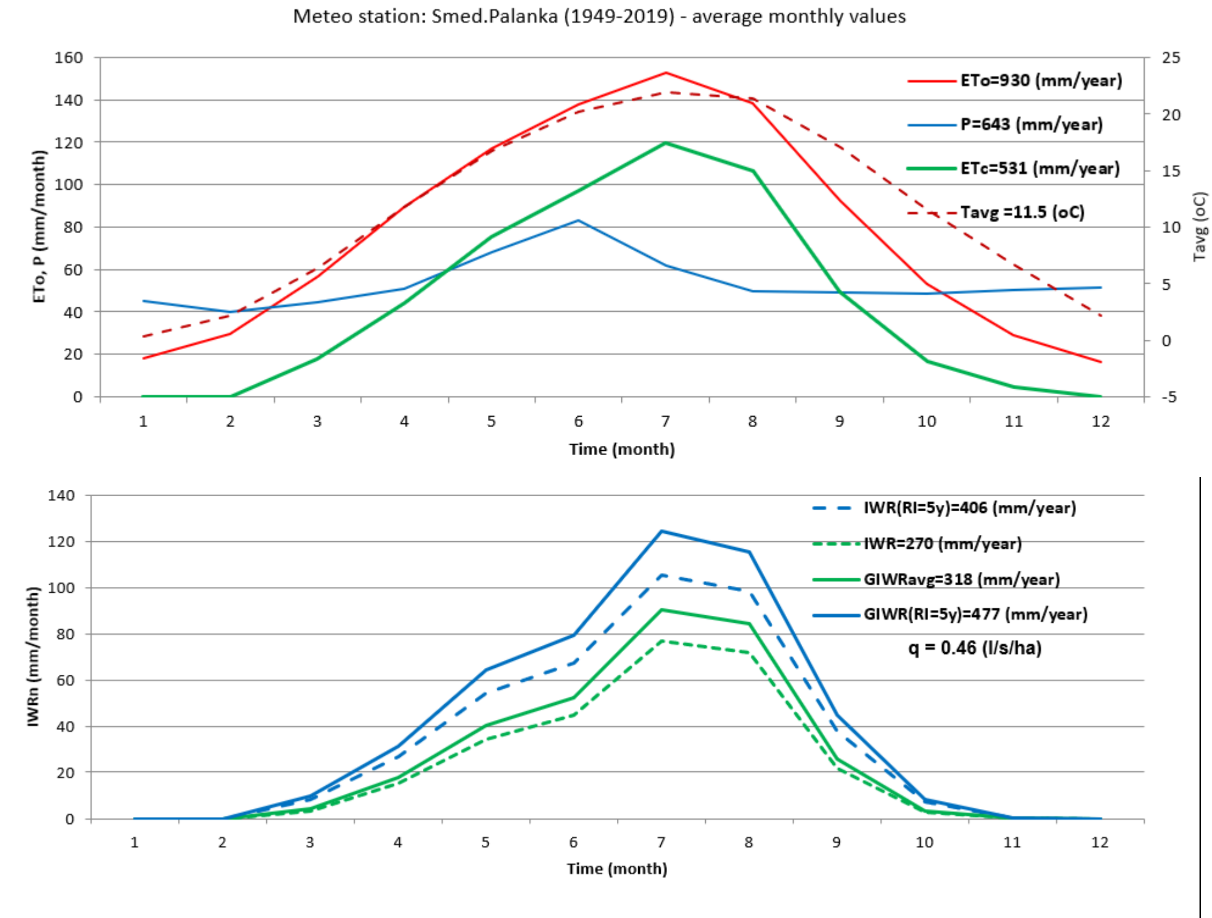
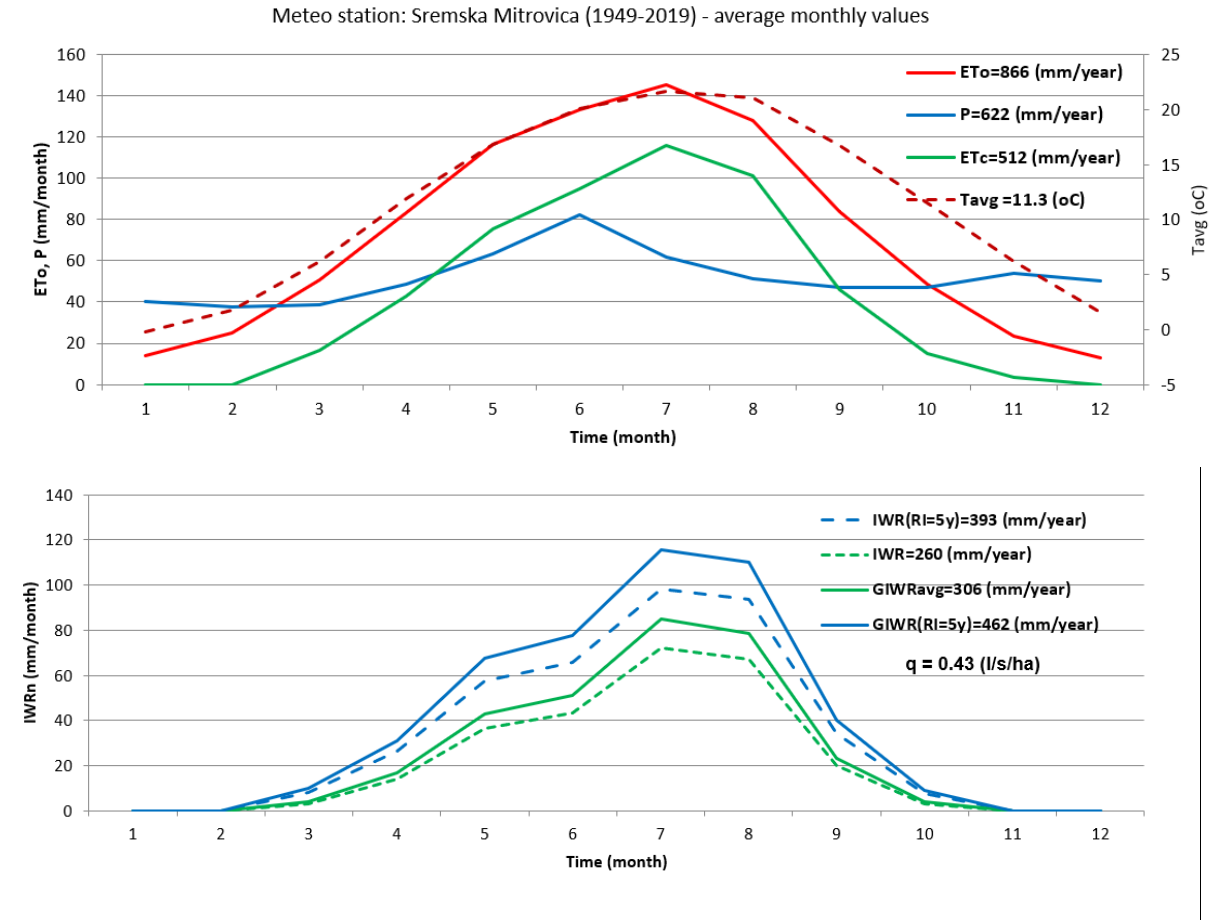


Figure 9.

Top graph – average monthly values of ET_0 (solid red line), ET_c (solid green line), *P* (solid blue line), presented on the left-side *y* axis, and of *T* (dashed line), presented on the right-side *y* axis;

Bottom graph – average monthly values of *IWR* (dashed green line), GIWR (solid green line), *IWR* (*RI* = 5) (dashed blue line) and *GIWR* (*RI* = 5) (solid blue line). The corresponding value of *q* is also indicated in the bottom graph.

2.2.7 Results for Sremska Mitrovica Meteorological Station



<u>Figure 10.</u>

Top graph – average monthly values of ET_0 (solid red line), ET_c (solid green line), *P* (solid blue line), presented on the left-side *y* axis, and of *T* (dashed line), presented on the right-side *y* axis;

Bottom graph – average monthly values of *IWR* (dashed green line), GIWR (solid green line), *IWR* (*RI* = 5) (dashed blue line) and *GIWR* (*RI* = 5) (solid blue line). The corresponding value of *q* is also indicated in the bottom graph.

2.2.8 Results for Valjevo Meteorological Station

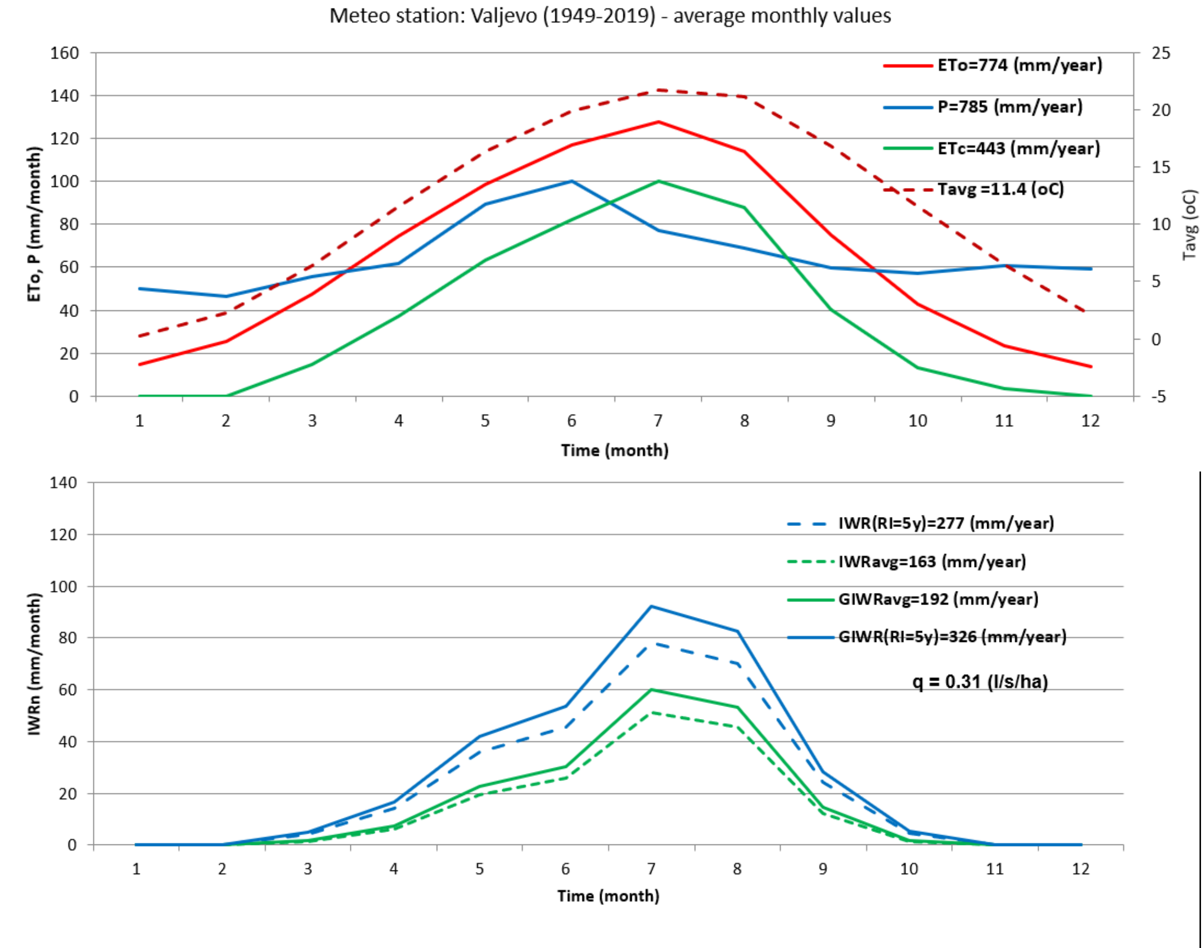


Figure 11.

Top graph – average monthly values of ET_0 (solid red line), ET_c (solid green line), *P* (solid blue line), presented on the left-side *y* axis, and of *T* (dashed line), presented on the right-side *y* axis;

Bottom graph – average monthly values of *IWR* (dashed green line), GIWR (solid green line), *IWR* (*RI* = 5) (dashed blue line) and *GIWR* (*RI* = 5) (solid blue line). The corresponding value of *q* is also indicated in the bottom graph.

2.3 Trends in Irrigation Water Requirements (IWR)

In order to analyse trends in the cumulative annual IWR values, Standardised Irrigation Water Requirement Index (*SIWRI*) has been calculated for 8 selected meteorological stations, as follows:

$$SIWRI = \frac{IWR - \overline{IWR}}{\sigma_{IWR}} \tag{7}$$

Clearly, SIWRI describes how much the IWR value deviates from the multi-year average $\overline{IWR}$. Hence, when *SIWRI* = 0, then $IWR = \overline{IWR}$. On the other hand, when *SIWRI* = ±1, that means a year has been dry/wet, since the IWR value deviates from $\overline{IWR}$ by one standard deviation. If the normal distribution is to be assumed, values higher than 0.84 indicate droughts with recurrence interval (RI) of 5 years or more.

Results are shown in Figure 12 for 8 selected meteorological stations.

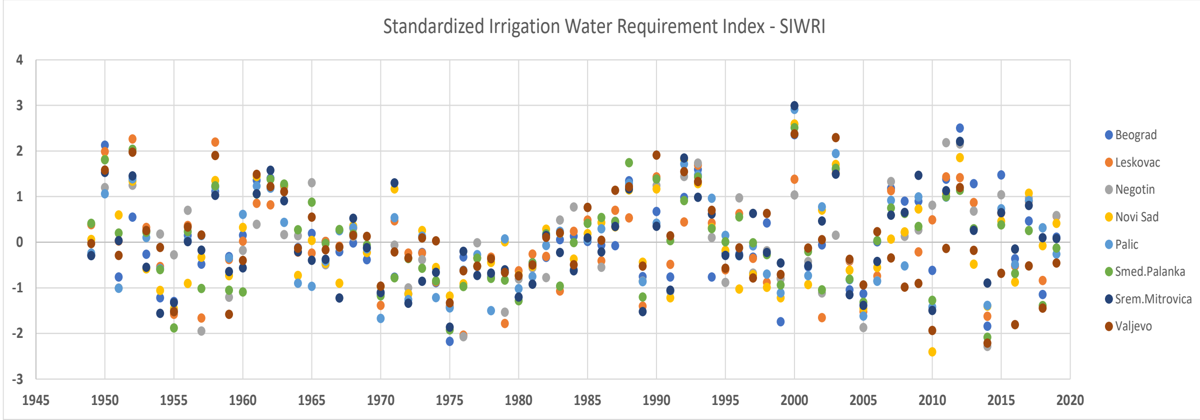


Figure 12. SIWRI Changes Through Years (from 1949 to 2019) for 8 Meteorological Stations Presented in Figure 2

Figure 12 shows that, for the period before the year 2000, there is a certain long-term trend with sequences of multiple consecutive wet or dry years in a row. Meanwhile, after the year 2000, extremely rainy and dry years take turns more frequently than before. It is well known that, in the years 2000 and 2012, the Republic of Serbia experienced severe droughts, which the results herein confirm. Based on the SIWRI values (please see Figure 12), the recurrence interval for the year 2000 reaches almost 100 years in case of some meteorological stations (e.g., Belgrade).

2.4 Spatial Distribution of IWR and ET_0

As explained in the methodology section, spatial distribution of ET_0 and IWR for the Republic of Serbia is calculated based on the 26 main meteorological stations (8 previously analysed, plus 18 additional - the full list is available in the Appendix), with full sets of data necessary for calculating ET_0, and 411 meteorological stations with precipitation data only (the full list is available in the Appendix). In total, the calculations have been performed for 437 points, and results presented in the form of two maps showing the spatial distribution of the annual cumulative ET_0 and IWR (please see Figure 13).

Furthermore, relevant meteorological data was acquired from the "Water Management Master Plan - Hydrometeorology Data" issued in 2009. Due to fact that complete sets of data were available for the period between 1949 and 2006, the maps herein have been created with reference to that period.

Results show that the south west part of Serbia has the lowest ET_0, highest precipitation and thus, the lowest IWR, while the IWR values for the regions with the highest irrigation potential mostly vary between 250-300 mm/year.

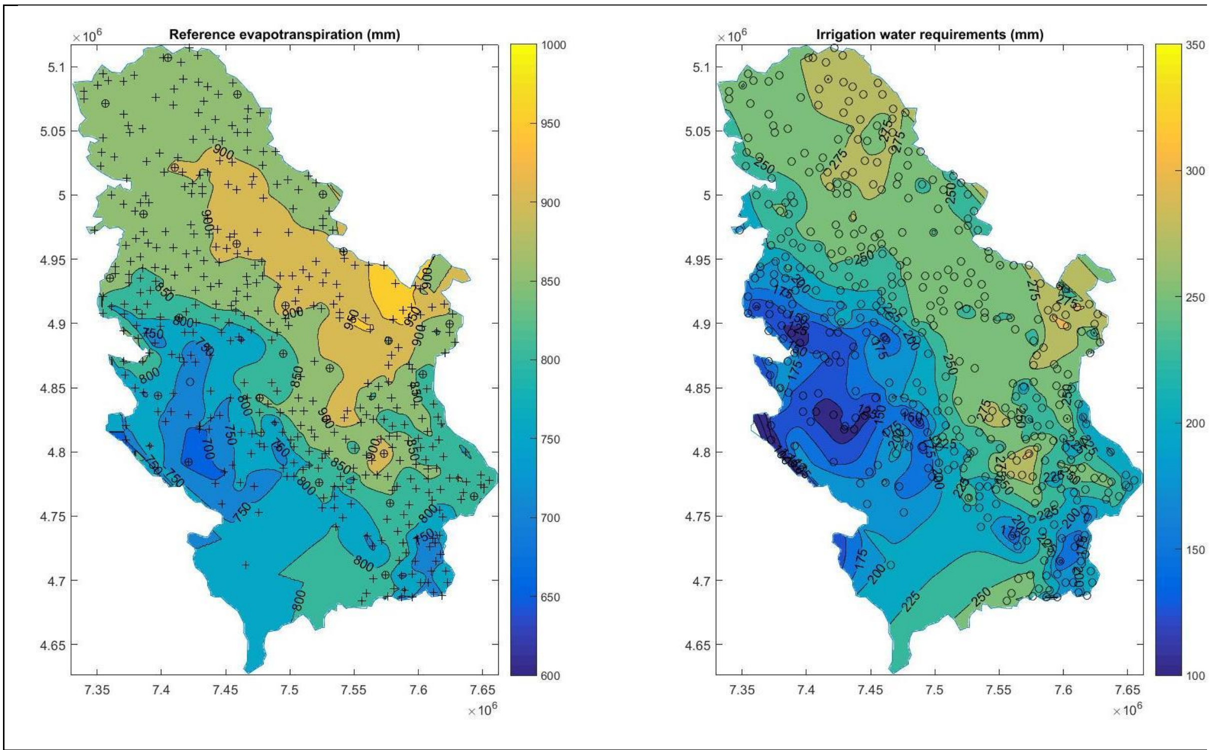


Figure 13. Spatial Distribution Maps of Annual Cumulative ET$_0$ (left) and IWR (right) Values

2.5 Conclusion

There are several important facts that can be discerned from the present analysis:

- Gross Irrigation Water Requirements (GIWR) range from 300 to 360 mm/year for an average year, except in the south west parts of Serbia with lower GIWR (< 250 mm/year).
- Gross Irrigation Water Requirements increase about 50% in a drought year with recurrence interval of RI = 5 years.
- Design irrigation module is about 0.45 - 0.55 l/(s ha), except in the south west areas, where the values are lower than 0.4 l/(s ha).

It should be emphasized that these are general estimates, while local variations are expected, mostly due to different local crop patterns, as well as local climate conditions and soil traits. Therefore, detailed IWR calculations are necessary for each project individually.

3 Irrigation Water Availability in the Republic of Serbia

Water quantities available for irrigation purposes are estimated in this chapter. Generally, there are several water sources that should be considered:

- Surface water – irrigation water abstraction directly from rivers (streams);
- Groundwater – irrigation water abstraction from the groundwater-bearing layers using wells; and,

- Reservoirs – irrigation water abstraction from reservoirs of water stemming from higher-stream discharges, to be used in the summer drought periods.

3.1 Surface Water – Direct Abstraction from Rivers (Catchments)

In order to estimate possible river irrigation water abstraction, 35 hydrological stations were selected, based on their spatial distribution and data availability.

Analysed discharge data covers the period from 1990 to 2019 (main data sources are the annual reports of the Republic Hydrometeorology Service of Serbia).

Available irrigation water is calculated based on the average monthly discharge values.

A complete list of hydrological stations is given in Table 2, together with the corresponding catchment areas (*A*) and the average discharge (*Q*). Exact locations of the listed stations have been mapped in Figure 14.

Table 2. List of 35 hydrological stations, their geographical data, corresponding rivers and catchments, and the average monthly discharge values

Catchment	StationID	River	Station name	X	Y	A (km2)	Zo (m.a.s)	Q (m3/s)
Drina	45865	DRINA	BAJINA BAŠTA	7383425	4871075	14797	211.47	294.40
	45882	DRINA	RADALj	7352959	4921062	17490	129.47	331.39
	45837	LIM	PRIJEPOLjE	7390050	4805150	3160	443.37	69.20
	45892	JADAR	LEŠNICA	7363500	4944625	959	103.47	7.52
Dunav	42010	DUNAV	BEZDAN	7334254	5081102	210250	80.64	2253.60
	42020	DUNAV	BOGOJEVO	7350350	5044540	251593	77.46	2706.24
	42055	DUNAV	SMEDEREVO	7494175	4946950	525820	65.36	5028.50
	44020	TISA	SENTA	7430200	5087875	141715	72.8	776.90
	45090	SAVA	SREMSKA MITROVICA	7390175	4981125	87996	72.22	1505.97
	42401	TAMIŠ	JAŠA TOMIĆ	7489150	5031950	5334	73.46	39.21
	42730	PEK	KUSIĆE	7542825	4952550	1220	76.17	8.17
	42527	MLAVA	VELIKO SELO	7524825	4927750	1124	91.46	7.58
Ibar	47295	IBAR	LOPATNICA LAKAT	7465225	4835150	7818	224.68	55.19
Južna Morava	47590	JUŽNA MORAVA	MOJSINjE	7539613	4831920	15390	136.28	83.10
	47570	JUŽNA MORAVA	ALEKSINAC	7557825	4820575	14284	157.63	71.98
	47530	JUŽNA MORAVA	VLADIČIN HAN	7587325	4729745	3052	321.71	17.66
	47665	VETERNICA	LESKOVAC	7577445	4761580	500	224.18	3.43
	47740	JABLANICA	PEČENjEVCE	7575735	4773545	891	205.82	3.34
	47640	VLASINA	VLASOTINCE	7592600	4758760	879	254.39	6.67
	47528	JUŽNA MORAVA	VRANjSKI PRIBOJ	7583625	4717840	2775	349.98	9.47
Kolubara	45905	KOLUBARA	VALjEVO	7411575	4903325	340	179.65	3.38
	45910	KOLUBARA	BELI BROD	7436625	4914375	1896	99.32	14.75
Nišava	47920	NIŠAVA	PIROT	7629630	4780650	1745	364.27	14.26
	47990	NIŠAVA	NIŠ	7573575	4798350	3870	187.88	25.42
Timok	42921	BELI TIMOK	KNjAŽEVAC	7602150	4826525	1242	211.63	6.80
	42929	BELI TIMOK	ZAJEČAR	7604375	4861650	2150	124.41	10.14
Toplica	47880	TOPLICA	PROKUPLjE	7548050	4787425	1774	234.95	8.44
Zapadna Morava	47350	MORAVICA	ARILJE	7428450	4846750	830	326.69	10.54
	47120	ZAPADNA MORAVA	MILOČAJ	7470400	4848000	4658	194.27	37.53
	47195	ZAPADNA MORAVA	JASIKA	7524250	4829350	14721	138.56	97.48
Velika Morava	47090	VELIKA MORAVA	LJUBIČEVSKI MOST	7510950	4937900	37320	73.42	219.86
	47040	VELIKA MORAVA	BAGRDAN	7516250	4880375	33446	100.94	199.32
	47010	VELIKA MORAVA	VARVARIN	7530500	4842275	31548	126.13	185.17
	47075	JASENICA	SM.PALANKA (JASENICA)	7496391	4910735	496	101.82	1.67
	47076	KUBRSNICA	SM.PALANKA (KUBRSNICA)	7497366	4912445	743	100	1.61

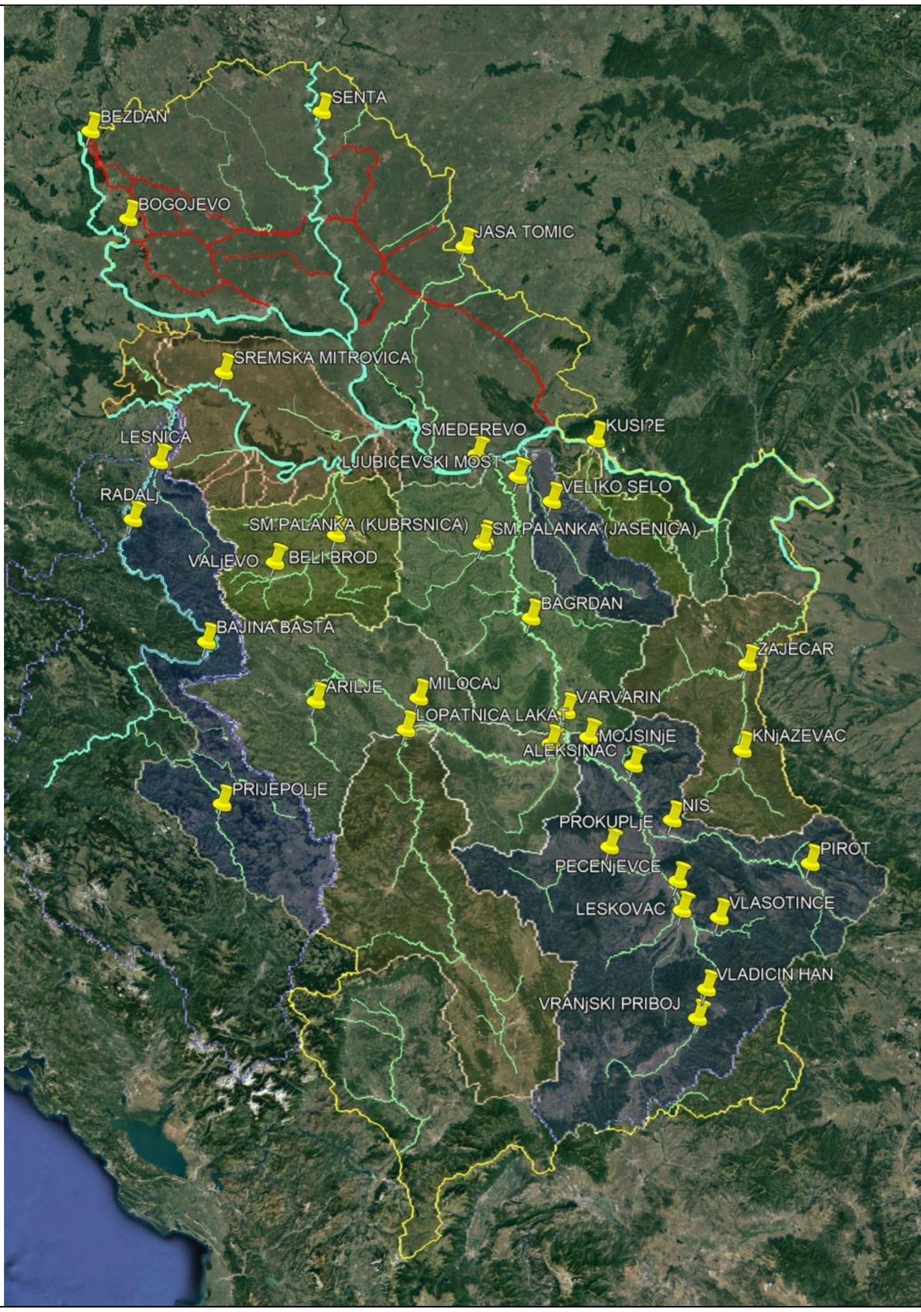


Figure 14. Locations of 35 Hydrological Stations and Catchment Area Indicators

3.1.1 Irrigation Water Quantity Estimation Methodology

A potential surface area that can be irrigated with water abstracted directly from a river can be determined based on the estimated potential river discharge and the previously computed Irrigation Water Requirements (IWR). For the purposes of the present all-encompassing strategic-level analysis, the estimates of the available irrigation surface water are based on the average monthly discharge data. However, more detailed analyses of specific areas require a catchment water management model, which would use average daily discharge values, as the water is abstracted directly from the river and not retained in reservoirs. This is especially important for smaller rivers, where daily discharge values can differ significantly from the monthly average.

Irrigation Water Availability (Q_{irr}) is determined based on the difference between (monthly) river discharges with 80% and 90% probability of occurrence, multiplied by factor of $f < 1$, as a precautionary measure:

$$Q_{irr} = f(Q_{80\%} - Q_{90\%}) \qquad (8)$$

$Q_{80\%}$ and $Q_{90\%}$ values are estimated using the statistical analysis of monthly discharge values, which is explained later on in the present brief.

Please note that the $Q_{80\%}$ assumption provides for a 20% chance that there will be a lack of irrigation water in the recurrence interval of RI = 5 years. This further implies that the irrigation system has been designed for a water deficit once in 5 years, which is a common practice.

Discharge value of $Q_{90\%}$ is used as the downstream minimum, which indicates that irrigation should cease when the river discharge is lower than $Q_{90\%}$. Downstream minimum is a water management category that relies on downstream water use (Q_{dwns}) and the ecological water requirements (Q_{ecol}) values. Downstream minimum is calculated as the maximum of those two values - $max(Q_{ecol}, Q_{dwns})$.

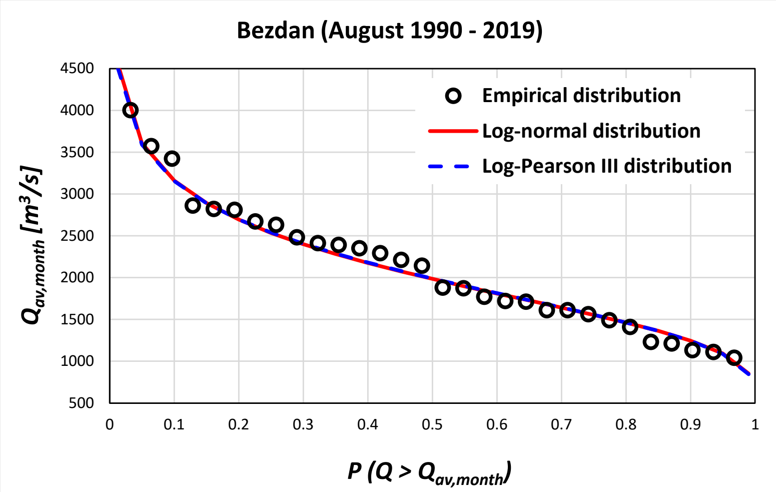
There are different criteria for estimating Q_{ecol}, but the most common one is using discharge with probability of occurrence of 95% ($Q_{ecol} = Q_{95\%}$). However, this value is calculated based on the average daily discharges for a whole year, and not on the average monthly values. Another reason why probability of 90% is used instead of 95% is to leave enough water for other potential downstream water requirements (Q_{dwns}) that are not considered here. However, water abstraction values for other purposes are much lower compared to the irrigation requirements, especially having in mind that more than 80% of water abstracted for water supply and/or industry is returned to streams to be utilized by downstream users, which is not the case with irrigation. Based on the comparison between the $Q_{90\%}$ and the estimates of Q_{ecol} for several hydrological stations, it has been concluded that $Q_{90\%}$ is an adequate value for a downstream minimum, and, as such, it can be used for further analyses.

Finally, in order to err on the side of caution, an assumption is made that only two-thirds of the gross available water ($Q_{80\%}$ - $Q_{90\%}$) is used for irrigation (f = 2/3), while the remaining reserves are a compensation for:

- the fact that calculations are not done using daily, but rather monthly discharge data that are lower (not on the safe side); and,
- the possibility of a significant rise in water demand by other users, or a climate change scenario that can significantly lower the water availability in the future.

The presented methodology for calculating the irrigation water quantity availability is used for 35 hydrological stations from Table 2, for each month of the vegetation period (April to September). In order to determine $Q_{80\%}$ and $Q_{90\%}$, different probability distributions of average monthly flows have been analysed in a 30-year period (1990 – 2019). As presented in Figure 15, Weibull Empirical Distribution (dots) is compared to log-normal (solid line) and log-Pearson III (dashed line) distributions for two hydrological stations (Bezdan and Ljubičevski Most). Finally, log-normal distribution is adopted as the relevant one, and it is further used for the determination of $Q_{80\%}$ and $Q_{90\%}$.

Year	Bezdan Qaug (m3/s)	Ljub.Most Qaug (m3/s)
1990	1210	39
1991	3570	164
1992	1110	72
1993	2140	29
1994	1230	40
1995	1610	76
1996	1710	59
1997	2820	134
1998	1490	44
1999	2210	194
2000	2480	65
2001	1870	76
2002	4000	136
2003	1130	63
2004	1720	107
2005	2810	188
2006	2630	104
2007	1610	62
2008	2390	77
2009	2410	90
2010	3420	142
2011	2290	73
2012	1770	52
2013	1560	55
2014	2860	249
2015	1410	63
2016	2670	112
2017	2350	67
2018	1040	182
2019	1880	63
Qavg(m3/s)	2113	96



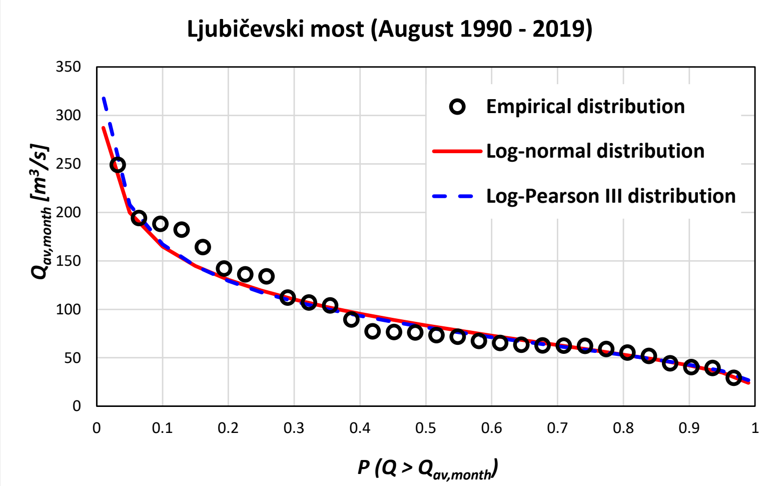


Figure 15.
Comparison between Weibull Empirical Distribution (dots), log-normal (solid line) and log-Pearson III (dashed line) distributions for the average August discharges between 1949 and 2019 on the Danube River (Bezdan Station) and the Velika Morava River (Ljubičevski Most Station)

As presented in Figure 15, $Q_{80\%}$ and $Q_{90\%}$ values can be both *Q(P = 0.8)* and *Q(P = 0.9)*, respectively, for all 35 hydrological stations. The introduction of the obtained discharge values into the equation no. 8, together with *f* = 2/3, results in the calculation of monthly Q_{irr} values presented in Table 3. Further analysis showed that the month of August is most often a critical month, when both hydrological and agricultural droughts coincide (GIWR is high and Q_{irr} is at its lowest – please see Table 3).

Table 3. Q_{irr} calculation for each of the 35 hydrological stations during the 7-month vegetative period (from April till October)

Catchment	StationID	River	Station name	A (km2)	Q (m3/s)	April	May	June	July	August	Sept.	Oct.
Drina	45865	DRINA	BAJINA BAŠTA	14797	294.40	37.77	34.53	19.53	11.21	**8.38**	9.01	14.29
	45882	DRINA	RADALj	17490	331.39	35.77	33.92	20.99	13.58	**9.18**	10.10	15.73
	45837	LIM	PRIJEPOLjE	3160	69.20	9.63	8.12	4.48	1.98	**1.14**	1.76	2.72
	45892	JADAR	LEŠNICA	959	7.52	0.88	0.61	0.57	0.25	**0.14**	0.12	0.20
Dunav	42010	DUNAV	BEZDAN	210250	2253.60	176.89	151.57	180.51	144.19	**144.56**	128.65	98.53
	42020	DUNAV	BOGOJEVO	251593	2706.24	211.96	185.11	203.33	161.93	**163.89**	148.83	106.17
	42055	DUNAV	SMEDEREVO	525820	5028.50	443.77	364.57	359.90	257.31	**237.27**	240.31	231.68
	44020	TISA	SENTA	141715	776.90	104.93	80.71	61.12	44.21	**37.26**	32.52	35.13
	45090	SAVA	SREMSKA MITROVICA	87996	1505.97	163.45	136.26	96.12	56.60	**45.17**	58.72	79.61
	42401	TAMIŠ	JAŠA TOMIĆ	5334	39.21	5.56	4.59	3.48	2.18	**1.54**	1.41	1.31
	42730	PEK	KUSIĆE	1220	8.17	1.34	0.78	0.40	0.23	**0.19**	0.15	0.23
	42527	MLAVA	VELIKO SELO	1124	7.58	1.26	0.73	0.50	0.28	**0.23**	0.15	0.22
Ibar	47295	IBAR	LOPATNICA LAKAT	7818	55.19	7.54	5.06	3.51	2.60	**1.91**	1.91	2.20
Južna Morava	47590	JUŽNA MORAVA	MOJSINjE	15390	83.10	13.29	8.24	5.22	3.01	**2.40**	1.85	2.61
	47570	JUŽNA MORAVA	ALEKSINAC	14284	71.98	12.24	7.18	4.58	2.51	**2.07**	1.68	2.35
	47530	JUŽNA MORAVA	VLADIČIN HAN	3052	17.66	2.66	1.60	1.05	0.60	**0.47**	0.34	0.59
	47665	VETERNICA	LESKOVAC	500	3.43	0.63	0.37	0.19	0.10	**0.08**	0.11	0.11
	47740	JABLANICA	PEČENjEVCE	891	3.34	0.58	0.29	0.14	0.06	**0.04**	0.03	0.06
	47640	VLASINA	VLASOTINCE	879	6.67	1.08	0.73	0.47	0.28	**0.21**	0.18	0.21
	47528	JUŽNA MORAVA	VRANjSKI PRIBOJ	2775	9.47	1.62	0.87	0.47	0.25	**0.17**	0.18	0.26
Kolubara	45905	KOLUBARA	VALjEVO	340	3.38	0.43	0.28	0.26	0.13	**0.08**	0.08	0.11
	45910	KOLUBARA	BELI BROD	1896	14.75	1.79	1.32	1.17	0.65	**0.42**	0.38	0.49
Nišava	47920	NIŠAVA	PIROT	1745	14.26	1.92	1.34	1.13	0.61	**0.60**	0.51	0.67
	47990	NIŠAVA	NIŠ	3870	25.42	3.80	2.55	1.84	1.02	**0.96**	0.80	1.05
Timok	42921	BELI TIMOK	KNjAŽEVAC	1242	6.80	1.24	0.73	0.38	0.21	**0.15**	0.13	0.17
	42929	BELI TIMOK	ZAJEČAR	2150	10.14	1.83	1.07	0.57	0.31	**0.23**	0.19	0.25
Toplica	47880	TOPLICA	PROKUPLjE	1774	8.44	1.49	0.82	0.45	0.27	**0.18**	0.17	0.22
Zapadna Morava	47350	MORAVICA	ARILJE	830	10.54	1.60	1.10	0.84	0.57	**0.34**	0.32	0.40
	47120	ZAPADNA MORAVA	MILOČAJ	4658	37.53	4.86	3.59	2.74	1.89	**1.22**	1.16	1.55
	47195	ZAPADNA MORAVA	JASIKA	14721	97.48	13.53	8.97	6.29	4.73	**3.43**	3.14	3.91
Velika Morava	47090	VELIKA MORAVA	LJUBIČEVSKI MOST	37320	219.86	33.08	21.62	14.57	10.04	**7.45**	6.07	7.64
	47040	VELIKA MORAVA	BAGRDAN	33446	199.32	30.49	19.17	11.95	8.86	**6.52**	5.35	7.04
	47010	VELIKA MORAVA	VARVARIN	31548	185.17	27.86	17.87	11.07	8.15	**6.00**	5.09	6.73
	47075	JASENICA	SM.PALANKA (JASENICA)	496	1.67	0.22	0.16	0.10	0.05	**0.03**	0.03	0.04
	47076	KUBRSNICA	SM.PALANKA (KUBRSNICA)	743	1.61	0.14	0.13	0.10	0.07	**0.04**	0.04	0.05

3.1.2 Catchment Results

After estimating Q_{irr} for each hydrological station based on the statistical analysis results, these values should be assigned to the corresponding catchment areas listed in Table 3 and denoted in Figure 14. This was done by assigning the Q_{irr} value for the most downstream catchment hydrological station to the cumulative Q_{irr} of the catchment confluence areas and the tributary upstream catchments. Hence, by analysing catchments in the upstream direction, Q_{irr} values related to individual catchment areas can be simply calculated using the water balance equation.

After estimating Q_{irr} for each catchment, the potential irrigation areas can be determined based on the previously calculated design irrigation module q, as follows:

$$A_{irr} = Q_{irr}/q \quad (9)$$

Južna Morava, Zapadna Morava and Velika Morava Subcatchments

These three subcatchment areas are presented in Figure 16 with the relevant downstream stations bolded in the corresponding table. Since Južna and Zapadna Morava are the two main tributaries of the Velika Morava River, it is clear that Q_{irr} = 7.45 m^3/s ("Ljubičevski Most" - the most downstream station on Velika Morava) is the cumulative Q_{irr} for the three subcatchment areas. Based on Q_{irr} values for the downstream stations on Južna and Zapadna Morava subcatchments, Q_{irr} = 2.40 m^3/s and Q_{irr} = 3.43 m^3/s are used as corresponding irrigation discharge values respectively, leaving Q_{irr} = 7.45 – 2.40 – 3.43 = 1.62 m^3/s for the Velika Morava subcatchment (check Figure 16).

Based on the design module *q*, which is about 0.5 l/(s ha) for the central region of the Republic of Serbia, gross potential irrigation area A_{irr} for the overall Morava catchment, with direct abstraction from rivers, is about A_{irr} = 7.45/0.5x1000 ≈ 15000 ha, while A_{irr} for Južna, Zapadna and Velika Morava subcatchments are around 5000, 7000 and 3000 ha, respectively.

Catchment	StationID	River	Station name	A (km2)	August	Qirr (m3/s)
Južna Morava	47295	IBAR	LOPATNICA LAKAT	7818	1.91	2.40
	47590	**JUŽNA MORAVA**	**MOJSINjE**	**15390**	**2.40**	
	47570	JUŽNA MORAVA	ALEKSINAC	14284	2.07	
	47530	JUŽNA MORAVA	VLADIČIN HAN	3052	0.47	
	47665	VETERNICA	LESKOVAC	500	0.08	
	47740	JABLANICA	PEČENjEVCE	891	0.04	
	47640	VLASINA	VLASOTINCE	879	0.21	
	47528	JUŽNA MORAVA	VRANjSKI PRIBOJ	2775	0.17	
	47920	NIŠAVA	PIROT	1745	0.60	
	47990	NIŠAVA	NIŠ	3870	0.96	
	47880	TOPLICA	PROKUPLjE	1774	0.18	
Zapadna Morava	47350	MORAVICA	ARILJE	830	0.34	3.43
	47120	ZAPADNA MORAVA	MILOČAJ	4658	1.22	
	47195	**ZAPADNA MORAVA**	**JASIKA**	**14721**	**3.43**	
Velika Morava	**47090**	**VELIKA MORAVA**	**LJUBIČEVSKI MOST**	**37320**	**7.45**	1.62
	47040	VELIKA MORAVA	BAGRDAN	33446	6.52	
	47010	VELIKA MORAVA	VARVARIN	31548	6.00	
	47075	JASENICA	SM.PALANKA (JASENICA)	496	0.03	
	47076	KUBRSNICA	SM.PALANKA (KUBRSNICA)	743	0.04	

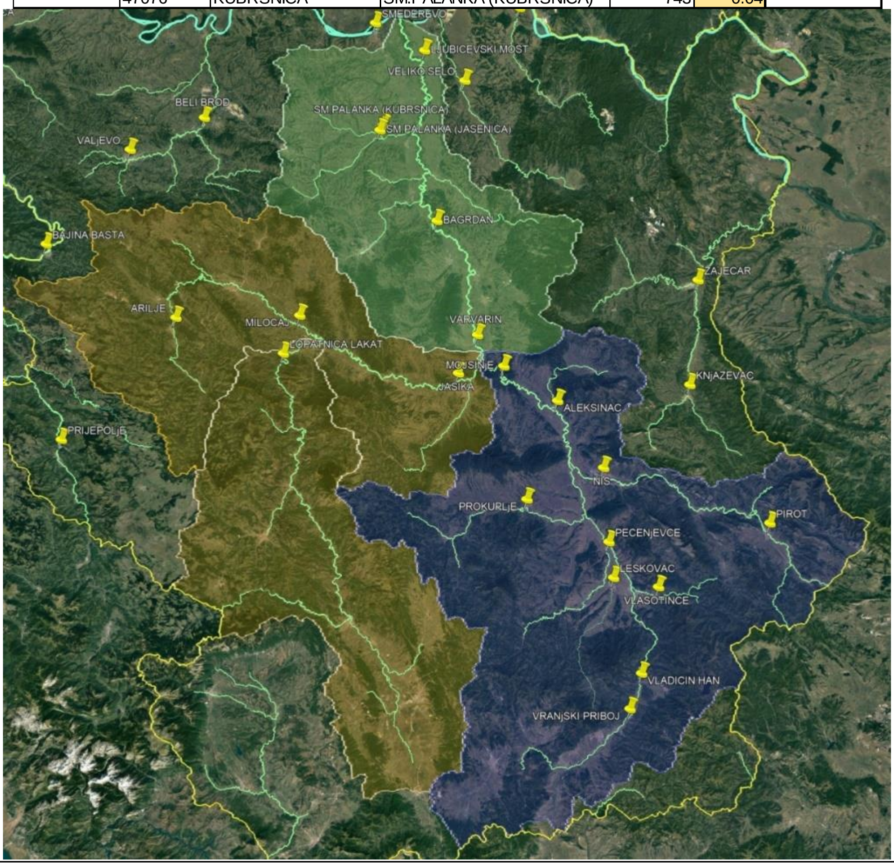


Figure 16.
Morava catchment, consisting of Južna Morava, Zapadna Morava and Velika Morava subcatchments, together with corresponding hydrological stations

Kolubara Catchment

The approach presented assumes that the relevant hydrological station is located downstream enough (close to the confluence with the Sava River), so that the corresponding Q_{irr} can be assigned to the whole (sub)catchment area. However, this is not the case with the Kolubara Catchment, since the most downstream hydrological station Beli Brod covers only 52 % of the whole catchment area (please see Figure 17). Therefore, the corresponding Q_{irr} = 0.42 m^3/s is increased proportional to the catchment area, resulting in Q_{irr} = 0.42/0.52 ≈ 0.8 m^3/s.

Based on q = 0.4 l/(s ha) value used for western Serbia, estimated A_{irr} for the Kolubara Catchment is around 0.8/0.42x1000 ≈ 2000 ha.

StationID	River	Station name	A (km2)	August	Qirr (m3/s)
45905	KOLUBARA	VALjEVO	340	0.08	0.8
45910	KOLUBARA	BELI BROD	1896	0.42	

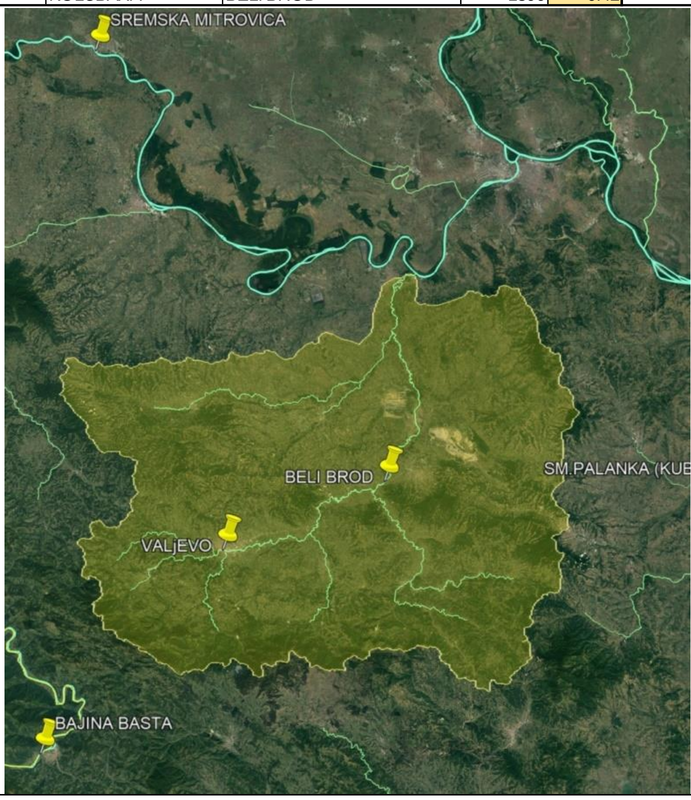


Figure 17.
Kolubara Catchment and the corresponding hydrological stations

Mlava, Pek & Timok Catchments

In this section, results for the three independent catchments (Mlava, Pek and Timok catchments), located in the east part of Serbia, are presented (please see Figure 18). Similar to the Kolubara Catchment, due to fact that downstream hydrological stations do not cover the entire catchment areas of Timok and Mlava, the corresponding Q_{irr} values are increased proportionally to their areas. Results are presented in Figure 18 and summarized below (q = 0.52 l/(s ha) is used for this region):

- Mlava Catchment - Q_{irr} = 0.39 m^3/s; A_{irr} = 0.39/0.52x1000 ≈ 750 ha;

- Pek Catchment – Q_{irr} = 0.19 m^3/s; A_{irr} = 0.19/0.52x1000 ≈ 360 ha; and,
- Timok Catchment – Q_{irr} = 0.47 m^3/s; A_{irr} = 0.47/0.52x1000 ≈ 900 ha.

Results clearly show that there is not enough water for irrigation of large areas, and the only way of increasing potential irrigation areas would be the construction of reservoirs.

StationID	River	Station name	A (km2)	August	Qirr (m3/s)
42730	PEK	KUSIĆE	1220	0.19	**0.19**
42527	MLAVA	VELIKO SELO	1124	0.23	**0.39**
42921	BELI TIMOK	KNjAŽEVAC	1242	0.15	**0.47**
42929	BELI TIMOK	ZAJEČAR	2150	0.23	

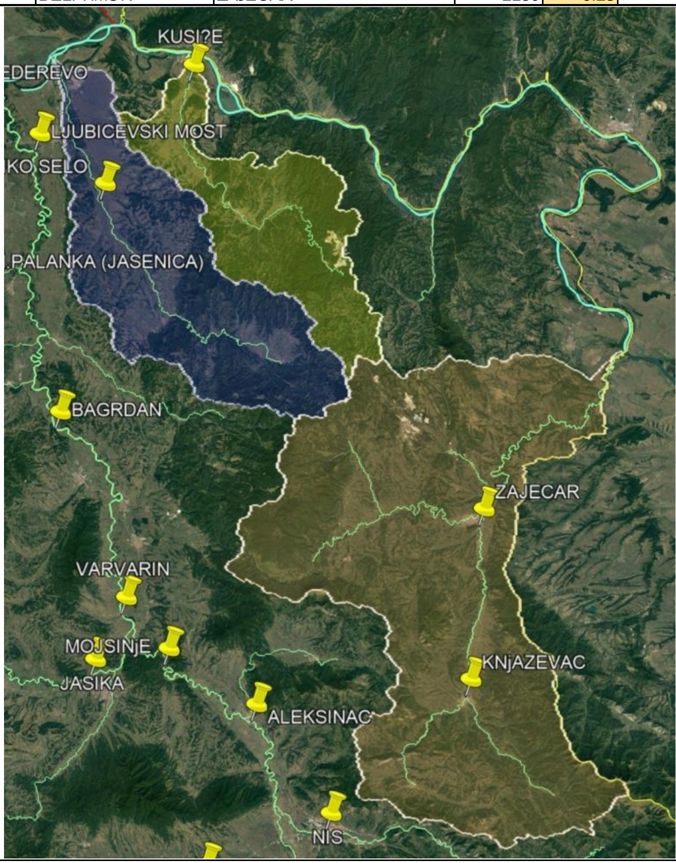


Figure 18.
Mlava, Pek and Timok catchments together with the corresponding hydrological stations

Drina Catchment

Drina is a transboundary river with a catchment area of 17720 km^2 extending across 3 countries: Montenegro, Serbia and Bosnia-Herzegovina, each of them having about 1/3 of the catchment area on their territory.

The estimated value of Q_{irr} is about 9.3 m^3/s, equal to the sum of Q_{irr} for Radalj Hydrologial Station (9.18 m^3/s – Drina River) and Q_{irr} for Lesnica Hydrologial Station (0.14 m^3/s – Jadar River). Please consult Figure **19** for more details. The available water has to be divided between Bosnia-Herzegovina and Serbia, so it can be assumed that Q_{irr} for Serbia is around 9.3/2=4.65 m^3/s.

The main potential irrigation areas are situated at the most downstream part of the river Drina (Mačva in Serbia and Semberija in Bosnia- Herzegovina). It should be noted that the canal and gate for Semberija water abstraction have already been constructed, while the Semberija irrigation system has been designed and partly build (the projected and designed area of the Semberija irrigation system is about 8500 ha).

Having in mind that q = 0.45 l/(s ha) is adopted for this region, A_{irr} = 4.65/0.45x1000 ≈ 10300 ha is an approximate area that can be irrigated with water directly withdrawn from the Drina River.

StationID	River	Station name	X	Y	A (km2)	Zo (m.a.s)	August	Qirr (m3/s)
45865	DRINA	BAJINA BAŠTA	7383425	4871075	14797	211.47	8.38	9.3
45882	DRINA	RADALj	7352959	4921062	17490	129.47	9.18	
45837	LIM	PRIJEPOLjE	7390050	4805150	3160	443.37	1.14	
45892	JADAR	LEŠNICA	7363500	4944625	959	103.47	0.14	

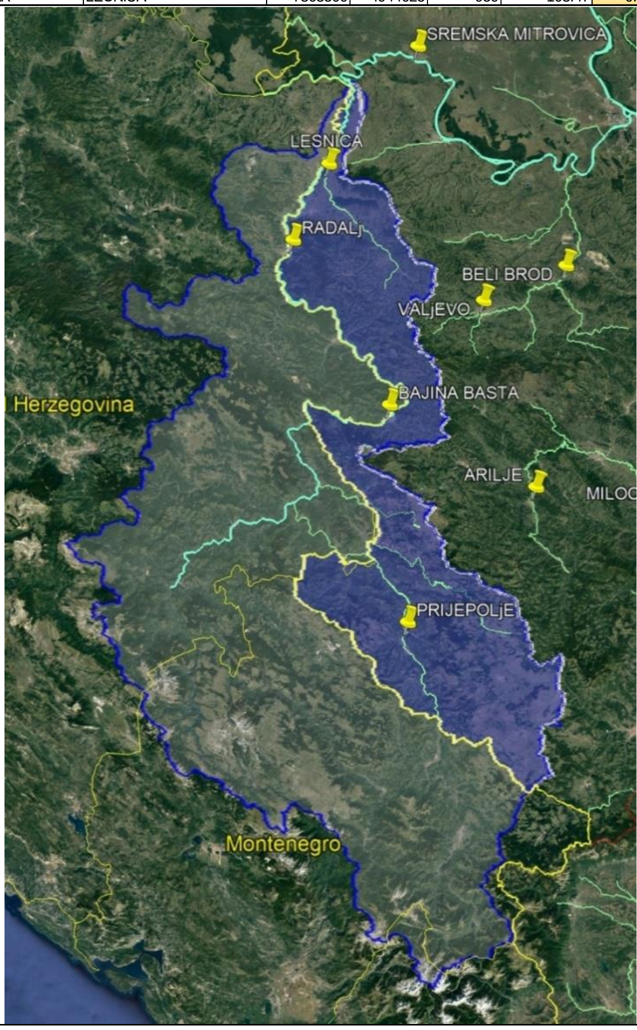


Figure 19.

Drina Catchment with the corresponding hydrological stations

Sava Catchment

Sava is a transboundary river and an international waterway.

Estimated Q_{irr} for the Sava Catchment is based on the data from the Sremska Mitrovica Hydrological Station. Bearing in mind that the river Drina is a tributary of the Sava River, based on the water balance approach, the value of Q_{irr} = 35.9 m^3/s for the Sava Catchment is calculated as a difference between Q_{irr} for Sremska Mitrovica (45.2 m^3/s) and Q_{irr} for the Drina

Catchment (9.3 m^3/s). Please consult Figure **20** for more details. The determined Q_{irr} value is close to the discharge value already planned for abstraction in the two technical documents on two potential irrigation regions located on the left and right banks of the river Sava: General Design for Irrigation of the Srem Region and General Design for Irrigation of the Mačva Region. By assuming a value of q = 0.46 l/(s ha) for this region, the potential irrigation area that can be supplied with water directly withdrawn from Sava is around A_{irr} ≈ 35.9/0.46x1000 ≈ 78000 ha.

Note that there is a potential water management conflict of interest between water withdrawal for irrigation and drought water transport, due to fact that Sava is an international waterway.

StationID	River	Station name	X	Y	A (km2)	Zo (m.a.s)	August	Qirr (m3/s)
45090	SAVA	SREMSKA MITROVICA	7390175	4981125	87996	72.22	45.17	**35.90**

Figure 20.
Sava Catchment with the corresponding Sremska Mitrovica station

Dunav, Tisa and the DTD System

The highest potential for irrigation is in the north of Serbia. The potential is recognized and identified based on water availability and irrigable land surface area.

DTD hydro system was designed and partly built to be used for irrigation, as well as for other water management tasks (drainage, flood protection, water transport and environmental water requirements).

Most of the irrigation water that might be directed towards the DTD channel network could be withdrawn from the Danube River (Bezdan and Bogojevo hydro profiles). The estimated available water for irrigation from the Danube is 164 m^3/s, meaning that the potential irrigation area is about 300000 ha. It should be noted that the existing structures in the hydro nodes of Bezdan and Bogojevo, as well as in the downstream channels, do not have enough capacity at the present moment for the maximum potential irrigation water abstraction.

Moreover, it should be noted that there is a potential water management conflict during periods of drought, because the Danube is an international waterway, thus international obligations must be met and water management priority rules defined and established.

Another hydro node for irrigation water abstraction is the Tisa River Dam.

The estimated available water for irrigation from **Tisa** is 37.3 m^3/s, meaning that the potential irrigation area is about 70000 ha.

Again, there is potential water management conflict when it comes to water transport during drought years, having in mind that Tisa is also an international waterway.

Additional 3000 ha could abstracted from the river Tamiš for irrigation.

StationID	River	Station name	X	Y	A (km2)	Zo (m.a.s)	August	Qirr (m3/s)
42010	DUNAV	BEZDAN	7334254	5081102	210250	80.64	144.6	**164**
42020	DUNAV	BOGOJEVO	7350350	5044540	251593	77.46	163.9	
44020	TISA	SENTA	7430200	5087875	141715	72.8	37.3	**37.3**
42401	TAMIŠ	JAŠA TOMIĆ	7489150	5031950	5334	73.46	1.54	**1.5**

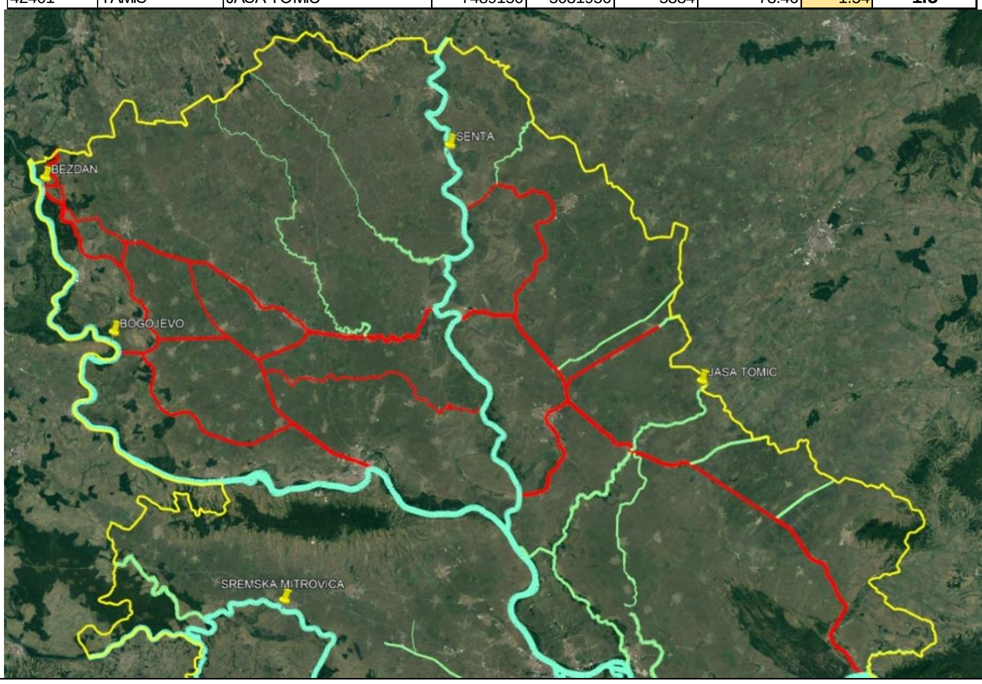


Figure 21.

The Danube and Tisa catchments, together with the DTD system

3.2 Groundwater – River Alluvium Abstraction

Ground water for irrigation purposes can be abstracted only from the river alluvium layers. There are several reasons for this limitation:

- The main reason stems from the **Water Law,** where it is stated that high quality groundwater that could be readily used for water supply, cannot be used for other purposes;
- Water supply is a priority, so springs, especially in karst regions, cannot be used for irrigation;
- 80% of water supply in Serbia relies on groundwater, so it can be abstracted for irrigation purposes only from water-bearing layers that can be replenished during the non-irrigation periods. Please note that using water from deep groundwater-bearing layers is considered groundwater mining, and it is not in accordance with sustainable development principles.

Based on the aforementioned, it is clear that alluvium layers of large rivers are the only possible source of groundwater for irrigation purposes (dark blue areas in Figure 22), as the abstraction from these sources is considered delayed abstraction from the river itself. In such cases, the aquifer is used as a retention basin that is gradually refilled with water non-irrigation periods.

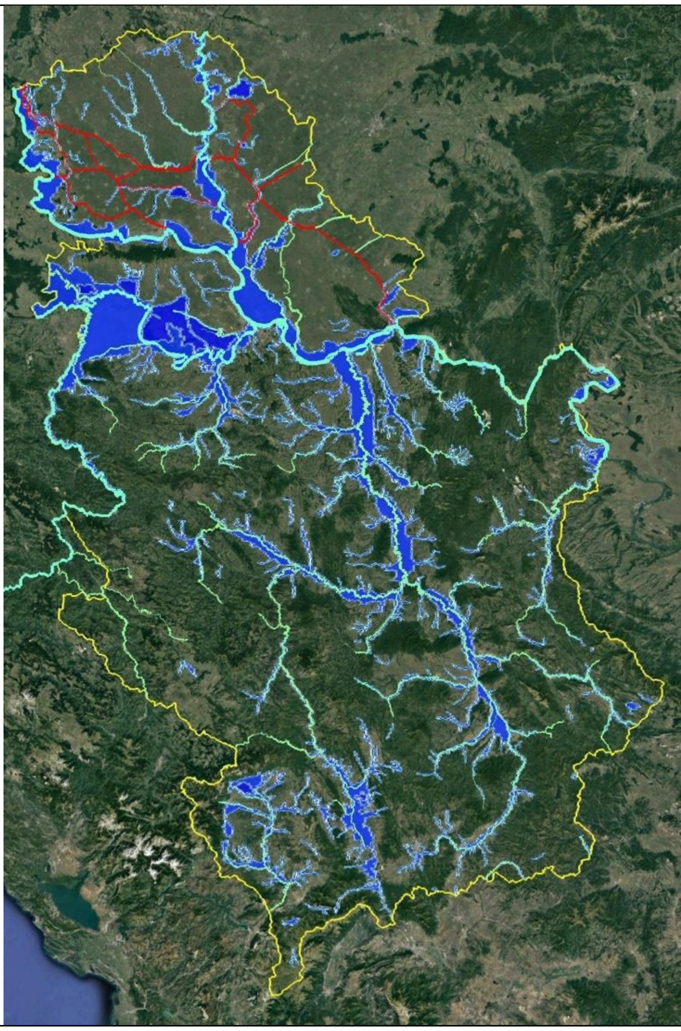


Figure 22.
Marked areas of river alluviums that can be used for irrigation purposes
under the conditions explained in the text

Furthermore, there are certain **preconditions and prerequisites that need to be met and fulfilled in technical documentation before groundwater is used for irrigation:**

- The detailed analysis and modelling proving that the abstraction of groundwater for irrigation purposes will not affect the present and future water supply in the region;
- The detailed analysis and modelling proving that groundwater is able to replenish itself during non-irrigation seasons, so that irrigation will not have a permanent effect on the groundwater balance; and,
- The detailed analysis and modelling proving that irrigation will not have a long-term effect on groundwater quality.

Available groundwater abstraction (so-called dynamic reserve) is estimated based on previous analyses, studies and projects summarized and presented in the *Water Management Strategy for the Territory of the Republic of Serbia by 2034 ("The Official Gazette of the Republic of Serbia", no. 3/20172017).* Data on potential groundwater abstraction for irrigation purposes presented here should be considered as a generalized approximation.

Due to the uncertainties involved in the approximate data presented here, detailed investigation and analysis is required for each project (area) individually. First of all, it is unclear whether the data acquired from the Strategy (presented in Table 4) is related to the maximum or the average capacity of wellfields that can be used for irrigation. Furthermore, the potential wellfield capacity in periods of drought is unknown. That is why the present results concerning the potential groundwater abstraction should only be understood as a rough estimate.

Table 4. Available abstraction from groundwater (dynamic reserves) in different regions

Catchment	Region	Dynamic reserves [m^3/s]
Dunav	Bezdan-Sombor	1,0-1,5
	Kovin-Dubovac	1,5
	rest on the left bank	0,5-1,0
	Kostolačko ostrvo & region Kostolac and Smederevo	1-1,5
	Veliko Gradište region	0,5-1,0
	rest on the right bank	0,5-1,0
Sava	Srem	1,0-2,0
	Mačva	2,0-2,5
	rest	0,5
Morava	V. Morava upstream od Požarevca	0,7-1,0
	V. Morava downstream Požarevac	0,7-1,0
	Južna Morava	0,3-0,5
	Zapadna Morava	0,3-0,5
Rest		0,5-1,0

Based on the dynamic reserves presented in Table 4, and the adopted value of q = 0.5 l/(s ha), a generalized approximation of the available irrigation water abstracted from river alluviums is made:

- Danube alluvium – $Q_{irr} \approx 5\ m^3/s$, $A_{irr} \approx 5/0.5x1000 = 10000$ ha;
- Sava alluvium - $Q_{irr} \approx 3.5\ m^3/s$, $A_{irr} \approx 3.5/0.5x1000 = 7000$ ha; and,
- Morava alluvium - $Q_{irr} \approx 2\ m^3/s$, $A_{irr} \approx 2/0.5x1000 = 4000$ ha.

3.3 Irrigation Reservoirs

3.3.1 Existing Reservoirs Planned for Irrigation

There are not that many existing reservoirs used for irrigation. None of them is a single-purpose reservoir designed for irrigation only. Usually reservoirs are built primarily for flood protection, but are alternatively used for irrigation. Most of the reservoirs with volumes above 2 Mm^3 are located in the Srem region, along the streams stemming from the Fruška Gora Mountain (please see Table 5 and Figure 23).

Table 5. List of Existing Reservoirs Used for Irrigation

Name	River	Settlement	Region	V [$10^3\ m^3$]
Tisa	Tisa	Novi Bečej	Srednjebanat.	160.1
Velebit	Adorjan	Kanjiža	Severnobački	5.27
Borkovac	Borkovac	Ruma	Sremski	1.52
Šelevrenac	Šelevrenac	Inđija	Sremski	3.124
Međeš	Međeš	Šatrinci	Sremski	1.416
Vraneš	Manđeloški p.	Sr. Mitrovica	Sremski	
Pavlovci	Kudoš	Ruma	Sremski	3.235
Moharač	Moharač	Erdevik	Sremski	2.343

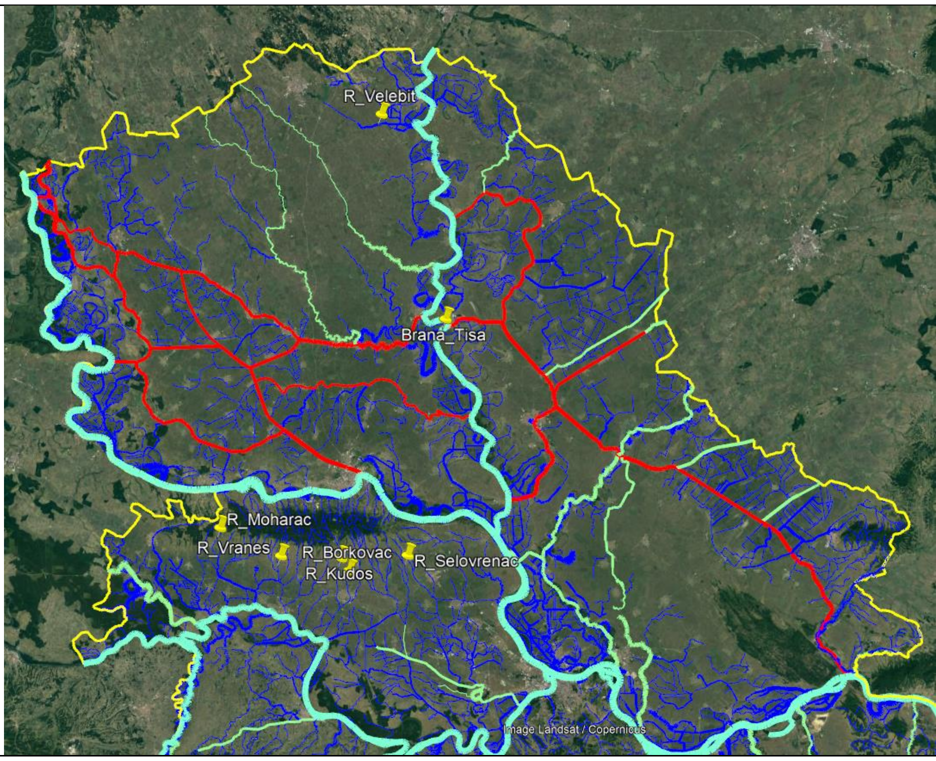


Figure 23. Existing Reservoir Locations Used for Irrigation

The present data pertains to the existing reservoirs with volumes higher than 2 Mm^3 *(source: Water Management Strategy for the Territory of the Republic of Serbia by 2034)*. A reservoir created upstream from the River Tisa Dam (Novi Bečej hydro node) is also included on the list, because it was meant to be used for irrigation purposes, alongside other water management tasks (flood protection, water transport, environmental protection). Based on the available volumes, it can be concluded that all the reservoirs, except the Tisa reservoir, are sufficient for smaller-area irrigation only.

For example, the recent calculations have shown that the Moharač reservoir (please see Figure 24), with volume of 2 Mm^3 and the catchment area of 19.5 km^2, can be used for irrigation of about 400 ha.

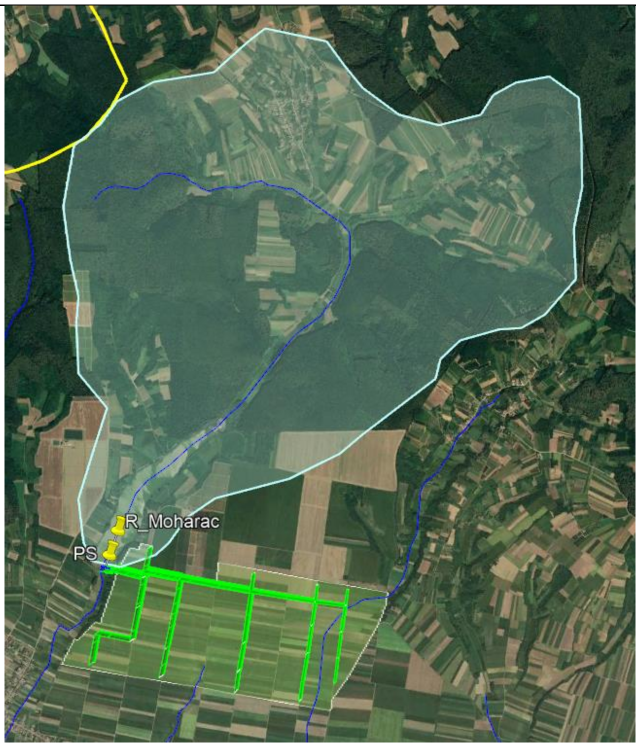


Figure 24. Moharač reservoir and its corresponding catchment area

3.3.2 Multipurpose Reservoirs

Building dams and creating large reservoirs that would be a part of the regional irrigation system is probably not a realistic goal at this moment in time, having on mind that it would be difficult to prove the feasibility of these projects. On the other hand, multipurpose reservoirs with clearly defined operation rules are of great importance in the future water resource management in Serbia.

Flood Protection Reservoirs

For example, after the flood event that happened in 2014, more than 20 reservoirs have been planned for flood protection in the Kolubara Catchment (please see Figure 25). Initially, these were planned as single-purpose reservoirs for flood protection only, but, with adequate rules of operation, including an early warning flood protection system and adequate dam drawdown facility design providing fast pre-flood water removal capabilities, these reservoirs could become multipurpose reservoirs also used for irrigation. This is especially important for the Kolubara Catchment, where it has been calculated and shown that direct river abstraction would result in only about 2000 ha of land irrigated.

As an example, the recent analysis results for reservoirs Pambukovica and Kamenica (please see Figure 26), primarily meant for flood protection, have shown their potential for irrigation:

- Pambukovica (10.6 Mm^3) – A_{irr} = 2500 ha; and,
- Kamenica (11.1 Mm^3) – A_{irr} = 1800 ha.

The rough estimate is that there is a potential irrigation capacity of up to 20000 ha from the planned flood protection reservoirs in the Kolubara Catchment.

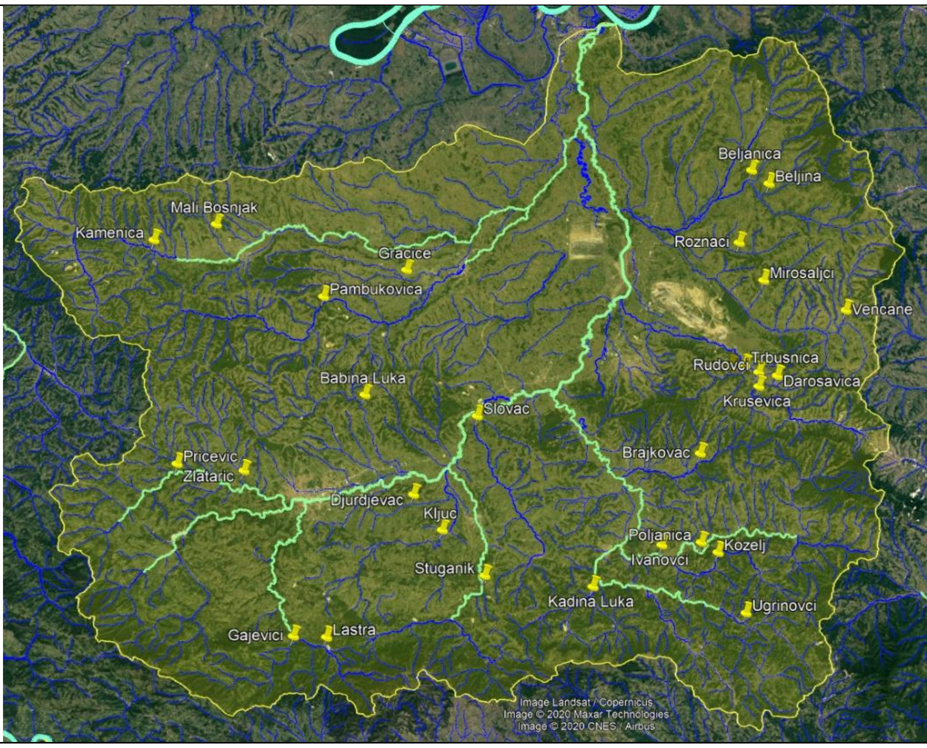


Figure 25. Flood protection reservoirs in the Kolubara catchment that could be used for irrigation purposes

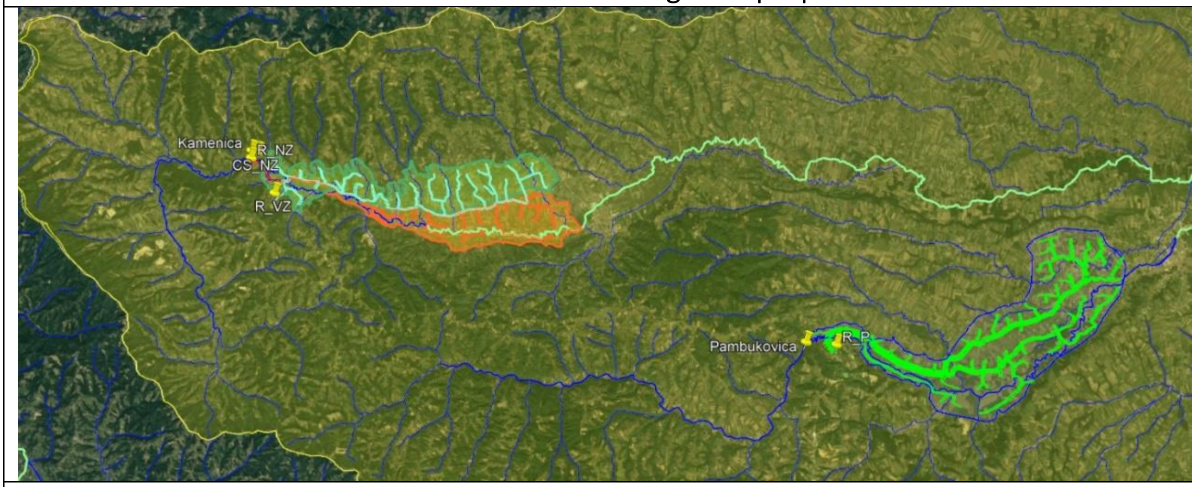


Figure 26. Pampukovica and Kamenica Reservoirs

Water Supply Reservoirs

Moreover, it is well-known from previous analyses that water supply reservoirs have irrigation potential. Water supply reservoirs are planned and designed as part of the regional water supply systems with volumes defined based on demographic and industrial growth projections and specific consumption during the 1980s. Obviously, most of those projections were overestimations. List of reservoirs is shown in Table 6, while their locations are mapped in Figure 27.

A conservative estimate is that 12000 ha can be irrigated from selected reservoirs. However, it should be emphasized that water supply reservoirs could be used for irrigation only if detailed investigation, analyses and modelling prove that adherence to certain water management rules is possible, namely that they:

- would not affect present and future water supply development in the region;
- would not significantly increase the risk of water supply deficit in drought years; and,
- would not have a long-term effect on reservoir water quality.

Table 6. List of water supply reservoirs that could be used for irrigation purposes

Reservoir	River	Year built	Type	Height (m)	Width (m)	Volume (10^6 m^3)
Bovan	Moravica	1978	Z	52	151	59
Gruža	Gruža	1984	L	52	288	65
Barje	Veternica	1991	K	75	326	41
Prvonek	Banjska	2005	K	88	250	20
Stuborovni	Jablanica	2018	K	74	430	52

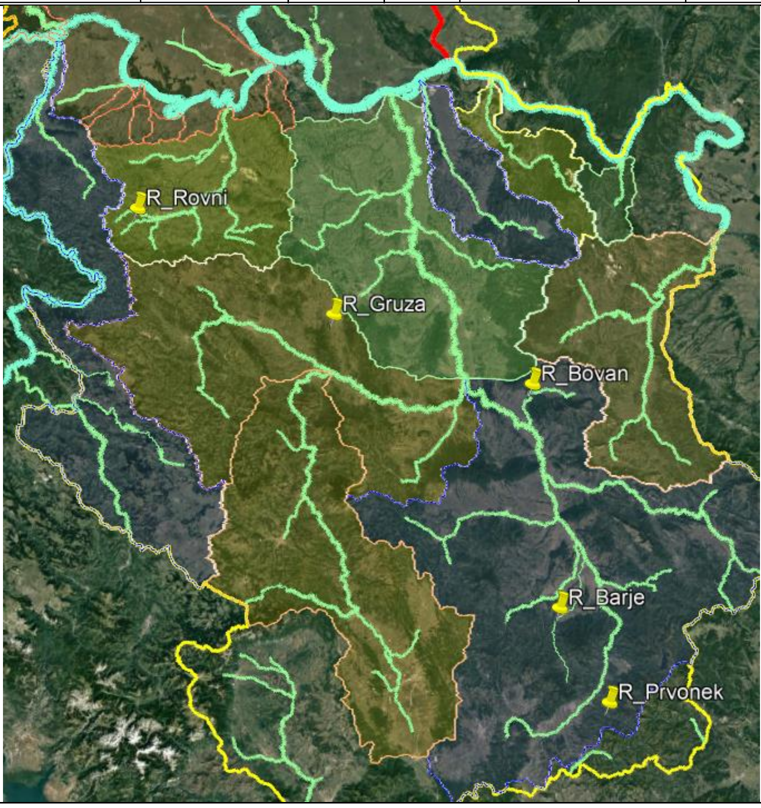


Figure 27. Locations of the existing water supply reservoirs that could be used for irrigation

4 Conclusions

The potential for irrigation in terms of Irrigation Water Requirement (IWR) and Irrigation Water Availability (IWA) in the Republic of Serbia can be characterized by significant spatial differences.

Even though the north part of the Republic of Serbia (Vojvodina) has low precipitation rates, there is a huge potential for irrigation with water abstracted mainly from the Danube and Tisa rivers and directed through the DTD canal system to individual irrigation beneficiaries. Also, there is potential for water abstraction from the Sava River for the irrigation of Srem region in Vojvodina. Based on the present analysis, a total estimated potential irrigated area is about 450000 ha. It should be noted that there is a potential water management conflict during droughts, as the Danube, Tisa and Sava are international waterways. In addition, it is necessary to invest in the reconstruction and refurbishment of the DTD canal system and the adjacent accompanying hydro nodes in order for it to meet its irrigation potential.

South from the Sava River there is much less potential for irrigation in terms of water availability. The Mačva region can be irrigated with water abstracted from Drina, Sava and groundwater levels (an alluvium that those two rivers had created). Due to fact that Drina is a transboundary river, potential abstraction from Drina has to be divided between Serbia and Bosna-Herzegovina. Based on the present analysis, potential irrigated area with water from Drina and its alluvium is more than 17000 ha.

In the Kolubara Catchment, the water available for direct abstraction from rivers is very scarce. It is estimated that only about 2000 ha could be irrigated in this way. In order to extend and expand the potential irrigated area, reservoirs need to be built. About 20 reservoirs for flood protection are planned in the Kolubara Catchment area. With proper design and water management rules, some of these reservoirs could be used for irrigation as well. This would increase the potential irrigated area to more than 20000 ha. Moreover, the Kolubara Catchment contains the Rovni reservoir, that was built as part of the Kolubara regional water supply system, and could be potentially used as an additional irrigation source.

Velika Morava has an irrigation potential of up to 15000 ha. If the irrigated area is divided between its main tributaries - Južna and Zapadna Morava, then the potential irrigated areas from direct river abstraction is 5000 ha for Južna Morava, 7000 ha for Zapadna Morava and 3000 ha for Velika Morava. Additional 4000 ha could be irrigated from groundwater. Additionally, 4 water supply reservoirs with volumes above 20 million m^3 exist in the Velika Morava Catchment - Gruža, Bovan, Barje and Prvonek, and, with proper water management rules, they represent potential irrigation sources.

Regions in the east part of Serbia, located in the catchments of rivers Mlava, Pek and Timok, far from the Danube River, have the least irrigation potential due to scarce water availability for direct river abstraction. The potential irrigation area is estimated to be around 2000 ha. This surface area could only be increased by building multipurpose reservoirs, where irrigation would be one of the potential purposes thereof. In terms of water availability, there is almost unlimited potential for irrigation in the east parts of Serbia that are close to the Danube River (regions in the proximity of Kladovo and Negotin).