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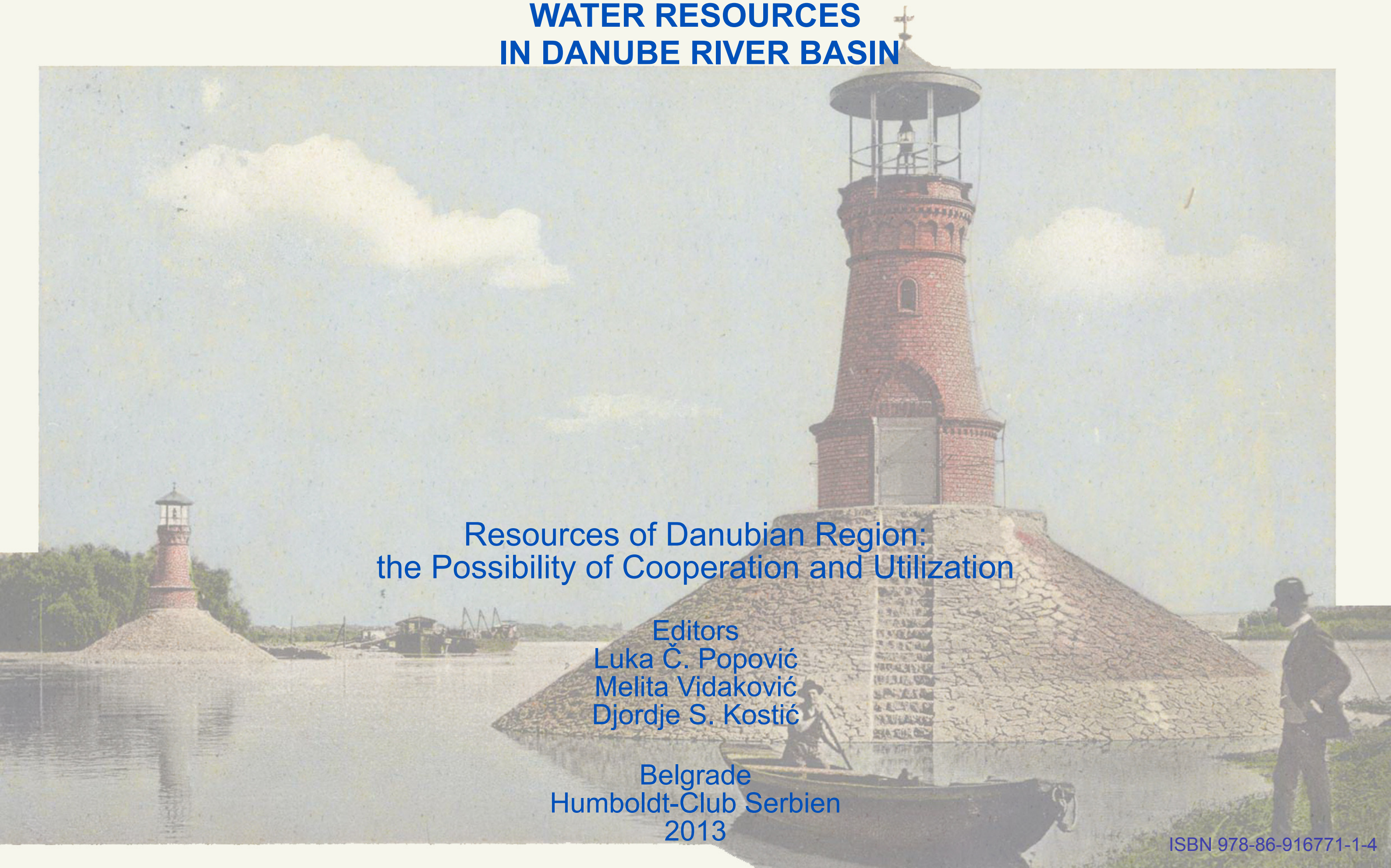
WATER RESOURCES IN DANUBE RIVER BASIN



Resources of Danubian Region:
the Possibility of Cooperation and Utilization

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Belgrade
Humboldt-Club Serbien
2013

ISBN 978-86-916771-1-4


ГРАД СМЕДЕРЕВО НА ДУНАВУ

Introduction

The Danube River is the second longest river in Europe and flows through – or from a part of the borders of ten countries. The total length of the main Danube catchment is 2,860 km. The total drained areas (including parts of nine countries/areas with Danube tributaries only) cover 817,000 km^2, which represents 8% of the total European land surface. Therefore, one can see that this area is of interest both historically and in relation to components of everyday life. This work deals with the water balance in this area.

The Danube River Basin is home to 81 million people with a wide range of cultures, languages and historical backgrounds.

Some Remarks on the History of the Danube Water balance

Co-operation in the field of hydrology on the official (supplementary to the regular exchange of the data for discharge forecast in the frame of the World Meteorological Organisation) began in 1972 as a co-operation among a group of states lead by UNESCO (Germany, Austria, Federal Republic of Yugoslavia) and a group of states (Czechoslovakia, Hungary, Soviet Union, Bulgaria, Romania) under the umbrella of the scientific working group for hydrology of the Danube (navigation) Commission in Budapest. This first phase of co-operation, which was later unified into the International Hydrological Programme produced a very interesting result – the Hydrological Monograph of the Danube River (Stančik et al., 1988) – a representative publication in the four languages, giving an overview of tabular processing and spatial distribution of the main hydrological elements (precipitation, superficial runoff depth and actual superficial evapotranspiration) in the whole Danube River Basin. The methodology at that time was based on the national contribution in the form of maps of the balance elements. The role of the co-ordinator was first to provide guidance in relation to methodological questions and secondly to bring together the national input in the form of isolines of the individual balance elements into "tailor-made" maps of water balance elements.

It was determined that this regional co-operation in the frame of the IHP UNESCO was about the great significance and it was decided that the topic would be studied further and follow-up volume to the Danube Hydrological Monograph would be published.

In the 1990s, a new initiative – at that time under the leadership of Dr. Oskar Behr (TU Vienna) – started to assemble a new version of the water balance for the whole Danube River Basin. The first methodological proposals were at the working meeting of the Chairmen of the NCs (National Committees) for the IHP UNESCO of the Danube Countries in Lednice (Czech Republic). At that meeting it was decided that the Slovak NC IHP UNESCO would be responsible for Water Balance on the whole area of the Danube Basin. The final results of this work, concerning the water balance in the Danube River Basin, will be presented in this paper.

Water Balance Methodology and Results

The methodology and results of the present study are based on contemporary available technology and data processing tools. This section consists of three parts. The first deals with the GIS base and tools for improved input data preparation for the further study and processing. The second part describes data assembly. The third part of the study provides an evaluation of water modelling and tuning for selected balance regions using a modified mathematical model of water balance working with lumped parameters for each balance region.

Assessment of Water Dividing Lines

Construction of water divides was a task for each participating country itself (through IHP UNESCO NCs and notional hydrological services). The expected precision was a reference scale of 1:50,000 or better.

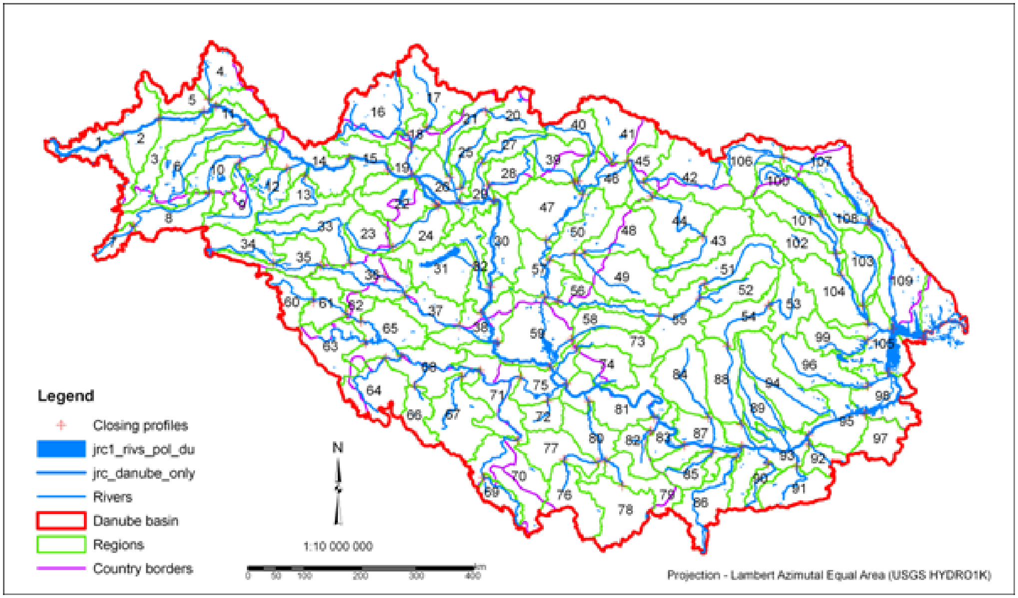

Figure 1.
Map of balance regions in the Danube River Basin

The water dividing lines from "boundaries" of balance regions. Therefore, the balance regions should be natural runoff areas (sub-basin or group of sub-basins) from our point of view with quasi-homogeneous characteristics if the vertical gradient of basic hydrometeorological elements. The region (some of them transboundary) must fully cover the whole territory of the Danube Basin. The resulting map of selected balance regions in the Danube River Basin can be seen in Fig. 1.

Maps of Water Balance Elements

The maps were prepared based on data provided by participating countries and their resolution is 1 km. The preparation map was constructed by interpolation of measured rain-gauge data. Kriging with extended drift was used for interpolation. The map of actual evapotranspiration was based on data from WatrBat simulations performed for sub-basins: Actual evapotranspiration was simulated by WatBal for each sub-basin was attributed to the centre of gravity of the sub-basin. The similar approach was used to construct the map of mean annual runoff. All calculation of water balance components were made for the period 1961-1990.

Map of Mean Annual Precipitation

The precipitation map is based on data from 1901 stations (rain gauges). The numbers of gauges from particular Danube countries and densities are given in Table 1.

Country	Number of precipitation stations	Approximate area (GIS) in Danube Basin (km^2)	Density of precipitation stations (km^2/ station)
CH	2	1,782	891
D	557	55,828	100
AT	687	80,338	117
CZ	56	21,627	386
SK	204	46,678	229
HU	82	92,759	1,131
SL	14	16,154	1,154
HR	19	33,710	1,774
SR	55	88,394	1,607
B& H	95	37,710	397
RO	74	230,739	3,118
BG	32	47,926	1,498
UA	17	30,759	1,809
MD	7	12,650	1,907
Sum or mean	1,901	797,054	

Table 1. Amount of stations used in precipitation map assembly

The spatial distribution of precipitation stations as well as the final map of mean annual precipitation are shown in Fig. 2.

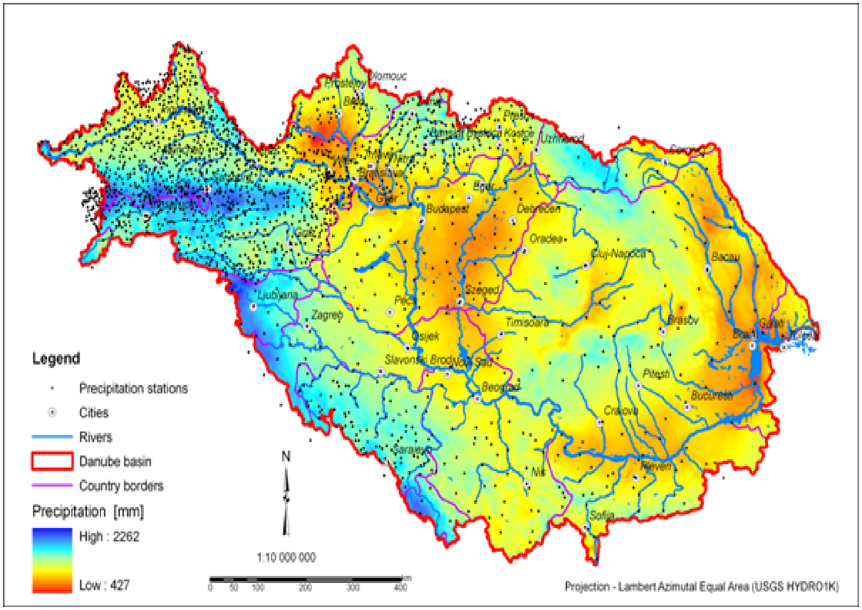

Figure 2.
Map of mean annual precipitation with location of precipitation stations

Comparison of measured precipitation with precipitation extracted from the interpolated map shows that for the majority of the point both values were comparable. Most of the differences among measured and interpolated precipitation were within the interval of $\pm 10\%$. It should be noted that measured precipitation represents a point value, while the extracted precipitation represents the area of 1 km^2, which is the resolution of precipitation map. The two values are therefore a priori different. Further differences between measured end extracted precipitation may be caused by the differences

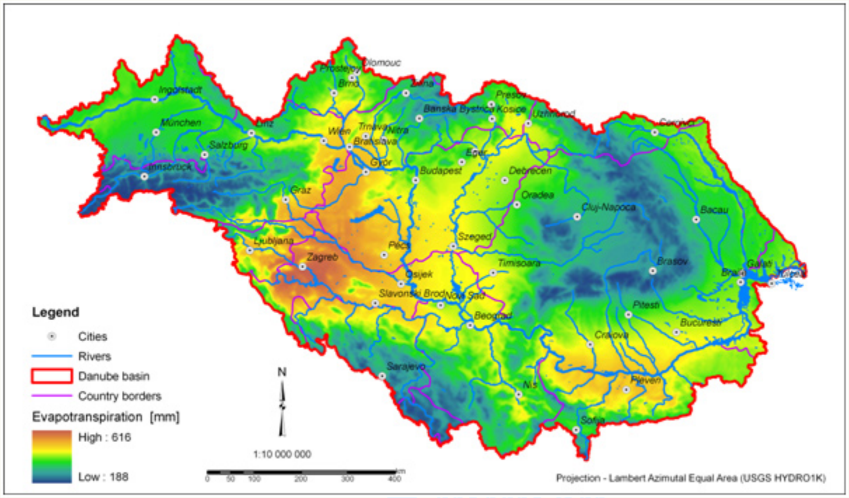

Figure 3.
Map of mean annual actual evapotranspiration

between the true elevation of the station that was used in interpolation and the elevation provided by the specific grid of the digital elevation.

Map of Mean Annual Actual Evapotranspiration

Mean annual actual evapotranspiration (Eta) for each sub-basin was simulated by WatBal model. The Eta values were attributed to the centres of gravity of the sub-basins. An evapotranspiration map was then created by interpolation among the centres of gravity using Kriging with extended drift. The map of the spatial distribution of mean annual evapotranspiration is shown Fig 3.

By comparison of Eta from WatBal with sub-basin actual evapotranspiration from the interpolated map can be seen that the sub-basin values extracted from the map are rather different from those by WatBal. The mean differences for all the sub-basin is about 3%, which means that the evapotranspiration from the map for the Danube Basin is 3% higher than that from WatBal.

The differences are within the interval ± 10% for about 56% of the sub-basin of the total number 101 of procesed sub-basin (Table 2). It can be seen that the differences exceeding ± 10% occur in mountain regions.

Differences (%)	Evapotranspiration No. of sub-basin	Runoff No. of sub-basin
Higher than -40%	0	3
-30 to -40%	1	3
-20 to -30%	6	9
-10 to -20%	16	13
0 to –10%	30	14
0 to 10%	27	14
10 to 20%	8	20
20 to 30%	4	9
30 to 40%	4	5
Higher than 40%	5	11

Table 2 . Comparisions of evapotranspiration and runoff from interpolated maps with WatBal (evapotranspiration) and measured values (runoff)

Map of Mean Annual Runoff

The map of mean annual runoff was constructed in the similar way as the map of mean annual evapotranspiration. Measured runoff values were attributed to the centre of gravity of each sub-basin

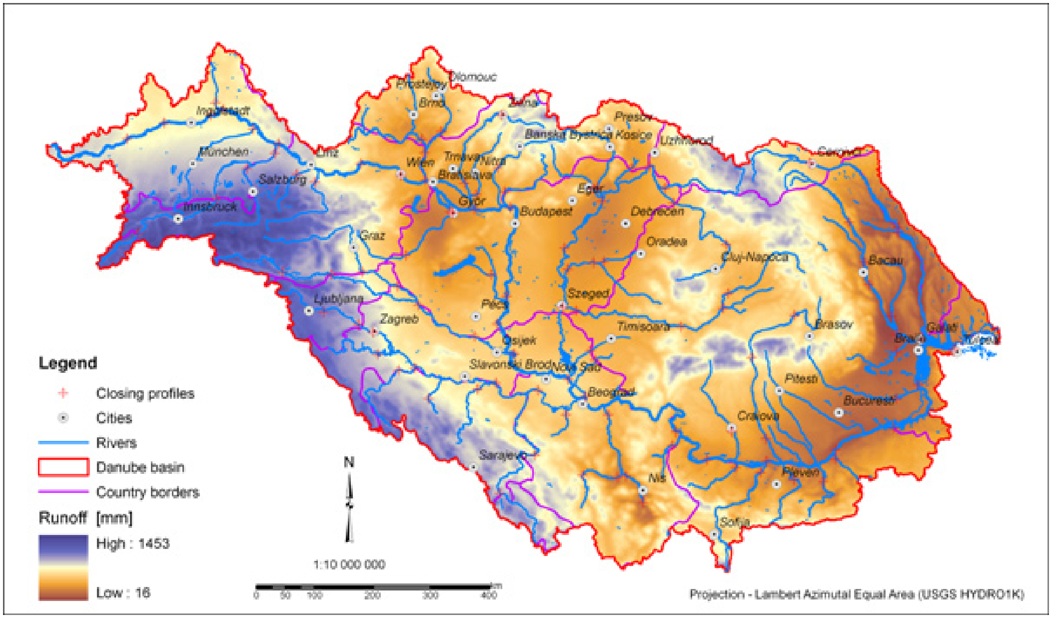

Figure 4.
Map of mean annual runoff

and kriging with extended drift was used to interpolate the map. The interpolated map of mean annual runoff is shown in Fig. 4.

Comparison with the measured runoff and runoff extracted from the interpolated map as a result can be concluded that the mean difference for all sub-basin was 8%, which means that the map overestimated measured runoff for whole Danube Basin by 8%. Table 2 indicates that small differences among measured and interpolated runoff, i.e. the ones from interval ± 10% existed just for about one fourth of catchments. The differences were higher than ± 20% for about 40% of sub-basin.

Preview of water balance in Danube River Basin

In the previous section it was analysed the approach and performed the application of methodology for the Danube Basin water balance estimation. A summary of final results related to individual countries is shown in Table 3. It can be seen from this table, that the total area of the Danube Basin included into processing was only 797,054 km^2. This is because "small" part of the Danube in some countries (Italy, Poland, Macedonia, Albania) and part of the Danube Delta below the profile Ceatal Izmail were not included in Table 3.

Country	Area in the Danube Basin		Precipitation (mm)	Actual evapotranspiration (mm)	Runoff depth (mm)
	Km^2	%	Mean	Mean	Mean
CH	1,782	0.22	1,093.6	343.0	916.6
D	55,828	7.00	969.8	507.4	449.9
AT	80,338	10.08	1,040.2	482.6	603.5
CZ	21,627	2.71	694.0	524.7	196.4
SK	46,678	5.86	716.1	516.5	234.9
HU	92,759	11.64	599.2	559.2	133.4
SL	16,154	2.03	1,308.5	562.3	659.3
HR	33,710	4.23	935.9	582.1	395.0
SR	88,394	11.09	758.8	509.9	252.7
B& H	37,710	4.73	1,052.2	499.9	501.0
RO	230,739	28.95	676.0	493.2	198.5
BG	47,926	6.01	669.1	540.4	164.0
UA	30,759	3.86	832.9	496.9	297.2
MD	12,650	1.59	579.8	523.5	74.0
Sum or mean	797,054	100.00	784.6	513.5	292.2

Table 3. Selected characteristics of the Danube countries: statistics of precipitation, evapotranspiration and runoff were extracted from the maps

Conclusions

Based on the results it can be concluded that the all examined water balance components are unevenly distributed along the territory of the Danube Basin. The highest precipitation is registered in Slovenia (1,308.5 mm) and the lowest in Moldavia (579.8 mm) while the average annual precipitation falls to 784.6 mm in the Danube Basin. The average annual precipitation in the Serbian part of the Danube Basin is 758.8 mm, which is only 2.3% less than in the entire basin. The spatial pattern of evapotranspiration shows considerably lower variation compared to precipitation and it ranges between 343.0 mm in Switzerland and 582.1 mm in Croation. The mean annual evapotranspiration up to 513.5 mm in the Danube Basin corresponds to the evapotranspiration in Serbia (509.9 mm). The higest spatial distribution is registred for the runoff with values of 916.6 mm in the upper Danube Basin, Switzerland and only 74.0 mm in Moldavia. The average annual runoff in the Danube Basin is 292.2 mm, and in the Serbian part of the Danube Basin is 252.7 mm.

From the water balance components it is possible to conclude that the territory of the Danube Basin in Serbia is moderately poor with water resources in comparison with the entire basin. This conclusion is mostly based on runoff component because runoff from Serbian territory is about 15% less.

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