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DETERMINATION OF WATER RESOURCES IN RIVERS IN THE BULGARIAN BASINS OF THE LOWER DANUBE

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Abstract: Object of the study is surface water bodies from category “rivers” according to Water Framework Directive 2000/60/EC. Surface water assessment is important for number of activities such as: water management in the country, making reports to international agencies, determining the change of the resources in the light of upcoming climate changes. The determination of water resources is based on information of hydrometric stations from the monitoring network system in the National Institute of Meteorology and Hydrology — Bulgarian Academy of Sciences (NIMH-BAS) in which real ongoing and available water flows that are subject of management are registered. In the study a technology for surface water bodies in the Bulgarian basins of the lower Danube is applied which has been developed in the frame of cooperative project together with the Ministry of Environment and Water. This is absolutely true for the Bulgarian section of the Danube River basin which is expressed in big number and variety of hydrological homogeneous sections. The river flow is characterized with annual and inter-annual variability determined by climatic factors and anthropogenic influences. The main obtained results of the present hydrologic studies are the usage of transferred information from gauged to ungauged watersheds and the estimation of the surface water bodies’ resources using original regression relationships based on multiannual hydrological information from the NIMH-BAS monitoring network. The relationships delineate the hydrological homogeneous areas with similar conditions of flow formation. The estimated resources have significant usefulness for all State institutions managing the water in the Danube basin and have already been introduced in the operative and management practice.

Key words: watershed, water bodies, hydrological homogeneous areas, regionalization

Introduction

Determination of surface water resources in ungauged basins and catchments is regarded as one of the most difficult tasks in the hydrology of surface water, but of great importance for numerous activities linked to the water management and water consumption. The goal of regionalization is a transfer of information from observed to non-observed catchments and stretches. Widely used are the

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following three methods for determination of the “donor” — analogue with the optimal values of the parameter for the modelling of runoff for ungauged catchments: regression, spatial proximity and physical resemblance (Zhang & Chiew, 2009).

The object of the study is surface water bodies from category “rivers”, in accordance with the Water Framework Directive 2000/60/EU (The European Parliament and the Council of the European Union, 2000) for the Bulgarian part of the Danube catchment area.

The aim of the study is a determination of water resources of surface water bodies in the Bulgarian sub-basins at the Lower Danube. The investigation is based on the hydrological information of the hydrometric stations at the monitoring network system of the National Institute of Meteorology and Hydrology to the Bulgarian Academy of Sciences (NIMH-BAS). River runoff is characterized with annual and interannual variability formed by the natural factors and anthropogenic influences. The real measured flows in use for the referent period reflect the real river runoff and the real resource of each water body — the climatic alterations and anthropogenic effects are registered in the data. The resource of the water body is estimated at the last point of each body and represents the calculated runoff of the whole watershed till this point. The available resource of surface water is permanently changed as result of human activities which has a significant impact on their natural condition. The big changes in the river water regimes on the Bulgarian territory begin in the 60s with massive hydrotechnical constructions and in the late 70s — early 80s their lasting significant impacts are established.

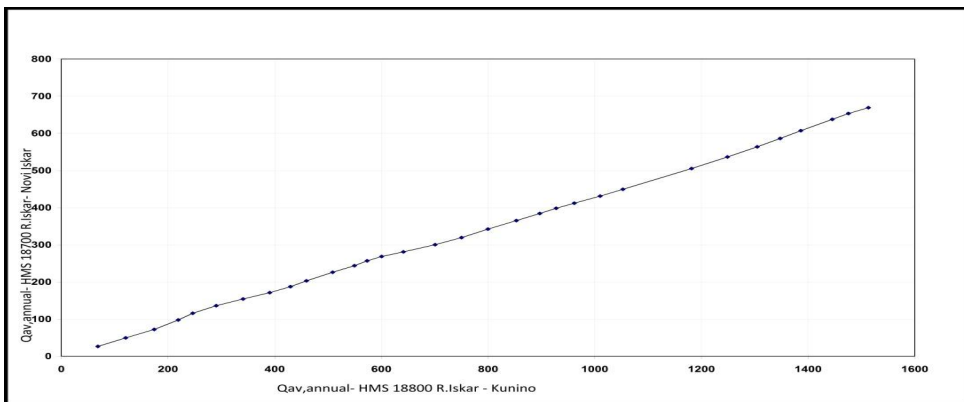


Figure 1. Double cumulative curves of average annual flow of the Iskar River station Novi Iskar and station Roman /Kunino/

This fact determines the choice of the reference period 1981–2012. In this period, the runoff may be considered permanently altered but homogeneous suitable for statistical processing of information and reflecting the current state of surface water now. Double cumulative curves or aggregated lines of water flows of the two key hydrometric stations in the main valley of the Iskar River confirm the homogeneity of the selected reference period — Figure 1.

Methodology

The NIMH surface water monitoring network system currently consists of about 200 active hydrometric stations that partially cover the large number of water bodies in category “rivers” on the territory of the country. For this reason, in most common cases, information from hydrometric stations cannot be used directly to determine the resources of the water bodies. The number of bodies is very big but the density of monitoring network is relatively rare. On the other hand there is a partial or non-representative or a complete absence of information concerning the water usage and the water transfer both in the frame of studied bodies and the whole watersheds. The use of such information, if the information exists, does not allow the determination of real available water resources to water bodies. For this reason the transfer of real-registered information from gauging stations is the only reliable way and the basis for development of methodical approach for the resources of surface water determination. In the world practice there are two major methodological approaches for water resources determination in the non-observed river stretches (Nathan & McMahon, 1990; Hall & Minns, 1999; Zhang & Chiew, 2009; Ninov & Karagiozova, 2014; Yankova, Gocheva, & Dimitrov, 2015; Karagiozova, Ninov, & Rankova, 2016): *regionalization* of characteristic water flows depending on physico-geographical factors and *a balance approach*. The balance approach requires a huge amount of information related to surface water use of any kind (water supply, irrigation, and water releases from the reservoirs, accumulation of water, etc.) including the water transfer among the watersheds. This type of information is missing or usually is not representative. That is why the use of regionalization approach is preferred for the resource determination based on registered flows at the hydrometric observation network. The next two characteristics of the catchments are often used – the area and/or the altitude. Respectively two main regression relations are generally applied (Nathan & McMahon, 1990; Hall & Minns, 1999; Zhang & Chiew, 2009; Ninov & Karagiozova, 2014; Yankova et al., 2015; Karagiozova et al., 2016):

1. $Q_o = f(H_{cp})$ — relationship between the runoff and average altitude
2. $Q_o = f(F)$ — relationship between the runoff and catchment area

One of the best correlations in hydrological practice in Bulgaria, proven in numerous investigations related to the surface water, is between runoff and catchment area. This fact was revealed in previous studies considering the Bulgarian rivers and especially during the implementation of the national projects of the Ministry of Environment and Water (2000, 2014, 2016) where the whole country territory was under investigation. There are many reasons why the catchment area is a suitable independent parameter for water analyses in not observed river stretches. Landscape features, the behavior of the river system and the hydrological processes are changing with the changing of the catchment area. For example the highland catchments are usually steep with landslides and are quickly shaping the river flows while lowland catchments which are older and the influence of groundwater dominates have a wide floodplain terraces. The floods can be frequent events i.e. catchment area reflects the conditions of formation of a runoff. Noticing the big influence of the catchment area for flow formation this parameter is applied for the most suitable comprehensive/integral index in the accepted regionalization approach.

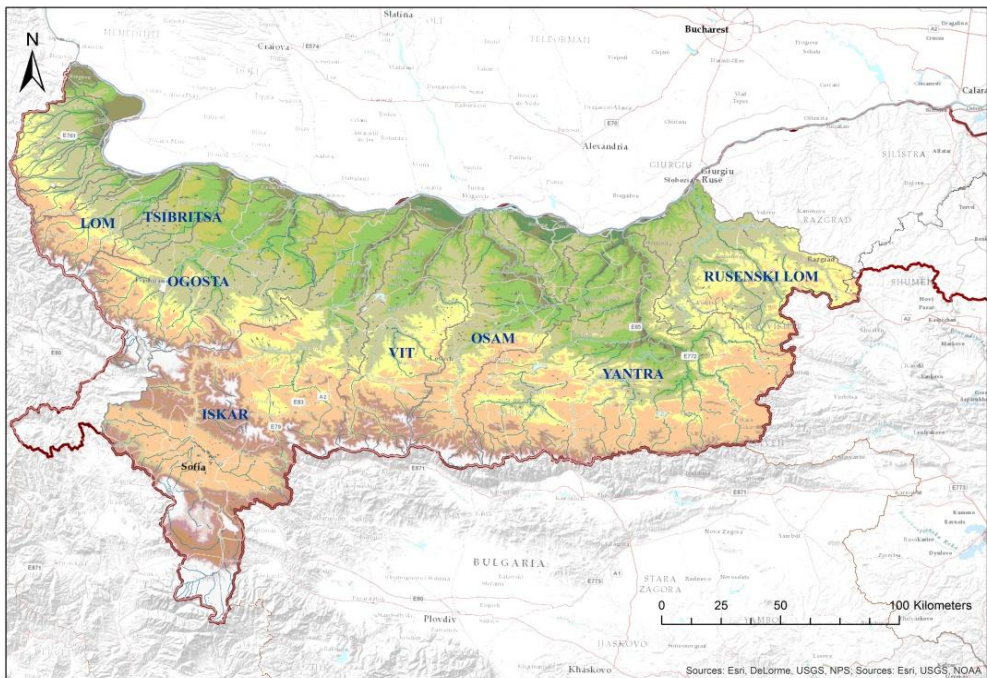


Figure 2. Basin of the Lower Danube – Ogosta River (rivers west of Ogosta), Iskar, Vit, Osam, Yantra, Rusenski Lom. Sources: ESRI, USGS.

It was mentioned above the Bulgarian Danube River Basin is a part of the international river basin of the Danube River and has an important role in the water resources formation. To the North Bulgarian sub-catchment borders with the Republic of Romania, the Black Sea region to the East River, on the West by the Republic of Serbia and to the South East and West Aegean River Basin. The basin of the Lower Danube under the Water Act covers most of northern Bulgaria and includes the valleys of these rivers flowing into the Danube: Ogosta river (there are some smaller rivers west of Ogosta as well), Iskar, Vit, Osam, Yantra, Rusenski Lom — Figure 2.

Results

Runoff-forming factors

On the Bulgarian Danube valley the density of the river network is relatively small. There are 62 stations spread on the 47,235 km² territory. The majority of rivers are transit and spring from the Balkan Chain and the Rila Mountains (Iskar River). The big river basins are: Lom, Tsibritsa, Ogosta, Iskar, Vit, Osam, Yantra and Rusenski Lom. The discharge of the Bulgarian tributaries forms the resource contribution into Danube on the Bulgarian territory. The obtained homogenous hydrological regions are presented below with a small geographical description, figures of the Danube tributaries watersheds with delineated hydrological regions (Figures 3, 5, 7, 9, 11) and figures with regions (Figures 4, 6, 8, 10, 12) with regional relationships or donor analogs.

Characteristics of the catchment area of the Ogosta river and west of the Ogosta River

In the northwestern part of Bulgaria between Western Balkan Mountains Timok river, the Danube and the river Iskar collect their runoff for about ten rivers. Several smaller tributaries inflow into the Danube: Topolovets, Voinishka, Vidbol, Archar, Skomlya, Lom, Tsibritsa, Ogosta, Skat (Figures 3 and 4).

They originate from the main Stara Planina edge except Tsibritsa and Skat rivers collecting water from the foothills of the Balkan Mountains.

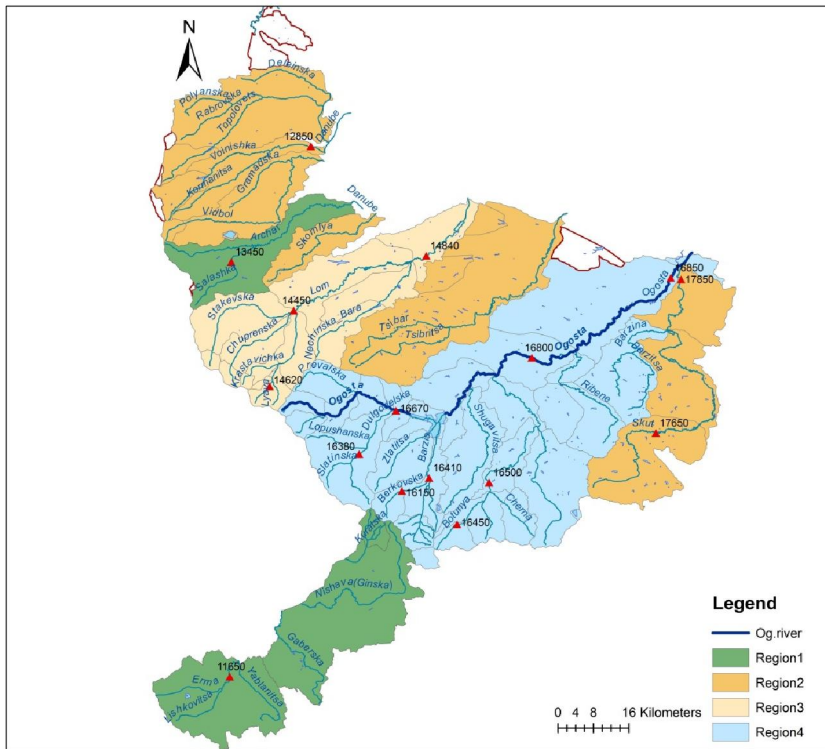


Figure 3. Separate regions west of the Ogosta River and the Ogosta River

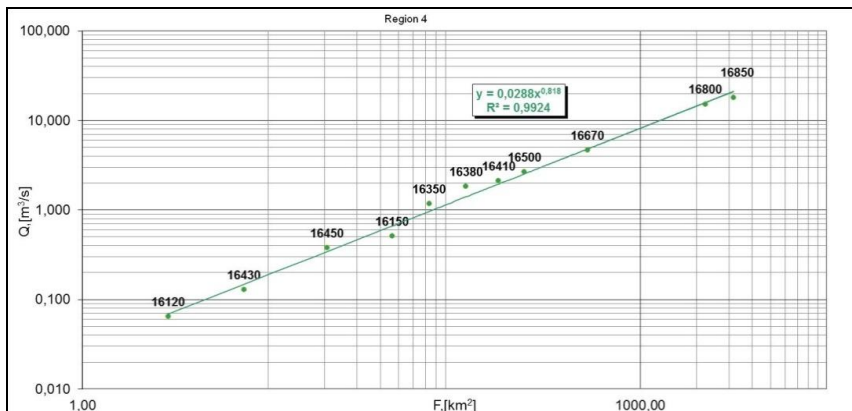


Figure 4. Regional relationship of Region 4 — riverswest of the Ogosta River

Region 1 — South from the Balkan Mountains; Regression equation with $Q_{nor} = 0.0053 * F^{0.9952}$ and $R^2=0.9992$. **Region 2** — In front of the Balkan Mountains with $Q_{nor} = 0.004 * F^{0.8791}$ and $R^2=0.9871$. **Region 3** — River Lom with Q_{nor}

= $0.1429 * F^{0.5056}$ and $R^2=0.9992$. **Region 4** — Higher parts of the Balkan Mountains with $Q_{nor} = 0.0288 * F^{0.818}$ and $R^2=0.9924$.

Characteristics of the catchment area of the Iskar River

It is the longest inner river which springs from South Bulgaria and crosses from south to north Balkan Mountains (Iskar Valley) inflows into the Danube River (Figures 5 and 6).

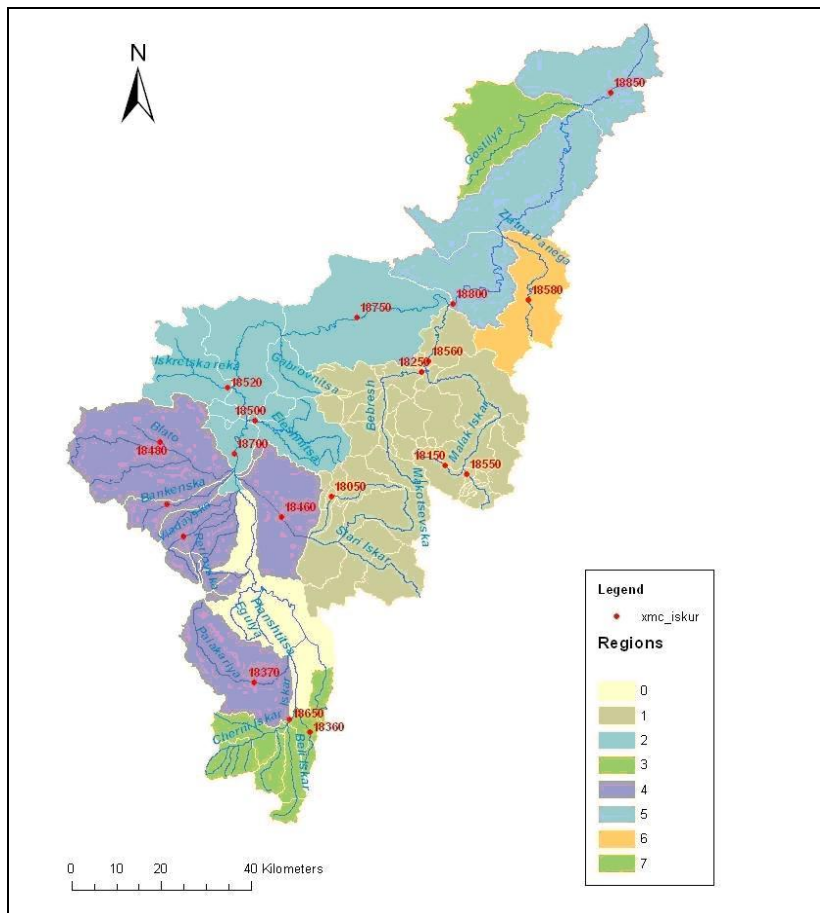


Figure 5. Separate regions of the Iskar River Watershed

Stations in use are Malki Iskar-Svode; Malki Iskar-Etropole; Bebresh-Svode; Suha-Boikovets. The example of the **Region 1** — The right tributaries without the Zlatna Panega River with regression equation $Q_{av} = 0.0248 * F^{0.8188}$ and $R^2=0.9877$. **Region 2** — The Iskar River in the middle part of watershed and

tributaries with $Q_{av} = 0.0185 * F^{0.8791}$ and $R^2=0.9891$. **Region 3** — Higher parts of tributaries with $Q_{av} = 0.0342 * F^{0.9364}$ and $R^2=0.9603$. **Region 4** — Rivers flowing through high fields in the watershed with $Q_{av} = 0.0405 * F^{0.6156}$ and $R^2=0.9561$. **Region 5** — After the Iskar Kunino station to the entry into the Danube, using donor analog. **Region 6** — The Zlatna Panega River, using donor analog.

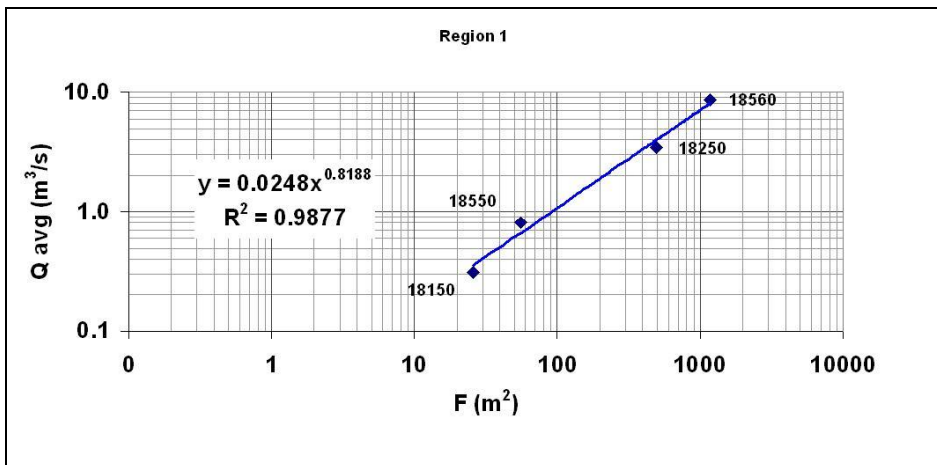


Figure 6. Regional relationship — Region 1 of the Iskar River Watershed

Region 7 — The Gostilya River with a donor analog as the last one. **Region 0** - River section with technogenic character of the runoff and not subject to regionalization or analogy to define.

Characteristics of the catchment area of the rivers Vit and Osam

The catchment area of the river Vit is limited to the west of the watershed of the Iskar River and east respectively of the watershed of the river Osam. At the beginning the river has adopted its main tributary — the Beli Vit where under Teteven the river Cherni Vit inflows (Figures 7 and 8).

Region 1 covers part of the watershed, located in the Danube Valley with $Q = 0.0006 * F^{1.2632}$ and $R^2=0.9993$. The used hydrometric stations are: the Kamenitsa River at the village of Bejanovo, the Vit River near the village of Krushovitsa, the Vit River near the village of Disevitsa, the Osam River near the village of Izgrev. **Region 2** covers parts of the watershed, including fore and northern slopes of the Balkan Mountains with $Q=0.0931 * F^{0.6714}$ and $R^2=0.9729$.

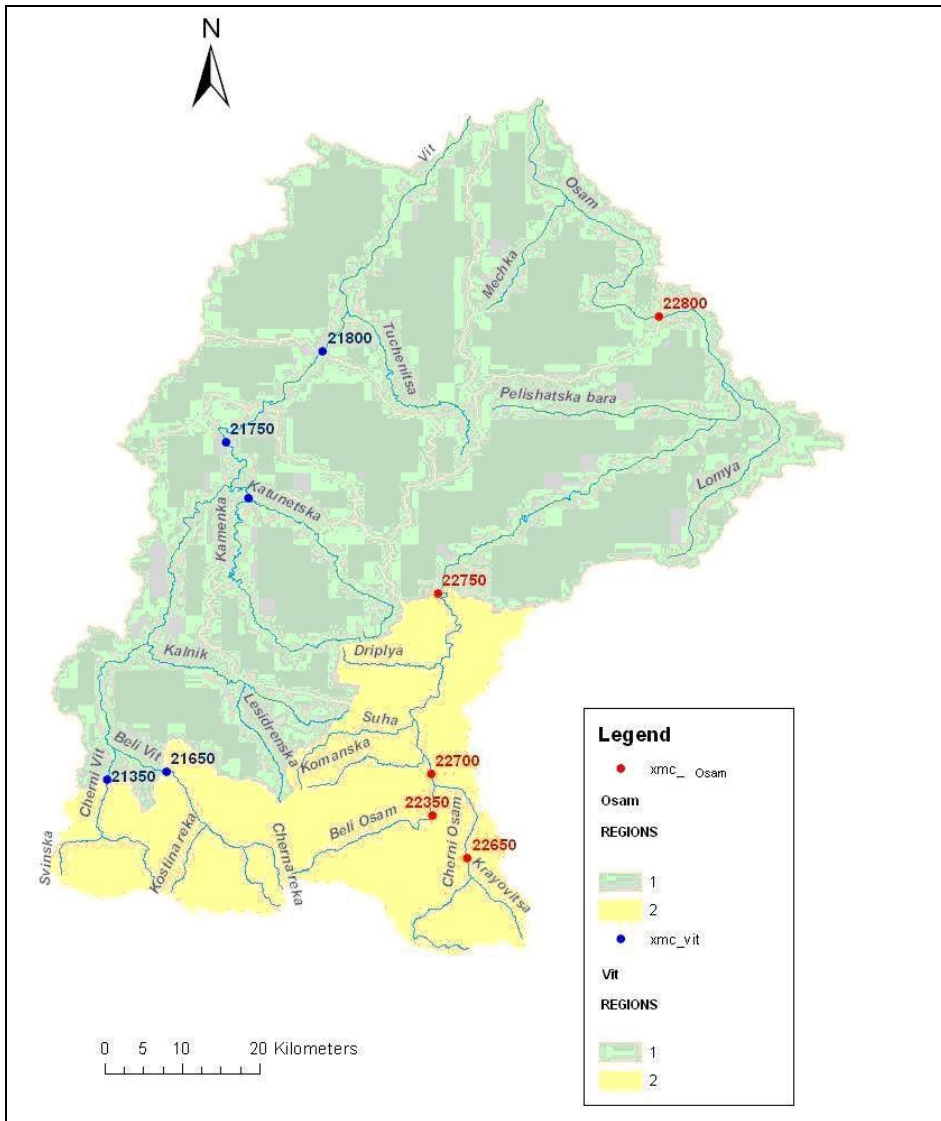


Figure 7. Separate regions of the Watershed Vit and Osam

Formed by the merger of the rivers Black and White Osam at the town of Troyan, the Osam River begins. In addition, its two major tributaries originate from the northern slopes of the Balkans located in the Central Balkan Mountains (Figures 7 and 8).

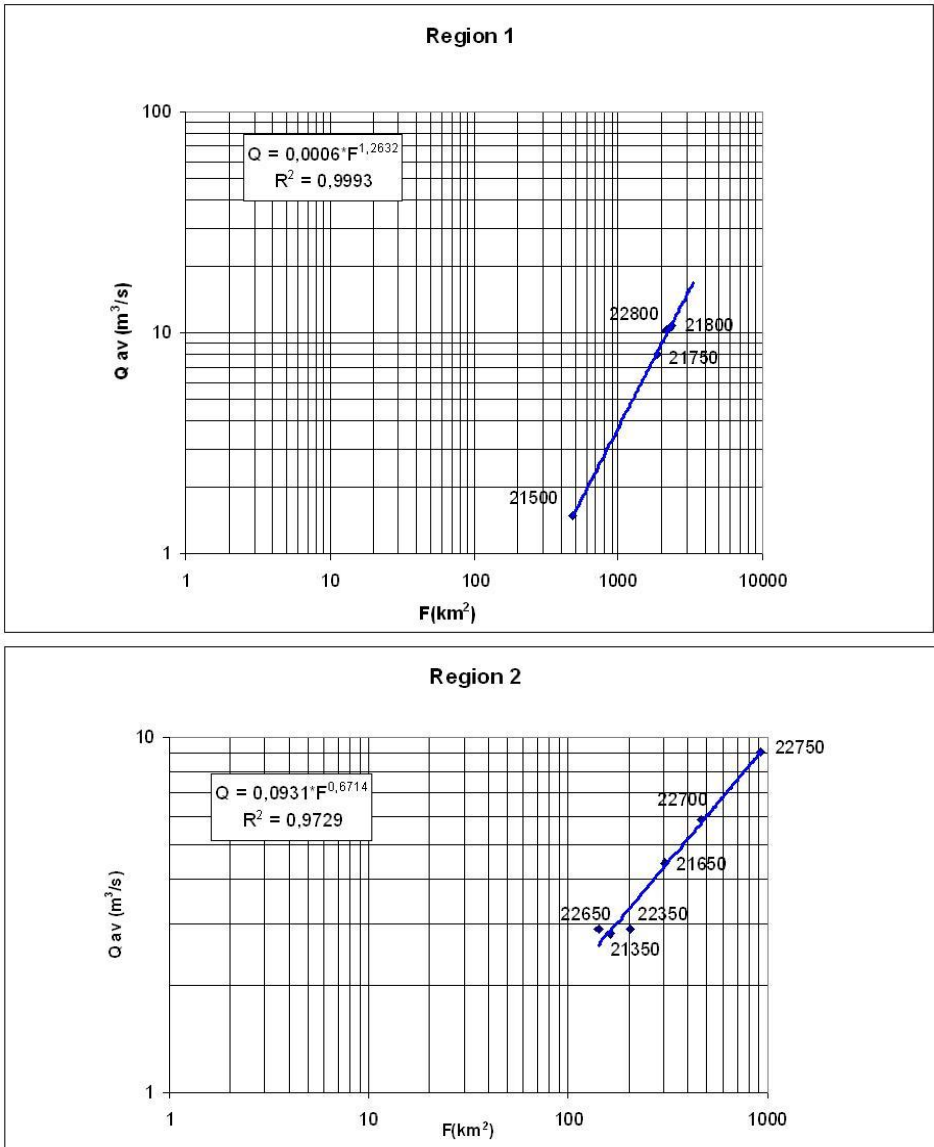


Figure 8. Regional relationships of the Watershed Vit and Osam

Region 1 covers the lower part of the watershed, located in the Danube Valley with $Q = 0.0006 * F^{1.2632}$ and $R^2 = 0.9993$. **Region 2** covers parts of the watershed, including fore and northern slopes of the Balkan Mountains with regional relationship $Q = 0.0931 * F^{0.6714}$ and $R^2 = 0.9729$.

Characteristics of the catchment area of the river Yantra

The Yantra River is the second largest river in the region (Figures 9 and 10).

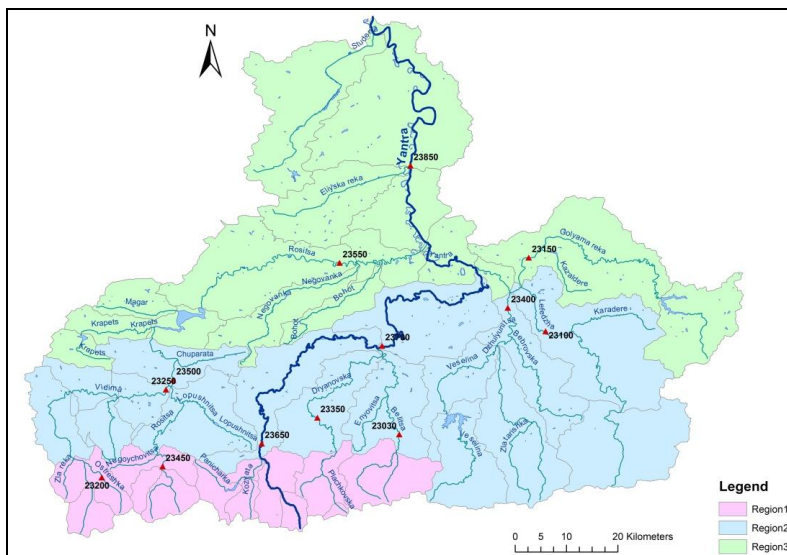


Figure 9. Separate regions of the Yantra River Water

Region 1 is the upper mountain tributaries with $Q_{nor} = 0.0438 * F^{0.7986}$ and $R^2 = 0.9951$. **Region 2** is the middle part of the Yantra River with $Q_{nor} = 0.0168 * F^{0.8909}$ and $R^2 = 0.9716$. **Region 3** is the lowland tributaries with $Q_{nor} = 0.0007 * F^{1.2536}$ and $R^2 = 0.9937$.

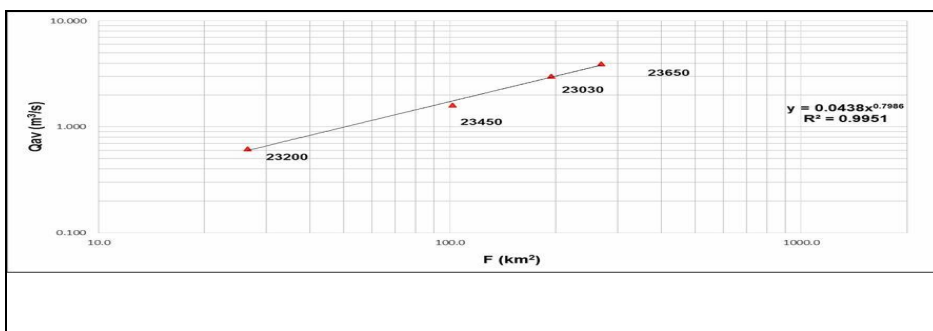


Figure 10. Regional relationship — Region 2 of the Yantra River Watershed

As an example, the Table 1 below demonstrates the final calculated water resources of all water bodies (48) in the Yantra River.

Table 1. Water resources of water bodies in the Yantra River

<i>N</i> ₂	Water body name	Q_{av} (m ³ /s)	<i>N</i> ₂	Water body name	Q_{av} (m ³ /s)
1	BG1YN130R1029	53.522	25	BG1YN400R1431	0.894
2	BG1YN200R028	1.372	26	BG1YN400R1531	2.731
3	BG1YN300R026	0.752	27	BG1YN400R1631	3.396
4	BG1YN307R1027	43.022	28	BG1YN600L019	2.029
5	BG1YN307R1127	24.109	29	BG1YN600L024	0.624
6	BG1YN400L005	0.124	30	BG1YN600R022	3.037
7	BG1YN400L009	6.627	31	BG1YN600R1020	3.349
8	BG1YN400R007	0.195	32	BG1YN600R1021	2.629
9	BG1YN400R010	0.449	33	BG1YN600R1025	2.453
10	BG1YN400R011	0.219	34	BG1YN600R1034	11.3
11	BG1YN400R1001	2.592	35	BG1YN600R1125	7.171
12	BG1YN400R1002	2.832	36	BG1YN700R1017	12.133
13	BG1YN400R1003	9.098	37	BG1YN800R1016	3.004
14	BG1YN400R006	0.343	38	BG1YN800R1033	3.512
15	BG1YN400R1012	8.908	39	BG1YN800R1116	0.251
16	BG1YN400R1031	4.734	40	BG1YN800R1133	2.625
17	BG1YN400R1101	1.156	41	BG1YN800R1216	1.878
18	BG1YN400R1102	0.648	42	BG1YN900L014	1.051
19	BG1YN400R1103	3.66	43	BG1YN900R1015	4.622
20	BG1YN400R1112	11.222	44	BG1YN900R1115	0.741
21	BG1YN400R1131	0.081	45	BG1YN900R1215	0.721
22	BG1YN400R1202	1.325	46	BG1YN900R1315	1.899
23	BG1YN400R1231	0.039	47	BG1YN900R1415	2.048
24	BG1YN400R1331	0.044	48	BG1YN600R1134	12.26

Characteristics of the catchment area of the river Rusenski Lom

The Rusenski Lom is situated in the eastern part of the Bulgarian Danube river basin. The Rusenski Lom River springs from relatively low flat part of the Danube plain and flows northward to the Danube (Figures 11 and 12).

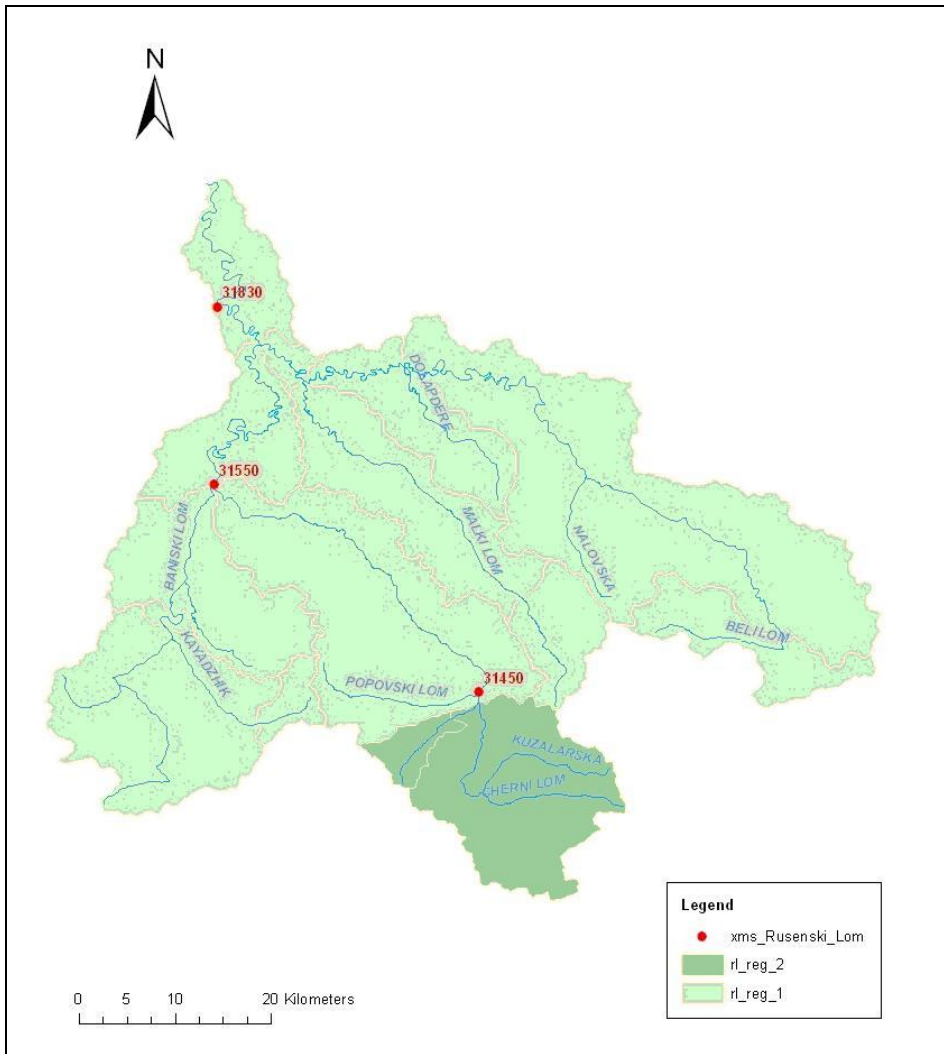


Figure 11. Separate regions in the Watershed of Rusenski Lom River

Region 1 shows the Northern part valley of the Rusenski Lom with the Cherni Lom River and the Kardam River using a donor analog.

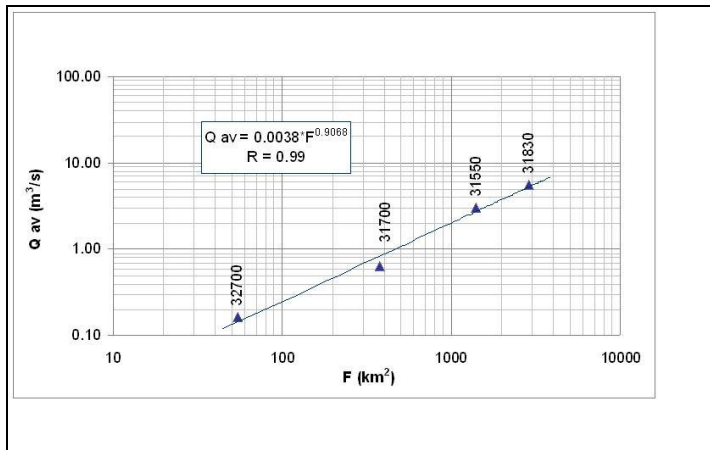


Figure 12. Regional relationship — Region 2 of the Rusenski Lom River

Region 2 shows the Rusenski Lom River to town Razgrad with a relationship $Q_{av} = 0.0038 * F^{0.9068}$ and $R^2 = 0.9868$.

Discussion

Using the mentioned above regionalization methodology the water resources are calculated for all surface water bodies in the Bulgarian Danube catchment — their number is 235. Below, in the Table 2, the calculated water resources are presented for the main Bulgarian tributaries (at the estuary part of the last water body) in million cubic meters for the referent period 1981–2012.

Table 2. Bulgarian Danube catchment resource assessment for the period 1981–2012

River basins by regions	Q[10 ⁶ m ³]
Lom	172
Ogosta	634
Skat	57
Iskar	1374
Vit	416
Osam	352
Yantra	1431
Russenski Lom	187

The results of this investigation have an important practical meaning. The estimated bodies' resources have significant usefulness for all State institutions managing the water in the Danube basin as the Ministry of Environment and

Water, Basin Directorate, Irrigation Systems EAD, etc. and are already introduced in the operative and management practices. The permits for water consumption given by the MEW could also be mentioned as an example of the usefulness of the present study.

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