REGULATION OF STREAMS IN THE SKOPJE REGION WITH MEASURES FOR REGULATION AND REHABILITATION OF THE RIVER BEDS

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ABSTRACT

The hydrography in the Skopje valley consists of several springs with Rasce and Studenciste as the most characteristic, and the river Vardar with its tributaries Treska, Markova Reka, and Kadina Reka on the right and Lepenec, Serava, and Pchinja on the left. This research identified an additional 115 streams in the appropriate classification of rivers, drainage canals, and torrents that are grouped and analyzed according to their river basin. Geographical, cartographic, hydrographic and methods of geographical information systems have been used, from which appropriate documentation has been prepared in vector form of the entire river and network of torrents. It is created in a geo-referenced model, whereas a referenced background is used from a raster topographic map with a scale of 1: 25000. The documentation process in the next phase of the research identifies the forms of the existing regulation of the recorded streams and river beds in an appropriate classification. Following the process of recording the hydrographic facilities and the forms of their regulation, recommendations for regulation and rehabilitation of specifically defined zones of the riverbeds in the Skopje region are defined. The synthetic materials, thematically, are presented in cartographic and tabular form with a textual explanation.

Keywords: streams, regulation, Skopje, GIS

INTRODUCTION

The Skopje Region is located in the northern part of the RN Macedonia. It covers the territory of the Skopje valley. To the north it stretches to the state border with Kosovo, to the east it borders the Kumanovo and Ovce Pole valleys, to the south it stretches along the heights of the mountain branch Goleshnica, and to the west along the heights of the mountains Karadzica, Suva Gora and Zeden. More specifically, the Skopje valley covers the territory, which is limited by the waterline along the mountains: Goleshnica, Karadzica, Suva Planina, parts of Suva Gora, and Zeden (the border intersects the Matka canyon on the river Treska near the newly built dam Kozjak) on the right side of Vardar, and then through the Dervenska Gorge of Vardar through the water section of Shar Mountain (via the gorge of the river Lepenec), Skopska Crna Gora and Gradishtanska Mountain joins the water section along the mountain Goleshnica near the confluence of the river Pchinja in Vardar in the Taorska Gorge. Within this framework, the valley covers

1,924.2 km2. According to the administrative-territorial division, the Skopje Region covers a territory of 1,814.54 km2 or 7% of the territory of RN Macedonia.
The relief of the Skopje valley consists of two major morphostructural forms, namely the mountains that limit the valley and the plain of the Skopje valley. It is about the mountain massifs Skopska Crna Gora in the north and northeast, which rises to about 1600 m asl (Ramno peak, 1658 m asl), mountain Gradishtanska Planina in the east (Venec 853 m asl. c.), the mountain Kitka (Kitka, 1589 m asl), the mountain Goleshnica (Lisec, 1935 m asl), mountain Mokra Planina with peak Solunska Glava 2539 m asl. from the south, the mountain Karadzica (Milenkov Kamen 2217 m asl), Suva Planina with Vodno (Krstovar, 1066 m asl), parts of the mountain Suva Gora (Tabahon 1748 m asl), mountain Zeden (Golem Zeden 1259 m asl) and lower branches of the mountain Shar Planina. The relative altitude of the relief in the Skopje valley ranges from 150-2540 m. The relative altitude of the plains is 150-300 m. Therefore, in a hypsometric sense, the relief in the Skopje valley consists of 344.0 km2 of plains, 778.9 km2 of hilly relief, and 801.3 km2 of typical mountain relief. The flats in the Skopje region are mainly spread in the Skopje Field (on the move from Gjorce Petrov, Aracinovo, Miladinovci, Katlanovo, Dracevo and the foot of Vodno). In the lower parts of the mountains (Skopska Crna Gora, Kitka, Goleshnica, Karadzica, Suva Gora with Osoj, Zeden, and Shar Planina up to about 750 m) there is a hilly relief, and in the higher parts (mainly over 750 m) there is a typical mountain relief.
The climate in the Skopje valley is characterized by an average annual temperature of 12.20C, an average annual rainfall of 515 mm, average annual sunshine of 2101 sunny hours, and, average relative humidity of 70%. According to these characteristics, in the plain part of the Skopje valley, there is a continental climate with mild Mediterranean influences. In the higher mountainous areas (Mokra Planina, Karadzica, Goleshnica, Skopska Crna Gora, and others) the climate is changing and there is a typical mountain climate.
The hydrography in the Skopje valley consists of several springs with Rasce (from which Skopje is supplied with water) and Studenciste (in the Matka canyon) as the most characteristic, and the river Vardar with its tributaries Treska (with the Fush tributary), Markova Reka and Kadina Reka on the right and Lepenec, Serava and Pchinja on the left. In the southeastern parts of Skopsko Pole, there are territories with high groundwater and accordingly the presence of wetlands (Aracinovo Swamp, Katlanovo Swamp) due to which several drainage canals have been built. In the Skopje Region, there are several accumulations, the most important of which are the accumulations Kozjak, Sv. Petka and Matka. It is rare that near Skopje there are several larger springs such as Rasce, Vrelo, and others.

METHODOLOGY

For the needs of the research regarding the regulation of streams in the Skopje Region, the following methods were used: geographical, cartographic, hydrographic, and geographical information systems.
By applying the stated methods, appropriate documentation for the territory of the Skopje Region has been prepared. A vector form of the entire network of rivers and springs is created in a geo-referenced model, whereas a substrate (from which information on the position and length of the subjects is predominantly drawn) is used Raster from a topographic map with a scale of 1: 25000 [1]. The synthetic materials, thematically, are presented in cartographic and tabular form with a textual explanation.

In the publication in the international journal Geografie, the analyzed are maximum, average, and minimum monthly flows of 13 natural watercourses in RN Macedonia, including HS Krusha on Kadina Reka [2]. According to the standard methodology using the Mann-Kendall test and the Sen's test. With this, the systemic results of the climate change in the Skopje Region of the only watercourse, which is included in the FFR group. Besides this stream, the Lepenec River belongs to the same group, without significant human influence on the water regime.
This research problem also aroused interest in interdisciplinary cooperation based on which several studies have been prepared and published that touch on the state of river flows and their need for regulation [3], [4], [5], [6]. For the needs of this paper, two strategic documents issued in 2017 were consulted as an already conducted studies regarding the erosion and action plan for the city of Skopje [7] and the establishment of green corridors along the rivers Serava and Lepenec [8].
In addition to the passive and active measures by the OECD recommendations and the chapter on North Macedonia published in Springer, it is crucial to increase the level of knowledge on the issue, free and open-source meteorological and hydrological data for the scientific community, more funding by the state in the field of hydrology and water management, restarting the existing and inactive and establishing new measuring stations by the HMA, which will provide timely and accurate results, which will be publicly available [9]. Although the annual coefficient of runoff in the nearby catchments is 23%, the daily extreme precipitation could be an extraordinary hydrological event as happened in Stajkovci, Skopje Region, significantly rising the surface runoff [11]. The modern used techniques are 3D printing of the extreme hydrological events about the different return periods [11].

CLASSIFICATION OF STREAMS IN THE SKOPJE REGION

The network of rivers in the Skopje region belongs to the river basin of the river Vardar, where it receives 5 major tributaries. Three of them flow from the right side: Treska, Markova Reka, and Moranska Reka, and two from the left: Lepenec and Serava. Here, especially downstream from Skopje to the entrance to the Taorska Gorge, due to the deposited material, the flow of Vardar is slow, and the riverbed has a curved shape, where except bends, meanders are also present.
The research identified an additional 115 streams in the appropriate classification of rivers, drainage canals, and torrents that are grouped and analyzed according to their river basin (with Vardar as the main recipient and on the level of its subsets) in the following order:

1. Vardar (id: 100);
   - a) Upper Vardar,
   - b) Vodno torrents,
   - c) Kisela Voda - Dracevo,
   - d) Skopsko Pole,
   - e) Skopska Crna Gora.
2. Treska (id: 200);
3. Lepenec (id: 300);
4. Serava (id: 400);
5. Markova Reka (id: 500);

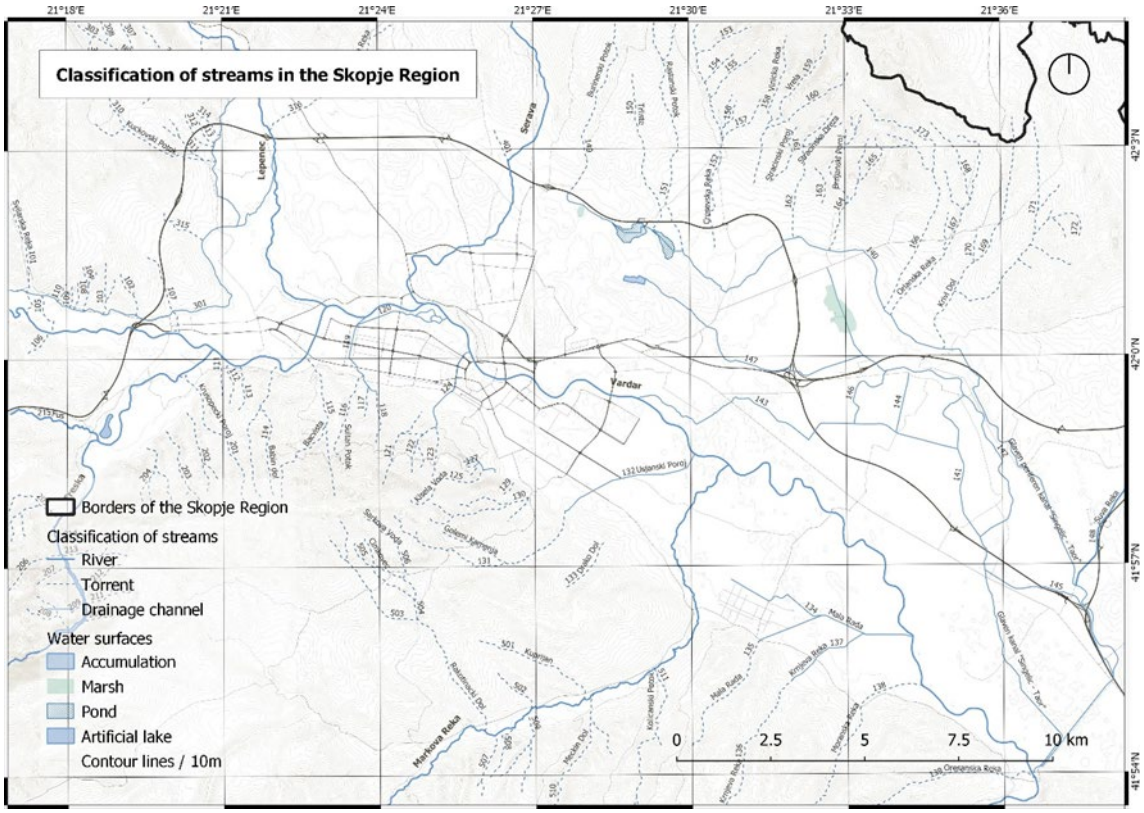

Figure 1. Classification and names of the streams in the Skopje Region.Data source: Agency for real estate cadastre. Topographic map 1:25000. sheets (681-4-3.; 681-4-4.; 682-3-3.; 731-2-1.; 731-2-2.; 732-1-1.) Skopje, AREC, 2004;

Transferred to an appropriate spreadsheet, each hydrographic unit representing a separate river basin, has its id number where the first number assigns the affiliation to a river basin (100) and the other 2 are ordinal numbers (102).

Consequently, a database is created as operational documentation through direct cartographic processing in which the following characteristics are developed for each of the registered hydrographic objects:

- id number that expresses their affiliation and order,
- Type of stream according to the classification,
- Name of the stream recorded from the cartographic substrate or the literature,
- River basin to which they belong,
- Subset to which they belong more specifically, and
- Stream length expressed in kilometers (km), obtained by digital processing

This structured database is tabularly processed and presented for each of the listed river basins and subsets for which physical distribution (length) separate and aggregate data are obtained.

The table shows the main streams of the river basins in the Skopje region and their lengths within the region. Consequently, the network of streams is elaborated for each river basin separately.

Table 1. Main streams of the river basin in the Skopje Region

id	Type	Name of the stream	Stream length in km (in the study area)	Stream starting point	Streams endpoint
100	River	Vardar	42.19	42° 0'42.93", 21° 16'54.06"	41° 53'32.13", 21° 35'42.78"
200	River	Treska	10.44	41° 57'8.409", 21° 17'54.31"	42° 0'8.156", 21° 20'50.22"
300	River	Lepenec	10.65	42° 4'59.20", 21° 20'14.78"	42° 0'44.90", 21° 23'0.559"
400	River	Serava	11.10	42° 4'58.02", 21° 26'31.82"	42° 0'47.24", 21° 24'51.42"
500	River	Markova Reka	16.78	41° 53'31.60", 21° 24'2.581"	41° 58'26.68", 21° 30'44.37"

1) Vardar

Vardar is the largest and most important river in RN Macedonia. It springs from a karst spring near the village Vrutok in the southwestern part of the Polog Valley at the foot of the mountain Shar Planina at an altitude of 683 m. It leaves our country near Gevgelija at an altitude of 43 m and flows into the Aegean Sea. The total length of the river is 388 km, of which 301 km belong to our country where it covers a river basin of 20,535 km2. Of the total length of the Vardar valley, two-thirds (207 km) is flat, and one-third (94 km) is a gorge valley. Through our country, it flows through five valleys and four gorges, including the Skopje valley where its length is 51km.

Within this research, the riverbed of the river Vardar is documented in a length of 42.19 km, with a starting point from the inflow of the Svilarska River in Vardar (near the village Dolno Svilare) in the west to the inflow of the Main Peripheral Canal "Singjelic - Taor" in Vardar near the village of Taor in the south-east. At that length, the river Vardar is a river basin of 73 streams (excluding the rivers Treska, Lepenec, Serava, and Markova Reka), which are classified according to their geographical-hydrographic unit and are divided into the following subsets: Upper Vardar, Vodno torrents, Kisela Voda - Dracevo, Skopsko Pole and Skopska Crna Gora.

Table 2. Classification of the Vardar river basin streams in the Skopje Region.

id	Type	Name	River basin	Subset	Length (km)
101	Torrent	Svilarska Reka	Vardar	Upper Vardar	3.22
102	Torrent		Vardar	Upper Vardar	1.42
103	Torrent		Vardar	Upper Vardar	2
104	Torrent		Vardar	Upper Vardar	1.77
105	Torrent		Vardar	Upper Vardar	1.19
106	Torrent		Vardar	Upper Vardar	0.81
107	Torrent		Vardar	Upper Vardar	2.38
108	Torrent		Vardar	Upper Vardar	0.8
109	Torrent		Vardar	Upper Vardar	0.58
110	Torrent		Vardar	Upper Vardar	0.54
		Total		**Upper Vardar**	**14.71**
111	Torrent	Krusopecki Poroj	Vardar	Vodno torrents	1.08
112	Torrent	Krusopecki Poroj	Vardar	Vodno torrents	1.16

113	Torrent	Krusopecki Poroj	Vardar	Vodno torrents	1.29
114	Torrent	Babin Dol	Vardar	Vodno torrents	6.57
115	Torrent	Bacvista	Vardar	Vodno torrents	6.71
116	Torrent	Sultan Potok	Vardar	Vodno torrents	2.72
117	Torrent	Trnodol	Vardar	Vodno torrents	0.73
118	Torrent	Kamen Dol	Vardar	Vodno torrents	1.33
119	Drainage canal	Western Vodno	Vardar	Vodno torrents	2.29
120	Drainage canal		Vardar	Vodno torrents	4.22
121	Torrent	Murtinec	Vardar	Vodno torrents	2.96
122	Torrent	Gornodnjanski Poroj	Vardar	Vodno torrents	2.12
123	Torrent	Gornodnjanski Poroj	Vardar	Vodno torrents	1.31
124	Drainage canal	Gornodnjanski Poroj	Vardar	Vodno torrents	2.59
125	Torrent	Kisela Voda	Vardar	Vodno torrents	2.55
126	Drainage canal	Eastern Vodno series	Vardar	Vodno torrents	0.89
127	Torrent	Przino	Vardar	Vodno torrents	0.73
128	Torrent	Przino	Vardar	Vodno torrents	0.39
129	Torrent		Vardar	Vodno torrents	0.41
130	Torrent		Vardar	Vodno torrents	5.95
		Total		**Vodno torrents**	**48.00**
131	Torrent	Golemi Kamenja	Vardar	Kisela Voda - Dracevo	8.31
132	Drainage canal	Usjanski Poroj	Vardar	Kisela Voda - Dracevo	3.96
133	Torrent	Drako Dol	Vardar	Kisela Voda – Dracevo	1.57
134	Drainage canal	Mala Rada	Vardar	Kisela Voda – Dracevo	7.18
135	Torrent	Mala Rada	Vardar	Kisela Voda – Dracevo	3.83
136	Torrent	Krnjeva Reka	Vardar	Kisela Voda – Dracevo	5.29
137	Drainage canal	Krnjeva Reka	Vardar	Kisela Voda – Dracevo	2.39
138	Torrent	Moranska Reka	Vardar	Kisela Voda – Dracevo	5.72
139	Torrent	Oresanska Reka	Vardar	Kisela Voda – Dracevo	5.88
		Total		**Kisela Voda – Dracevo**	**44.13**
140	Drainage canal	Main peripheral canal	Vardar	Skopsko Pole	28.46
141	Drainage canal	Main canal	Vardar	Skopsko Pole	17.29
142	Drainage canal		Vardar	Skopsko Pole	4.78
143	Drainage canal		Vardar	Skopsko Pole	10.17
144	Drainage canal		Vardar	Skopsko Pole	1.6
145	Drainage canal		Vardar	Skopsko Pole	5.06
146	Drainage canal		Vardar	Skopsko Pole	2.31
147	Drainage canal		Vardar	Skopsko Pole	7.15
148	River	Suva Reka	Vardar	Skopsko Pole	9.07
149	Torrent	Burinerski Potok	Vardar	Skopsko Pole	5.17
		Total		**Skopsko Pole**	**85.89**
150	Torrent	Trliste	Vardar	Skopska Crna Gora	4.55
151	Torrent	Rastanski Potok	Vardar	Skopska Crna Gora	8.2
152	Torrent	Cresevska Reka	Vardar	Skopska Crna Gora	6.81
153	Torrent	Straska Reka	Vardar	Skopska Crna Gora	1.7
154	Torrent		Vardar	Skopska Crna Gora	1.09
155	Torrent		Vardar	Skopska Crna Gora	1.88
156	Torrent		Vardar	Skopska Crna Gora	1.9

157	Torrent		Vardar	Skopska Crna Gora	1.63
158	Torrent	Vinicka Reka	Vardar	Skopska Crna Gora	4.23
159	Torrent	Vrela	Vardar	Skopska Crna Gora	3.21
160	Torrent		Vardar	Skopska Crna Gora	2.82
161	Torrent	Stracinski Poroj	Vardar	Skopska Crna Gora	1.73
162	Torrent	Stracinska Dreza	Vardar	Skopska Crna Gora	5.24
163	Torrent		Vardar	Skopska Crna Gora	1.09
164	Torrent	Brnjarski Poroj	Vardar	Skopska Crna Gora	5.24
165	Torrent		Vardar	Skopska Crna Gora	3.6
166	Torrent		Vardar	Skopska Crna Gora	6.52
167	Torrent	Orlanska Reka	Vardar	Skopska Crna Gora	6.13
168	Torrent		Vardar	Skopska Crna Gora	4.8
169	Torrent	Krivi Dol	Vardar	Skopska Crna Gora	7.89
170	Torrent		Vardar	Skopska Crna Gora	0.86
171	Torrent		Vardar	Skopska Crna Gora	6.28
172	Torrent		Vardar	Skopska Crna Gora	5.66
173	Torrent		Vardar	Skopska Crna Gora	3.32
		Total		**Skopska Crna Gora**	**101.55**
		Total (km)	**Vardar**		**294.28**

2) Treska

The river Treska is a right tributary of the Vardar. Its total length is 132 km, and the river basin covers 2,350 km2. The springs of Treska are Elovechka Reka, on the eastern side of the mountain Stogovo and Belichka Reka on the northern slopes of the mountain Ilinska Planina. The stream of Treska starts near the village Izvor in the Kichevo region. Through the Kichevo valley the river is called Golema Reka, and through Porece, Velika Reka. It is called Treska from the village of Zdunje to Skopje. Along the stream from Zdunje to the Skopje valley, in a length of 28 km, Treska flows through a steep canyon in which is the artificial lake Kozjak, formed by the dam built-in 2005. At the entrance to the Skopje valley, there is the artificial lake Matka created by the dam built-in 1937. Treska is flowing into the river of Vardar in the settlement Gjorce Petrov in the western part of Skopje.

Within this research, the riverbed of the river Treska is documented in a length of 10.44 km, with a starting point from the accumulation "Matka" of the Hydropower Plant Matka in the south to the confluence of the river Vardar near the village Krushopek and sports and recreation center Saraj. At that point, the river Treska is a river basin of 15 recorded streams.

Table 3.Classification of the Treska river basin streams in the Skopje Region.

id	Type	Name	River basin	Length (km)
201	Torrent	Krusopecki Poroj	Treska	4.62
201	Torrent	Krusopecki Poroj	Treska	4.62
202	Torrent		Treska	2.96
203	Torrent		Treska	2.91
204	Torrent		Treska	4.34
205	Torrent		Treska	4.05
206	Torrent		Treska	1.79
207	Torrent		Treska	0.88
208	Torrent		Treska	2.27
209	Torrent		Treska	0.36
210	Torrent		Treska	0.78
211	Torrent		Treska	2.17
212	Torrent		Treska	1.26
213	Torrent		Treska	3.17
214	Torrent		Treska	0.76
215	River	Fus	Treska	2.98
		Total (km)	**Treska**	**35.3**

3) Lepenec

The river Lepenec is formed in Kosovo by two rivers: Tisova Reka and Cerenacka Reka, whose spring areas are at an altitude of 1125 m, ie 1858 m, below the Shar Planina massif. It has a length of 75 km and extends over the territories of Kosovo (2/3 of the river basin) and North Macedonia (1/3 of the river basin). The river forms the border between the two countries in a length of 5 km. Within the Macedonian borders, the river basin of the river Lepenec extends to the northern part of the Skopje valley in a length of 15 km. It flows into the river Vardar near the Skopje settlement Zlokukjani at an altitude of 262 m. The river basin, up to the inflow into the river Vardar, is covering 770 m2 and the average height is 955 m asl. The river Lepenec in North Macedonia flows in a typical flat terrain where it leaves all sedimentary materials and creates a changeable bed that often meanders, especially before and after the village of Orman.

The riverbed of the river Lepenec is documented in a length of 10.56 km, with a starting point near the villages Orman and Nikishtane in the north to the inflow into the river Vardar. On that stretch, the river Lepenec is a river basin of 17 recorded watercourses with a total length of 48.28 km.

Table 4. Classification of the Lepenec river basin streams in the Skopje Region

id	Type	Name	River basin	Length (km)
301	Drainage canal		Lepenec	11.86
301	Drainage canal		Lepenec	11.86
302	Drainage canal		Lepenec	5.83
303	Torrent	Nikustanska Reka	Lepenec	5.32
304	Torrent		Lepenec	1.98
305	Torrent		Lepenec	1.35
306	Torrent		Lepenec	0.96
307	Torrent		Lepenec	1.37
308	Torrent		Lepenec	0.82

310	Torrent	Kuckovski Poroj	Lepenec	6.76
311	Torrent		Lepenec	1.97
312	Torrent		Lepenec	1.28
313	Torrent		Lepenec	0.76
314	Torrent		Lepenec	0.99
315	Torrent		Lepenec	1.44
316	Torrent	Banjanska Reka	Lepenec	4.85
317	Torrent		Lepenec	0.74
		Total (km)	**Lepenec**	**48.28**

4) Serava

The river of Serava is a left tributary of Vardar in the Skopje valley. The river basin extends on the southern slopes of the central area of the mountain Skopska Crna Gora and part of the Skopje valley. It is formed by two streams, which spring are at the peaks of Skopska Crna Gora, Jazirska Reka, northeast of the village Ljuboten at an altitude of 1500 m, and Radiski Potok which is formed by three streams: Pobushka, Turcevska and Ljubanska Reka, whose springs are located in the localities Przar and Crni Kamen at an altitude of 1300 m. All streams unite under the village of Ljubanci and form the Radishka River. After leaving the village of Radishani, the river enters the flat and fertile valley of Butelsko Pole and changes its name to the river Serava. Serava passes through Topaansko Pole and flows into the Vardar River just below the Ilinden Barracks to the south. Following river regulations, the river basin covers 94.5 km2. Serava in Vardar flows at an altitude of 243 m, and its total length is 21 km.

Within this research, the riverbed of the river Serava is documented in a length of 11.1 km, with a starting point north of the village Radishani in the north to the inflow of the river Vardar. In this move, Serava is regulated by a canal and is not a catchment area for any watercourse.

5) Markova Reka

Markova Reka is a right tributary of Vardar. It springs under the peak Ubava on Karadzica mountain at an altitude of 1,400 m, and it flows into Vardar between the villages of Gorno and Dolno Lisice at an altitude of 231 m. It is 29 km long and covers a river basin of 352 km2 and a slope of 1,169 m or 40 ‰. Its main tributary is Patishka Reka which sinks under the village Patishka Reka, so in its lower course, it is known as Suva Reka.

Within this research, the riverbed of Markova Reka is documented in a length of 16.78 km, with a starting point near the monastery Markov Manastir and the village of Markova Susica in the southwest to the inflow in the river Vardar between the villages of Gorno and Dolno Lisice in the north-east. On that move, Markova Reka is a river basin of 11 recorded streams.

Table 5. Classification of the Markova Reka river basin streams in the Skopje Region

id	Type	Name	River basin	Length (km)
501	Torrent	Kurpijan	Markova Reka	3.46
502	Torrent	Lokva Popova	Markova Reka	1.48
503	Torrent	Rakotinacki Dol	Markova Reka	8.51
504	Torrent	Cimkovec	Markova Reka	2.93
505	Torrent		Markova Reka	2.41
506	Torrent	Sarkova Voda	Markova Reka	2.2
507	Torrent		Markova Reka	1.91

508	Torrent		Markova Reka	1.69
509	Torrent		Markova Reka	3.6
510	Torrent	Meckin Dol	Markova Reka	4.95
511	Torrent	Kolicanski Potok	Markova Reka	5.87
		Total (km)	**Markova Reka**	**39.01**

REGULATED STREAMS IN THE SKOPJE REGION

Due to the specific genesis of the great waters with a coincidence of the flood waves in Upper Vardar, Treska, and Lepenec, Vardar very often flooded the city of Skopje. The greatest floods occurred in 1778, 1858, 1876, 1895, 1903, 1916, 1935, 1937, 1962, 1979. After the floods of 1895 and 1897, the then governor Hafus Mehmed-Pasha ordered the construction of defensive walls, which together with the development and expansion of the city were built. Such flood protection activities without other aesthetic and ecological aspects that would enrich the urban space, continued until 1937. The concept lasted until the great flood of 1962 when the need for a more studious approach to riverbed regulation emerged. The project for regulation of the riverbed of the river Vardar with a relatively successful hydro-technical conception was realized in the period 1970-1975. [12]

Apart from the floodwaters from the rivers, the cause of large floods and damage in the Skopje Region are the torrential floods. The great torrential flood was recorded in the 55s from the Krusopek torrent. Gornovodnjanski torrent constantly flooded houses in the lower part of the mountain Vodno. Mala Rada in the settlement of Dracevo, Strachinski Poroj, a river of Serava, and other streams also caused great damage in the area of the city of Skopje and the Skopje region. After the Second World War, exactly after the biggest floods in the XX century, caused by the torrents from Vodno, activities for intensive control of the erosion of the mountain Vodno started and they are realized in the second half of the XX century. The last major torrential floods occurred in 1951 when there was one dead case, many injured, and significant property damage. The measures taken after this catastrophe include afforestation, repair of the old ones, and construction of new drainage canals in the Vodno mountain. In recent history, the city of Skopje was affected by the storm on August 6, 2016, which led to a huge torrential flood in the northeastern part of the city, where part of the foothills of Skopska Crna Gora, including part of Skopsko Pole were most affected by the flood. Various inappropriate human activities (inappropriate urbanization, construction of facilities in the area of risk, usurpation of agricultural land, illegal logging on the mountain, engineering errors related to the Skopje ring road, absence or lack of activities of competent institutions for protection against erosion and torrents or activities during the occurrence of the danger - the event) significantly contributed to the magnitude of the damage. [7]

Such intensity of historical and recent disasters justifies the objectives of this research to create detailed documentation of the current situation of the regulated streams which conclusions will be drawn for further in-depth studies as a basis for future technical actions.

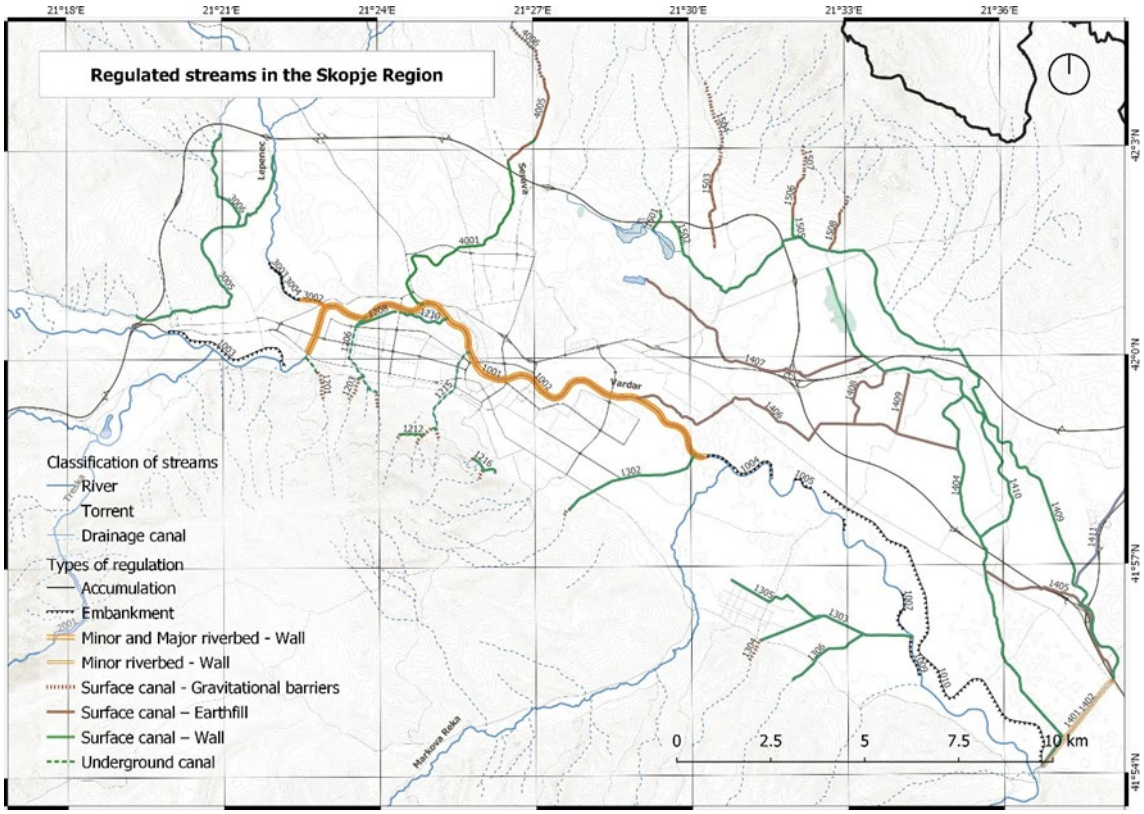

Figure 2. Regulated streams in the Skopje Region.
Data source: Agency for real estate cadastre. Topographic map 1:25000. sheets (681-4-3.; 681-4-4.; 682-3-3.; 731-2-1.; 731-2-2.; 732-1-1.) Skopje, AREC, 2004;

The documentation process of this phase of the research identifies the forms of the existing regulation of the recorded streams in an appropriate classification. Analyzed and grouped according to their river basin (with Vardar as the main recipient and on the level of its subsets) the forms and conditions of regulation are presented in the following order:

1) Vardar (id: 1000);
   - a. Upper Vardar,
   - b. Vodno torrents,
   - c. Kisela Voda - Dracevo,
   - d. Skopsko pole,
   - e. Skopska Crna Gora.
2) Treska (id: 2000);
3) Lepenec (id: 3000);
4) Serava (id: 4000);
5) Markova Reka (id: 5000);

Transferred to an appropriate tabular representation, each hydrographic unit representing a separate river basin has its id number where the first number assigns the belonging to the river basin (1000), the second the assignment to the subsets (1100), and the last 2 are ordinal numbers (1002).

Consequently, a database is created as operational documentation through direct cartographic processing in which the following characteristics are developed for each of the registered hydrographic objects:

- **id** number that expresses their affiliation and order,
- **Type of stream** according to the classification,

- **Name of the stream** recorded from the cartographic substrate or the literature,
- **River basin** to which they belong,
- **Subset** to which they belong more specifically,
- **Type of regulation** observed in the field or the literature,
- **Regulation starting point**
- **Length of regulation** expressed in kilometers (km), obtained by digital processing,
- **Regulation endpoint**

This structured database is tabularly processed and presented for each of the listed river basins and subsets for whose condition and form of regulation separate and aggregate data are obtained.

1) Vardar

Capital interventions and forms of regulation have been performed on the riverbed of the river Vardar. Due to the capacity, it possesses as a hydrographic object, on a larger scope of its riverbed, a type of regulation is performed from the minor and major riverbed - a wall of stone and mortar. The length of this regulation is about 14 km on both sides of the riverbed, and it starts from the bridge at the former factory Kuprom in the Skopje settlement Hrom, passes through the entire city and central area, and, ends after the village Gorno Lisice.

Additional regulations in the form of an embankment as a defensive line are made in the western and eastern parts of the river Vardar in the Skopje region. An embankment was built on the left side of the river Vardar in the western part of the city which starts at the bridge between the settlement Gjorce Petrov and the settlement Saraj and as a defensive line meanders at different distances from the riverbed of Vardar to the end of the settlement Hrom. An identical regulation facility was built in the eastern zone of the Skopje Region, starting at the end of the regulation with the minor and major riverbeds near the village of Gorno Lisice and ending at the village of Taor.

Table 6. Forms of regulation of the river Vardar in the Skopje Region

id	Type	Name	Type of regulation	Length (km)	Regulation starting point	Regulation endpoint
1001	River	Vardar	Minor and Major riverbed - Wall	14.03	42° 0'4.662", 21° 22'38.49"	41° 58'33.31", 21° 30'14.07"
1002	River	Vardar	Minor and Major riverbed - Wall	14.18	42° 0'5.514", 21° 22'36.96"	41° 58'34.78", 21° 30'20.20"
1003	River	Vardar	Embankment	3.74	42° 0'23.47", 21° 19'57.93"	41° 59'53.46", 21° 22'10.27"
1004	River	Vardar	Embankment	2.34	41° 58'34.78", 21° 30'20.20"	41° 58'14.56", 21° 31'32.10"
1005	River	Vardar	Embankment	0.57	41° 58'14.75", 21° 31'59.42"	41° 58'7.313", 21° 32'18.51"
1006	River	Vardar	Embankment	0.32	41° 57'39.95", 21° 32'56.93"	41° 57'30.59", 21° 32'57.06"
1007	River	Vardar	Embankment	0.64	41° 56'37.13", 21° 34'3.295"	41° 56'18.40", 21° 34'1.660"
1008	River	Vardar	Embankment	0.55	41° 56'20.36", 21° 34'1.133"	41° 56'4.786", 21° 34'3.386"
1009	River	Vardar	Embankment	1.05	41° 55'57.66", 21° 34'14.25"	41° 55'25.54", 21° 34'23.16"

1010	River	Vardar	Embankment	11.34	41° 58'2.927", 21° 32'33.72"	41° 54'6.387", 21° 36'41.11"
	Total (km)	**Vardar**		**48.76**		

a) Upper Vardar

In the streams belonging to this part of the river basin of the river Vardar, no form of regulation has been identified.

b) Vodno torrents

Due to the already mentioned natural disasters and phenomena that caused damage in the past in this part of the Skopje Region, technical and constructive interventions were necessary to regulate most of the torrential water streams from Mount Vodno. In this subset 20 regulated watercourses are registered in appropriate classification and form of regulation. Their regulation dates back to the 50s and 60s of the XX century, based on the project documentation (forest reclamation works, barriers, and regulations) from Poroj Projekt - Skopje. (Blinkov, Trendafilov, Minchev, Peshevski, 2017) According to the location characteristics, the torrents are grouped in the following hydrographic units: western, central, and eastern Vodno torrent series.

In the western series, forms of regulation are observed in the following torrential water streams: Bachvishta, Trnodol, Sultan Potok, and Kamen Dol. The regulation of the torrents is performed in the form of surface canals made of stone in cement mortar, wherein the steep parts of the streams additionally are performed by vertical gravitational barriers of the same material. A part of the regulated torrent Bachvishta has a constructed and covered canal. The other torrents such as Trnodol, Sultan Potok, and Kamen Dol are connected to a drainage canal that collects the water from the torrents and conducts it underground through the settlements Kozle, Taftalidze, and Karposh into the river Vardar.

In the area of the central series of torrents, forms of regulation have been observed in the following torrential watercourses: Kapishtec, Murtinec, and Gornovodnjanski torrents. The regulation of the surface canals is performed on the same principle from stone to cement mortar, with gravity partitions at specific positions in the field. The waters of the whole torrential series are occupied by an underground collection canal and conducted to the river Vardar.

The area of the eastern series is formed by the regulated Usjanski torrent, which was dimensioned to accept all torrential watercourses from the eastern series. But due to an incompletely implemented project, the waters of this series (torrential watercourses from Priporski Dol) flow down the streets through the regulated surface canal

Table 7. Forms of regulation of the Vodno torrents as a part of the river basin of Vardar in the Skopje Region

id	Type	Name	Type of regulation	Length (km)	Regulation starting point	Regulation endpoint
1201	Torrent	Bacvista	Surface canal - Gravitational barriers	0.74	41° 59'26.77", 21° 22'55.76"	41° 59'48.44", 21° 22'48.85"
1202	Torrent	Bacvista	Covered canal	0.52	41° 59'48.44", 21° 22'48.85"	42° 0'1.884", 21° 22'35.40"
1203	Torrent	Sultan Potok	Surface canal - Gravitational barriers	0.63	41° 59'25.48", 21° 23'25.94"	41° 59'43.09", 21° 23'36.96"
1204	Drainage canal	Sultan Potok	Surface canal - Walls	0.15	41° 59'43.09", 21° 23'36.96"	41° 59'46.13", 21° 23'41.85"
1205	Torrent	Kamenov Dol	Surface canal - Gravitational barriers	0.4	41° 59'14.30", 21° 23'59.42"	41° 59'32.80", 21° 23'57.32"
1206	Drainage canal	Western Vodno series	Covered canal	2.29	41° 59'32.80", 21° 23'57.32"	42° 0'27.81", 21° 23'34.07"
1207	Drainage canal	Western Vodno series	Surface canal - Walls	0.36	42° 0'27.81", 21° 23'34.07"	42° 0'35.81", 21° 23'45.10"
1208	Drainage canal	Western Vodno series	Surface canal - Walls	1.05	42° 0'27.81", 21° 23'34.07"	42° 0'40.44", 21° 24'16.32"
1209	Drainage canal	Western Vodno series	Covered canal	0.29	42° 0'40.44", 21° 24'16.32"	42° 0'39.39", 21° 24'28.93"
1210	Drainage canal	Western Vodno series	Surface canal - Walls	1.32	42° 0'39.39", 21° 24'28.93"	42° 0'34.72", 21° 25'20.14"
1211	Torrent	Murtinec	Surface canal - Gravitational barriers	0.14	41° 58'51.90", 21° 24'21.87"	41° 58'54.89", 21° 24'25.38"
1212	Torrent	Murtinec	Surface canal - Walls	0.63	41° 58'54.89", 21° 24'25.38"	41° 58'54.71", 21° 24'52.08"
1213	Torrent	Gornodnjanski Poroj	Surface canal - Gravitational barriers	0.56	41° 58'47.61", 21° 24'44.06"	41° 58'59.70", 21° 25'1.294"
1214	Torrent	Gornodnjanski Poroj	Surface canal - Gravitational barriers	0.3	41° 58'49.11", 21° 25'8.650"	41° 58'58.57", 21° 25'6.218"
1215	Torrent	Central Vodno series	Covered canal	2.59	41° 58'58.57", 21° 25'6.218"	42° 0'5.468", 21° 25'45.69"
1216	Torrent	Kisela Voda	Surface canal - Walls	0.85	41° 97'60.15", 21° 43'04.98"	41° 97'33.09", 21° 43'66.81"
1217	Torrent	Priporski Dol	Surface canal - Gravitational barriers	0.26	41° 58'16.89", 21° 25'56.14"	41° 58'23.28", 21° 26'0.817"
1218	Torrent	Priporski Dol	Surface canal - Gravitational barriers	0.04	41° 97'57.10", 21° 42'95.97"	
	Total (km)	**Vodno torrents**		**13.2**		

c) Kisela Voda - Dracevo

The following 3 torrential watercourses have been documented in this area: Usjanski Poroj (Golemi Kamenja), Mara Rada, and Krnjeva Reka. Usjanski Poroj (Golemi Kamenja) is formed opposite the village Usje, flows through the village Usje, settlement

Usje, settlement Gorno Lisice and through a regulated riverbed flows into the river Vardar. The regulation was performed in the same period as the Vodno torrents, using the same construction principles and building materials.
Mala Rada is a regulated riverbed with vertical gravitational barriers that collects water from the settlement of Dracevo, the village of Studenicani, and the village of Zelenikovo. The riverbed is regulated to the inflow into the river Vardar.

Table 8. Forms of regulation of the Kisela Voda - Dracevo torrents as a part of the river basin of the Vardar in the Skopje Region

id	Type	Name	Type of regulation	Length (km)	Regulation starting point	Regulation endpoint
1301	Torrent	Golemi Kamenja	Surface canal - Gravitational barriers	0.24	41° 57'43.96", 21° 27'33.74"	41° 57'49.21", 21° 27'39.43"
1302	Drainage canal	Usjanski Poroj	Surface canal - Wall	3.84	41° 57'49.21", 21° 27'39.43"	41° 58'36.42", 21° 30'4.555"
1303	Drainage canal	Mala Rada	Surface canal – Wall	4.29	41° 55'55.88", 21° 31'19.99"	41° 55'57.47", 21° 34'15.43"
1304	Torrent	Mala Rada	Surface canal - Gravitational barriers	0.65	41° 55'37.98", 21° 31'6.904"	41° 55'55.88", 21° 31'19.99"
1305	Drainage canal	Mala Rada	Surface canal – Wall	2.86	41° 56'48.09", 21° 30'46.11"	41° 56'16.20", 21° 32'29.92"
1306	Drainage canal	Krnjeva Reka	Surface canal - Wall	2.39	41° 55'21.68", 21° 31'56.55"	41° 55'59.79", 21° 33'21.16"
	Total (km)	**Kisela Voda - Dracevo**		**14.27**		

d) Skopsko Pole

The drainage system "Skopsko Pole" consists of the main peripheral canal Singelic-Taor, two main canals, and a tertiary network. The total length of all canals is about 40 km. The total drainage area is 6600 ha. The drainage system consists of two subsystems "Upper Zone" with 4500 ha and "Lower Zone" with 2100 ha and a peripheral canal. The collection canals are regulated either in the form of a stone wall in cement mortar or the form of eartfill surface canals. The "Skopsko Pole" system, in addition to its drainage function for the northeastern part of the Skopje Region, is important because it accepts all torrential watercourses from Skopska Crna Gora and through its main peripheral canal, Singelic-Taor leads them to the river Vardar.

Table 9. Forms of regulation of the Skopsko Pole drainage canals as a part of the river basin of the Vardar in the Skopje Region

id	Type	Name	Type of regulation	Length (km)	Regulation starting point	Regulation endpoint
1401	Drainage canal	Main peripheral canal "Singelic-Taor"	Minor riverbed - Wall	2.97	41° 55'20.12", 21° 38'5.263"	41° 54'6.165", 21° 36'43.38"
1402	Drainage canal	Main peripheral canal "Singelic-Taor"	Minor riverbed – Wall	2.95	41° 55'19.35", 21° 38'6.102"	41° 54'5.602", 21° 36'44.92"
1404	Drainage canal	Main canal	Surface canal – Wall	17.22	42° 1'15.99", 21° 32'38.96"	41° 54'6.551", 21° 36'42.73"
1405	Drainage canal	Tertiary network	Surface canal – Earthfill	5.06	41° 56'54.81", 21° 35'39.13"	41° 55'22.72", 21° 38'6.665"

1406	Drainage canal	Tertiary network	Surface canal - Earthfill	10.17	41° 59'24.99", 21° 28'56.91"	41° 58'39.19", 21° 35'8.554"
1407	Drainage canal	Tertiary network	Surface canal – Earthfill	7.15	42°1'7.660", 21° 29'7.849"	42° 0'0.525", 21° 33'20.08"
1408	Drainage canal	Tertiary network	Surface canal – Earthfill	2.31	41° 59'47.46", 21° 33'48.21"	41° 59'1.538", 21° 33'9.420"
1409	Drainage canal	Main peripheral canal "Singelic-Taor"	Surface canal – Wall	21.27	42° 1'31.47", 21° 29'52.26"	41° 55'19.58", 21° 38'5.815"
1409	Drainage canal	Tertiary network	Surface canal – Earthfill	1.6	41° 59'44.57", 21° 34'12.40"	41° 58'53.99", 21° 33'57.14"
1410	Drainage canal	Tertiary network	Surface canal – Wall	4.78	41° 59'25.88", 21° 35'15.45"	41° 57'23.07", 21° 35'33.56"
1411	River	Suva Reka	Surface canal - Earthfill	6.95	41° 59'49.24", 21° 38'56.17"	41° 56'40.86", 21° 37'24.00"
	Total (km)	**Skopsko Pole**		**82.43**		

e) Skopska Crna Gora

In this area, 5 regulated forms of torrential watercourses have been recorded: Cresevska Reka, Stracinska Dreza, Brnjarski Poroj, and Trliste.

Creshevska Reka, as the largest stream of this torrential series, was regulated in the 50s, and 60s of the XX century, when most of Skopsko Pole was agricultural land. The regulated riverbed passes through the villages of Bulacani and Cresevo and downstream crosses the ring road, where the regulation ends. The riverbed is made of a surface earthfill canal with gravity partitions built of stone in cement mortar.

Stracinska Dreza was regulated in the same period. In the upper gorge, the torrential watercourse is arranged with gravity barriers from stone to cement mortar. Downstream, through the village of Stracinci to the collection-peripheral canal, the riverbed is regulated as a surface earthfill canal with gravity partitions.

Opposite the village of Brnjarci, the torrential watercourse Brnjarski Poroj is regulated with gravity barriers made of stone in cement mortar. Downstream, through the village, up to the inflow into the collection canal, the riverbed is regulated as a surface earthfill canal with gravity partitions.

Table 10. Forms of regulation of the Skopska Crna Gora torrents as a part of the river basin of the Vardar in the Skopje Region

id	Type	Name	Type of regulation	Length (km)	Regulation starting point	Regulation endpoint
1501	Torrent	Trliste	Surface canal – Wall	0.63	42° 2'6.626", 21° 29'27.31"	42° 1'48.85", 21° 29'18.38"
1502	Torrent	Rastanski Potok	Surface canal – Wall	0.86	42° 1'57.04", 21° 29'39.76"	42° 1'31.47", 21° 29'52.26"
1503	Torrent	Cresevska Reka	Surface canal – Earthfill	2.51	42° 2'50.26", 21° 30'35.73"	42° 1'34.44", 21° 30'29.04"
1504	Torrent	Cresevska Reka	Surface canal - Gravitational barriers	2.29	42° 3'56.77", 21° 30'18.22"	42° 2'50.26", 21° 30'35.73"
1505	Torrent	Stracinska Dreza	Surface canal – Wall	0.66	42° 1'59.33", 21° 31'59.70"	42° 1'42.95", 21° 32'7.319"
1506	Torrent	Stracinska Dreza	Surface canal – Earthfill	1.19	42° 2'34.79", 21° 32'13.00"	42° 1'59.33", 21° 31'59.70"

1507	Torrent	Stracinska Dreza	Surface canal - Gravitational barriers	0.87	42° 3'0.629", 21° 32'12.43"	42° 2'34.79", 21° 32'13.00"
1508	Torrent	Brnjarski Poroj	Surface canal – Earthfill	1.1	42° 2'4.268", 21° 32'54.50"	42° 1'30.96", 21° 32'41.67"
1509	Torrent	Brnjarski Poroj	Surface canal - Gravitational barriers	0.46	42° 2'17.29", 21° 33'3.196"	42° 1'30.96", 21° 32'41.67"
	Total (km)	**Skopska Crna Gora**		**10.57**		

2) Treska

No form of riverbed regulation is identified on the Treska River. This condition is because two artificial accumulations have been built on their course in the high gorge, which is a sufficient regulatory factor for the river. Additionally, with the construction of the artificial lake Treska, the riverbed gets an additional moment of regulation taking into account the lake as an accumulation capacity in case of bigger water inflows.

3) Lepenec

The Lepenec riverbed is regulated only in the lower course, before the inflow into the river Vardar, in a length of 800 meters. The width of the riverbed with meanders, sand springs, and vegetation ranges from 400 meters wide near the village of Orman and the ring road to 70-40 meters near the confluence with the Vardar. Before the inflow into the river Vardar, two cascades were made to reduce the longitudinal fall of the riverbed. Although the river of Lepenec is one of the three rivers that can bring huge flood waves in Skopje, as well as overflow the river, still no serious technical and construction approach has been approached in the context of regulation of its riverbed.

Table 11. Forms of regulation of the river Lepenec in the Skopje Region

id	Type	Name	Type of regulation	Length (km)	Regulation starting point	Regulation endpoint
3001	River	Lepenec	Minor riverbed – Wall	0.79	42° 0'51.95", 21° 22'27.74"	42° 0'45.85", 21° 23'0.439"
3002	River	Lepenec	Minor riverbed – Wall	0.75	42° 0'50.99", 21° 22'27.63"	42° 0'44.89", 21° 22'58.63"
3003	River	Lepenec	Embankment	0.77	42° 1'22.60", 21° 21'53.86"	42° 1'2.413", 21° 22'8.947"
3004	River	Lepenec	Embankment	1.12	42° 1'17.93", 21° 21'59.88"	42° 0'51.95", 21° 22'27.74"
3005	Drainage canal		Surface canal - Wall	8.12	42° 2'55.77", 21° 21'59.58"	42° 0'37.67", 21° 19'20.61"
3006	Drainage canal		Surface canal - Wall	2.94	42° 3'14.52", 21° 20'58.18"	42° 1'54.55", 21° 21'16.55"
	Total (km)	**Lepenec**		**14.49**		

4) Serava

The river of Serava as a torrential river in the past caused damage and losses in its old stream that passed through the central city area of the city (Old Bazaar). For these reasons, with the deviation of the riverbed, its flow was changed and today, through an openly

regulated riverbed, the river flows into the river Vardar. Its riverbed was subject to regulation through 3 stages. The projects defined the arrangement of the riverbed to the village Radishani in a length of 10 km. The regulation started after the flood of the city of Skopje in 1962 and the earthquake in 1963. In the first phase, the riverbed in the length of 1.9 km was regulated, at the foot of the settlement Butel. Then, the second phase is realized with a deviation of the river flow to the west of a total length of 3.7 km. The third phase includes regulation in the length of 1.6 km and a determined riverbed with gravity barriers in the length of 2.6 km. From the settlement Butel to the confluence of the river Vardar, the regulation is performed as a canal with a trapezoidal profile, with a coated bottom and slopes. (Source: Main project for regulation of Serava river - III stage, Institute for Water Economy of RM).

Table 12. Forms of regulation of the river Serava in the Skopje Region

id	Type	Name	Type of regulation	Length (km)	Regulation starting point	Regulation endpoint
4001	River	Serava	Surface canal – Wall	6.1	42° 2'43.65", 21° 26'32.33"	42° 0'47.24", 21° 24'51.42"
4003	River	Serava	Surface canal – Wall	0.21	42° 3'8.819", 21° 27'2.223"	42° 3'4.661", 21° 26'55.41"
4005	River	Serava	Surface canal – Earthfill	2.44	42° 4'0.021", 21° 27'12.72"	42° 2'49.11", 21° 26'30.70"
4006	River	Serava	Surface canal - Gravitational barriers	1.74	42° 4'44.82", 21° 26'35.91"	42° 4'0.021", 21° 27'12.72"
	Total (km)	**Serava**		**10.49**		

5) Markova Reka

Markova Reka is a typical torrential river that in the past on several occasions caused damage and consequences on a larger scale (floods, collapsed bridges, damaged buildings, etc.), but in the scope of its riverbed are not yet recorded forms of regulation.

RECOMMENDATIONS FOR REGULATION AND REHABILITATION OF THE RIVERBEDS IN THE SKOPJE REGION

Following the process of documentation of the streams and the forms of their regulation, recommendations for regulation and rehabilitation of specifically defined zones of the riverbeds in the Skopje region are defined. This step is aimed at deepening the observation and improving the conditions in the riverbeds by noticing various anthropogenic influences and reducing the intensity of maintenance of existing regulation facilities.

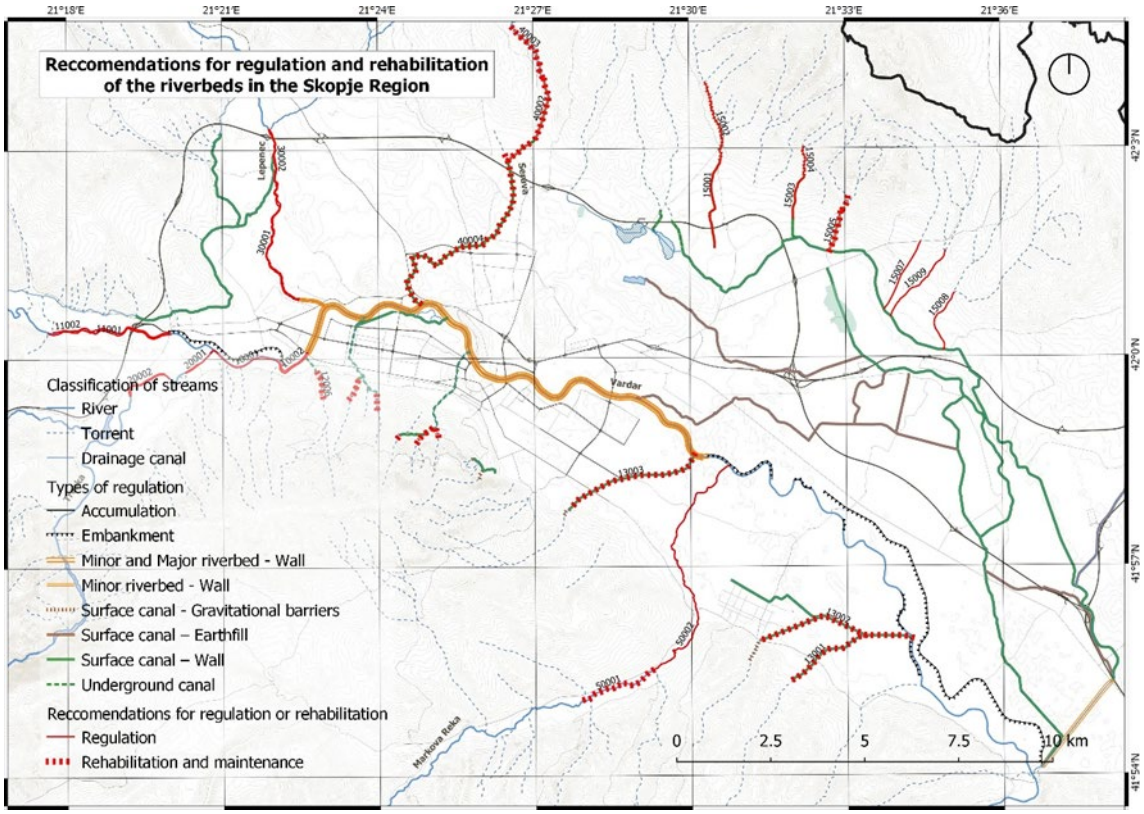

Figure 3. Recommendations for regulation and rehabilitation of the riverbeds in the Skopje Region
Data source: Agency for real estate cadastre. Topographic map 1:25000. sheets
(681-4-3.; 681-4-4.; 682-3-3.; 731-2-1.; 731-2-2.; 732-1-1.) Skopje, AREC, 2004;

This phase of the research identifies the positions in the watercourses for which regulation or rehabilitation and maintenance are proposed in their appropriate classification. Analyzed and grouped according to their river basin (with Vardar as the main recipient and on the level of its subsets) the recommendations are presented in the following order:

6) Vardar (id: 10000);
- a. Upper Vardar,
- b. Vodno torrents,
- c. Kisela Voda - Dracevo,
- d. Skopsko pole,
- e. Skopska Crna Gora.

7) Treska (id: 20000);
8) Lepenec (id: 30000);
9) Serava (id: 40000);
10) Markova Reka (id: 50000);

Transferred to an appropriate tabular representation, each hydrographic unit representing a separate river basin has its id number where the first number assigns the belonging to the river basin (10000), the second the assignment to the subsets (11000), and the last 3 are ordinal numbers (10003).

Consequently, a database is created as operational documentation through direct cartographic processing in which for each recommendation for regulation or rehabilitation of hydrographic facilities the following characteristics are developed:

- • **id** number that expresses their affiliation and order,
- • **Type of stream** according to the classification,

- • **Name of the stream** recorded from the cartographic substrate or the literature,
- • **River basin** to which they belong,
- • **Subset** to which they belong more specifically,
- • **Status of regulation** observed on the field or in the literature,
- • **Condition of the regulation** observed on the field or in the literature,
- • **Recommendations for regulation** or rehabilitation
- • **Length of recommendation for regulation** expressed in kilometers (km), obtained by digital processing,
- • **Recommendation starting point**
- • **Recommendation endpoint**

This structured database is tabularly processed and presented for each of the listed river basins and subsets for whose recommendations for regulation or rehabilitation separate and aggregate data are obtained.

1) Vardar

The riverbed of the river Vardar, as the main hydrographic element and river basin, has the highest degree of regulation within the Skopje valley. However, there are zones in which the continuity of regulation is interrupted, and thus the possibility of movement along the riverbed. As well as anthropogenic influences are observed stimulated by the development and expansion of the surrounding settlements, which lead to damage and direct interventions on the riverbed. In the western part of the city of Skopje, the river Vardar divides the settlements Gjorce Petrov and Hrom on the left side of the stream and Saraj and Karpos on the right side. The left side, which belongs to the settlement Gjorce Petrov is regulated by a defensive line - an embankment that is in good condition. This type of regulation ends in the settlement of Hrom, where next to the bridge, at the former factory Kuprom, no type of regulation is observed, and at the same time, the movement along the riverbed is interrupted. For that reason, it is recommended to continue the regulation of this part of the riverbed to connect with the main quay of the river Vardar regulated by the Major and Minor riverbeds.

On this part of the river, on the right side which belongs to the settlements Saraj and Karpos, and in which the villages Krushopek, Laka, and Dolno Nerezi exist, there is an intervention in the riverbed of anthropogenic influences, primarily waste and debris that is delayed for a long time on the edge of the riverbed and as such settles or plums directly into the river. For that reason, it is necessary to initially rehabilitate with regulation the riverbed along its entire length from the recreation center Saraj to the settlement Dolno Nerezi, where it is connected to the main quay of the river Vardar.

Table 13. Recommendations for regulation or rehabilitation of the riverbed of the Vardar

id	Type	Name	Status of regulation	Condition of regulation
10001	River	Vardar	Unregulated	Anthropogenic influences
10002	River	Vardar	Unregulated	Anthropogenic influences
id	**Recommendation**	**Length (km)**	**Recommendation starting point**	**Recommendation endpoint**
10001	Regulation	3.19	42° 0'7.517", 21° 20'48.66"	42° 0'4.662", 21° 22'38.49"
10002	Regulation	1.01	41° 59'56.41", 21° 22'6.902"	42° 0'5.514", 21° 22'36.96"
	Total (km)	**4.2**		

a) Upper Vardar

In the part of the riverbed of Vardar known as Upper Vardar, the presence of anthropogenic influences that date from recent times is noticeable. Significantly dominant built content is visible next to the right bank of the riverbed, where facilities have been built and operated for light industry and production. The intervention on the riverbed is also noticeable, where the green protection zone that existed before the appearance of these buildings has been completely annulled. For that reason, it is proposed to regulate the riverbed in the indicated move in the length of 3.61 km, which would be regulated on both sides of the flow.

Table 14. Recommendations for regulation or rehabilitation of the riverbed of the Vardar in the part of Upper Vardar

id	Type	Name	Status of regulation	Condition of regulation
11001	River	Vardar	Unregulated	Anthropogenic influences
11002	River	Vardar	Unregulated	Anthropogenic influences
id	**Recommendations**	**Length of (km)**	**Recommendation starting point**	**Recommendation endpoint**
10001	Regulation	3.61	42° 0'22.67", 21° 17'38.54"	42° 0'21.84", 21° 19'59.81"
10002	Regulation	3.34	42° 0'23.71", 21° 17'44.23"	42° 0'23.14", 21° 19'57.50"
	Total (km)	**6.95**		

b) Vodno torrents

In the torrential watercourses belonging to the Vodno torrents subsets as part of the river basin of Vardar, a state of insufficient maintenance of the built forms of regulation has been observed, which include surface channels of stone in cement mortar with gravity barriers at certain positions. Due to the absence of continuous maintenance, their functionality is drastically reduced and noticeable are overgrown on the longitudinal and vertical buildings with vegetation of all types, including trees. For that reason, it is recommended to rehabilitate and further maintain all buildings for regulation of this type, which include the torrential watercourses Kamenov Dol, Murtinec, Sultan Potok, Gornovodnjanski torrent, and Bachvishta.

Table 15. Recommendations for regulation or rehabilitation of the Vodno torrents as a part of the river basin of Vardar in the Skopje Region

id	Type	Name	Status of regulation	Condition of regulation
12001	Torrent	Kamenov Dol	Gravitational barriers	Overgrown floodplains
12002	Torrent	Murtinec	Gravitational barriers	Overgrown floodplains
12003	Torrent	Sultan Potok	Gravitational barriers	Overgrown floodplains
12004	Torrent	Gornodnjanski Poroj	Gravitational barriers	Overgrown floodplains
12005	Torrent	Gornodnjanski Poroj	Gravitational barriers	Overgrown floodplains
12006	Torrent	Bacvista	Gravitational barriers	Overgrown floodplains

id	Recommendation	Length (km)	Recommendation starting point	Recommendation endpoint
12001	Rehabilitation and maintenance	0.45	41° 59'14.30", 21° 23'59.42"	41° 59'28.44", 21° 23'57.66"
12002	Rehabilitation and maintenance	0.14	41° 58'51.90", 21° 24'21.87"	41° 58'54.89", 21° 24'25.38"
12003	Rehabilitation and maintenance	0.63	41° 59'25.48", 21° 23'25.94"	41° 59'43.09", 21° 23'36.96"
12004	Rehabilitation and maintenance	0.3	41° 58'49.11", 21° 25'8.650"	41° 58'58.57", 21° 25'6.218"
12005	Rehabilitation and maintenance	0.56	41° 58'47.61", 21° 24'44.06"	41° 58'59.70", 21° 25'1.294"
12006	Rehabilitation and maintenance	0.74	41° 59'26.77", 21° 22'55.76"	41° 59'48.44", 21° 22'48.85"
	Total (km)	**2.82**		

c) Kisela Voda - Dracevo

The torrents built in the section Kisela Voda - Dracevo, which belongs to the river basin of Vardar noticeably is significantly reduced water flow as a result of the overgrown riverbed with the ground, shrubby and woody vegetation, waste of any nature, and deformed slopes of the riverbeds. For that reason, it is proposed cleaning, rehabilitation, and continuous maintenance of the collection canals Krnjeva Reka, Mala Rada, and the crucial Usjanski Poroj.

Table 16. Recommendations for regulation or rehabilitation of the Kisela Voda - Dracevo torrents as a part of the river basin of Vardar in the Skopje Region

id	Type	Name	Status of regulation	Condition of regulation
13001	Torrent	Krnjeva Reka	Surface canal – Wall	Overgrown with vegetation
13002	Torrent	Mala Rada	Surface canal – Wall	Overgrown with vegetation
13003	Torrent	Usjanski Poroj	Surface canal – Wall	Overgrown with vegetation

id	Recommendations	Length (km)	Recommendation starting point	Recommendation endpoint
13001	Rehabilitation and maintenance	2.39	41° 55'21.68", 21° 31'56.55"	41° 55'59.79", 21° 33'21.16"
13002	Rehabilitation and maintenance	4.29	41° 55'55.88", 21° 31'19.99"	41° 55'57.47", 21° 34'15.43"
13003	Rehabilitation and maintenance	3.84	41° 57'49.21", 21° 27'39.43"	41° 58'36.42", 21° 30'4.555"
	Total (km)	**10.52**		

d) Skopsko Pole

The public enterprise for water management within its regional office "Skopsko Pole" is an important entity that has legal competencies for flood control and continuous maintenance. Currently, all activities for the management of drainage canals in the part of Skopsko Pole that belong to the river basin of Vardar are maintained from this institution, and as such is evident good conditions of the drainage system with a satisfactory functionality.

e) Skopska Crna Gora

In the torrential series of Skopska Crna Gora, there are various forms of regulation in the moves of the torrents Cresevska Reka, Stracinska Dreza, and Brnjarski Poroj.

It is necessary to rehabilitate and continuously maintain the earthfill surface canal of Brnjarski Poroj, which is overgrown with vegetation, and therefore with reduced functionality. Downstream, throughout the village, up to the inflow into the peripheral drainage canal, anthropogenic influences have been observed, in its regulated form of earthfill surface canal with gravity partitions. Several makeshift bridges and culverts drastically reduce the canal profile. Therefore, the proposed is complete rehabilitation with the regulation of this torrential watercourse.
Stracinska Dreza contains the same forms of regulation, but also the same anthropogenic influences and lack of maintenance due to which there are floods on the gravitational barriers, as well as overgrowth with vegetation of the earthfill channels. Due to the great damage caused by the floods in 2016, the recommendation for this regulated flow of torrent watercourse to be subject to the new regulation.
Cresevska Reka riverbed deserves the greatest attention during its future treatment. It has the same forms of regulation that mainly occur damage from the last floods in 2016. A detailed analysis of the condition of the watercourse and arrangement of the riverbed of the Cresevska Reka to a permanent recipient in the peripheral collection canal is necessary. Its riverbed currently ends up in agricultural land that can easily be flooded by large floods.
There is also a need to regulate the unregulated torrential watercourses Krivi Dol and Orlanska Reka near the village Aracinovo, primarily in the part of the plain.

Table 17. Recommendations for regulation or rehabilitation of the Skopska Crna Gora torrents as a part of the river basin of Vardar in the Skopje Region

id	Type	Name	Status of regulation	Condition of regulation
15001	Torrent	Cresevska Reka	Surface canal - Earthfill	Overgrown with vegetation
15002	Torrent	Cresevska Reka	Gravitational barriers	Overgrown floodplains
15003	Torrent	Stracinska Dreza	Surface canal – Earthfill	Overgrown with vegetation
15004	Torrent	Stracinska Dreza	Gravitational barriers	Overgrown floodplains
15005	Torrent	Brnjarski Poroj	Surface canal – Earthfill	Overgrown with vegetation
15006	Torrent	Brnjarski Poroj	Gravitational barriers	Overgrown floodplains
15007	Torrent		Unregulated	Anthropogenic influences
15008	Torrent	Krivi Dol	Unregulated	Overgrown with vegetation
15009	Torrent	Orlanska Reka	Unregulated	Overgrown with vegetation

id	Recommendations	Length (km)	Recommendation starting point	Recommendation endpoint
15001	Regulation	2.51	42° 2'50.26", 21° 30'35.73"	42° 1'34.44", 21° 30'29.04"
15002	Regulation	2.29	42° 3'56.77", 21° 30'18.22"	42° 2'50.26", 21° 30'35.73"
15003	Regulation	1.19	42° 2'34.79", 21° 32'13.00"	42° 1'59.33", 21° 31'59.70"
15004	Regulation	0.87	42° 3'0.629", 21° 32'12.43"	42° 2'34.79", 21° 32'13.00"
15005	Rehabilitation and maintenance	1.1	42° 2'4.268", 21° 32'54.50"	42° 1'30.96", 21° 32'41.67"
15006	Rehabilitation and maintenance	0.46	42° 2'17.29", 21° 33'3.196"	42° 2'4.268", 21° 32'54.50"
15007	Regulation	3.23	42° 2'13.09", 21° 34'47.78"	42° 0'40.81", 21° 33'44.13"

15008	Regulation	3.5	42° 1'36.37", 21° 35'47.61"	42° 0'5.645", 21° 34'52.76"
15009	Regulation	3.29	42° 1'57.46", 21° 35'13.72"	42° 0'34.95", 21° 33'51.96"
	Total (km)	**18.44**		

2) Treska

The riverbed of the river Treska is in a constant form of regulation and protection from flooding in the surrounding areas through the already installed accumulations. For that reason, no additional forms of regulation have been observed in the riverbed. However, there is a significant occurrence of anthropogenic influences in certain zones and areas of the riverbed, in the part where pressure is created by the expansion of the existing settlements Krushopek and Grcec. Similar to the riverbed of the river Vardar, there is a noticeable delay in the huge amount of waste on the edge of the riverbed and the destruction of the existing protective vegetation, which poses a risk to water quality and visible destructive habitats in nature. Therefore, it is recommended to clean the existing condition and regulations to protect from further destructive actions along the river Treska.

Table 18. Recommendations for regulation or rehabilitation of the riverbed of the Treska

id	Type	Name	Status of regulation	Condition of regulation
20001	River	Treska	Accumulation	Anthropogenic influences
20002	River	Treska	Accumulation	Anthropogenic influences
20003	River	Treska	Accumulation	Anthropogenic influences
20004	River	Treska	Accumulation	Anthropogenic influences

id	Recommendations	Length (km)	Recommendation starting point	Recommendation endpoint
20001	Regulation	0.95	41° 59'48.59", 21° 20'17.38"	42° 0'7.517", 21° 20'48.66"
20002	Regulation	1.25	41° 59'28.92", 21° 19'12.31"	41° 59'47.77", 21° 19'52.10"
20003	Regulation	1.37	41° 59'28.99", 21° 19'13.84"	41° 59'43.70", 21° 19'57.81"
20004	Regulation	0.37	41° 59'49.19", 21° 20'17.25"	41° 59'55.86", 21° 20'30.34"
	Total (km)	**3.94**		

3) Lepenec

The river of Lepenec has large changes in water quantities that affect the occurrence of floods that occur not only along the river but also in various parts of the Skopje valley. During the occurrence of flood waves on the river Lepenec, the overflow occurs most often in the belt from the entrance of the river on the Macedonian border, to the village Orman and downstream, most often along the right bank of the river.

The recommendations for regulation of the Lepenec riverbed refer to both banks and as such are double calculated in the table. The recommendation covers the area from the ring road where Banjanska Reka flows into the river Lepenec, all the way to before the inflow into the river Vardar where Lepenec has a small part which is regulated by the Minor riverbed. The regulatory plan for this move must be particularly carefully planned and must be subject to a series of studies by interdisciplinary teams. This is primarily due to

the existing dense riparian vegetation, diversity of animal species and riparian vegetation, as well as diversity of vertebrates and invertebrates in the valley of the river.
There is a need for regulation and arrangement of the banks of the river Lepenec, especially in the downstream part of Gjorce Petrov, where the industrial zone is formed, in which the river loses its importance and becomes a channel for wastewater from production facilities. Its landscape values become invisible and marginalized from the occurrence of illegal landfills along the river, which are a direct threat to the water quality in the river, especially visible near the settlements of Bardovci, Zlokukjani, and Momin Potok.

Table 19. Recommendations for regulation or rehabilitation of the riverbed of the Lepenec

id	Type	Name	Status of regulation	Condition of regulation
30001	River	Lepenec	Unregulated	Anthropogenic influences
30002	River	Lepenec	Unregulated	Anthropogenic influences

id	Recommendations	Length (km)	Recommendations starting point	Recommendations endpoint
30001	Regulation	5.29	42° 3'17.96", 21° 21'53.75"	42° 0'50.99", 21° 22'27.63"
30002	Regulation	5.22	42° 3'17.46", 21° 21'55.30"	42° 0'51.95", 21° 22'27.74"
	Total (km)	**10.51**		

4) Serava

We can notice a proper form of regulation of the river Serava, but the need for continuous maintenance and cleaning is also evident. In many parts, the existing riverbed is overgrown with woody vegetation, which indicates a discontinuity in its maintenance and thus reduced flow capacity of the riverbed and opportunities for flooding, followed by the waste of various kinds. In the part at the end of the village Radishani, where the riverbed is regulated as an earthfill surface channel with gravity barriers, there is a risk of flooding as a consequence of the high potential of erosion in the riverbed which is covered with erosive sediment and with reduced useful height. It is necessary to clean them and further maintain the riverbed.

Table 20. Recommendations for regulation or rehabilitation of the riverbed of the Serava

id	Type	Name	Status of regulation	Condition of regulation
40001	Torrent	Serava	Surface canal - Earthfill	Overgrown with vegetation
40002	River	Serava	Surface canal - Earthfill	Overgrown floodplains
40003	River	Serava	Gravitational barriers	Overgrown floodplains
40004	River	Serava	Surface canal – Wall	Overgrown with vegetation

id	Recommendations	Length (km)	Recommendations starting point	Recommendations endpoint
40001	Rehabilitation and maintenance	0.45	42° 2'57.37", 21° 26'25.73"	42° 2'43.65", 21° 26'32.33"
40002	Rehabilitation and maintenance	2.44	42° 4'0.021", 21° 27'12.72"	42° 2'49.11", 21° 26'30.70"
40003	Rehabilitation and maintenance	1.74	42° 4'44.82", 21° 26'35.91"	42° 4'0.021", 21° 27'12.72"
40004	Rehabilitation and maintenance	6.1	42° 2'43.65", 21° 26'32.33"	42° 0'47.24", 21° 24'51.42"
	Total (km)	**10.73**		

5) Markova Reka

Markova Reka in the past on several occasions caused damage and consequences of torrential floods. The recommendations are due to its clearing and repair of the riverbed in the part where it passes through weekend settlements with dense construction such as Batinci village, but above all the anthropogenic influences that directly affect the unregulated riverbed caused by intensive construction activity from the newly built industrial complexes opposite the bridge in front of the Dracevo settlement. From the same factors, usurpations of the riverbed on a larger scale, such as waste disposal and sand storage, are also visible. In this section, as a reaction to the intensive urbanization in the continuation of the eastern urban zone, it is necessary to clear and restore the riverbed and regulate it with protection from further impacts.

Table 21. Recommendations for regulation or rehabilitation of the riverbed of the Markova Reka

id	Type	Name	Status of regulation	Condition of regulation
50001	River	Markova Reka	Unregulated	Anthropogenic influences
50002	River	Markova Reka	Unregulated	Anthropogenic influences

id	Recommendations	Length (km)	Recommendations starting point	Recommendations endpoint
50001	Rehabilitation and maintenance	2.26	41° 55'5.451", 21° 27'55.23"	41° 58'26.68", 21° 30'44.37"
50002	Regulation	7.22	41° 55'5.451", 21° 27'55.23"	41° 58'26.68", 21° 30'44.37"
	Total (km)	**9.48**		

DISCUSSIONS AND CONLUSIONS

Reflecting in a hierarchical order, this study documented the main network of rivers in the Skopje Region which belongs to the river basin of Vardar with its 5 tributaries. In the analyzed area their total length is 91.16 km of which 42.19 km belong to the river Vardar. The research identified an additional 115 streams in the appropriate classification of rivers, drainage canals, and torrents that are grouped and analyzed according to their river basin. Their total length is 396.9 km of which 294.28 km belong to the river basin of Vardar, 35.3 km to the river basin of Treska, 28.28 km to the river basin of Lepenec, and 39.01 km to the river basin of Markova Reka.

The objective of this research is to create detailed documentation of the current situation of the regulated streams and identify the existing forms of regulation of the streams in an appropriate classification. Analyzed according to their river basin we can conclude that the river of Vardar is regulated in a total length of 48.76 km of which 28.21 km with major and minor wall riverbeds and 20.55 km with an embankment. The river of Lepenec is regulated in a total length of 14.49 km and the river Serava in the length of 10.49 km. Torrential water streams from the Vodno mountain according to this study area are regulated in a total length of 13.12 km in an appropriate form of regulation, but dominantly as a wall or earthfill surface canal with gravitational barriers. In the same form of regulation, the torrential water streams of the area Kisela Voda – Dracevo are regulated in a total length of 14.27 km. The drainage system "Skopsko Pole" is consisted of 82.43 km regulated canals regulated either in the form of a stone wall in cement mortar or in the form of eartfill surface canals. Torrential water streams from the area of Skopska Crna Gora are regulated in a total length of 10.57 km.

Following the process of documentation of the streams and the forms of their regulation, recommendations for regulation and rehabilitation of specifically defined zones of the

riverbeds in the Skopje region are defined. This phase of the research identifies the positions in the watercourses for which regulation or rehabilitation and maintenance are proposed in their appropriate classification according to their river basin. The riverbed of Vardar, as the main hydrographic element and river basin, is recommended to be additionally regulated in a total length of 11.15 km, mainly in its western part. Recommendations for regulation are defined for the other rivers in a length of 3.94 km for the river of Treska, 10.51 km for the river of Lepenec, and 7.22 km for the river of Markova Reka. An additional recommendation for regulation is defined for the torrential water streams in the area of Skopska Crna Gora with a total length of 16.8 km. Recommendations for rehabilitation and maintenance are defined for the torrential water streams of Vodno in a length of 2.83 km, of the area Kisela Voda – Dracevo in a length of 10.52 km, and of the area Skopska Crna Gora in a length of 1.56 km. In the same manner, this type of recommendation is defined for the river of Serava in a length of 10.73 km and the river Markova Reka in a length of 2.26 km.

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