FLOOD FORMATION MECHANISM OF THE DEVASTATING FLOOD IN THE TOWN OF MIZIYA, BULGARIA IN AUGUST 2014

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Abstract
The publication aims to study the factors involved in the formation of the devastating flood in the town of Miziya in the Republic of Bulgaria in August 2014. The natural and anthropogenic flood formation factors in the river basin are researched in details. The flood formation mechanism is researched and the main conclusions about the situation and future flood risk management in the basin are developed. The following scientific research methods are used in the publication: differentiated approach, complex (combinatory) approach, geographical scientific approach (chronological and chorological), mathematical-statistical method and spatial analysis method.

Key words: flood formation mechanism, spatial analysis, Miziya, Bulgaria.

INTRODUCTION

As a result of heavy rains in the period from 31 July to 2 August 2014 the level of the Skat River increased and on 2 August 2014 it flooded the town of Miziya. The water level remained unchanged until the afternoon of 5 August 2014 when it began to drop slightly. As of 7 August 2014 the water level dropped and the river resumed its normal course. The streets of the town are positioned higher than the housing and yard areas, therefore the yards remained under water.

Meanwhile, the tributaries of the Skat River also overflowed and caused floods – the Barzitsa River (right tributary) and the Barzina River (left tributary). The areas between the rivers were flooded.

Flood damage was devastating – two human casualties, many houses were destroyed or uninhabitable and numerous citizens of the town of Miziya were affected. To avoid such disastrous consequences in future, it is necessary to plan and implement adequate measures. However, the definition of the measures depends on a detailed analysis of the flood's formation mechanism in Miziya. Therefore, the aim of the publication is to investigate and clarify the flooding formation mechanism, including the natural and anthropogenic factors, which caused the flood in Miziya in the period 2–7 August 2014.

THEORETICAL BACKGROUND

The research is based on the concept that the river basin is a system (Figure 1) with a certain ratio of organisation, which is widely recognized as the most fundamental landscape unit for the water cycle, the cycle of sediments, and dissolved geochemical and biogeochemical constituents. Catchments integrate all aspects of the hydrological cycle within a clearly defined area in a way that can be studied, quantified and acted upon (Wagener et al. 2004). Drainage basins are commonly viewed by scientists as

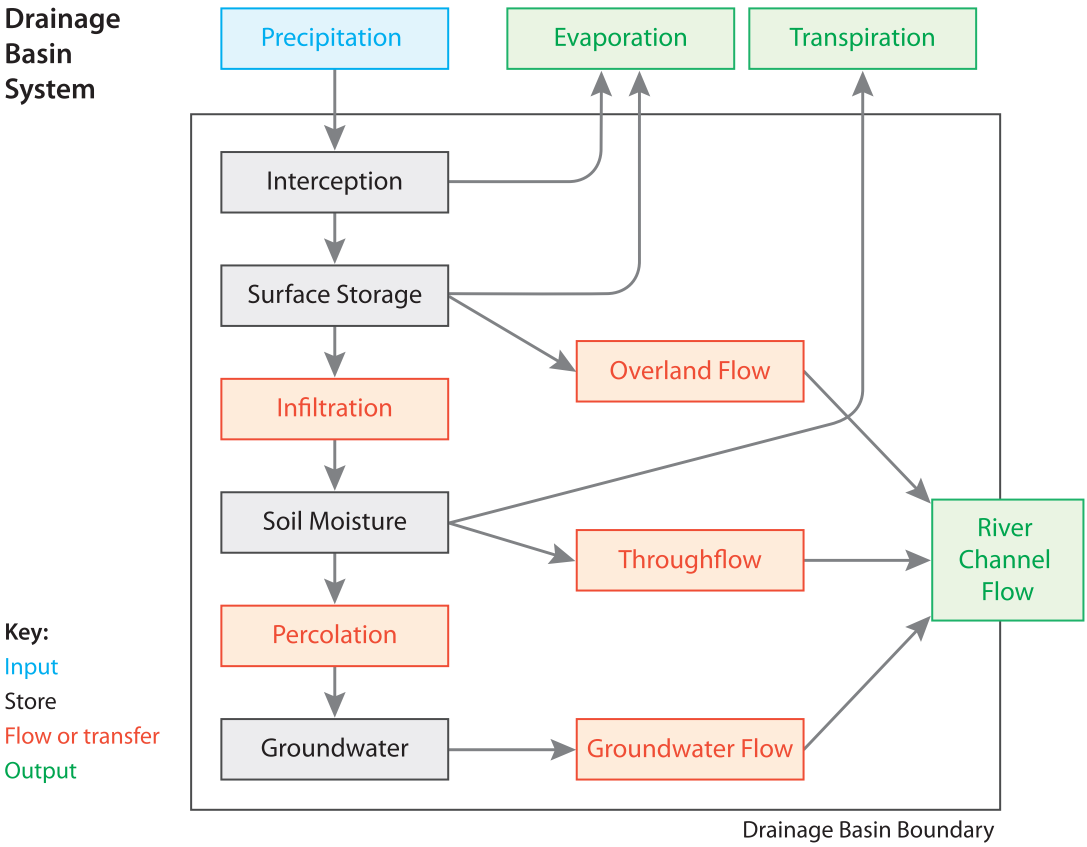

Figure 1 Drainage Basin System. Source: Wagener et al. 2004; own processing.

open systems. Inputs into these systems include precipitation, snow melt, and sedimentation. Drainage basins lose water and sediment through evaporation, deposition, and streamflow. We need to understand, manage and/or deal with the space-time variability of catchment responses to climatic inputs (water and energy) on the land's surface. Understanding the spatial and temporal variability of the hydrological processes aggregated to the catchment scale, as well as their extremes and their scaling behaviour in time and space, is important for a number of applications, such as flood estimation, drought mitigation, water resources systems analysis, etc. (Murugesu 2005). The complex cause-effect relationships between the climatic, meteorological, hydrographic, orographic, geological, soil-vegetation and other factors are important in this respect.

A number of factors influence the input, output, and transport of sediments and water in a drainage basin. Such factors include topography, soil type, bedrock type, climate and vegetation cover. The geology, climate and disturbance regimes of an area influence the shape and condition of a watershed.

Human activities can modify the natural disturbance regimes by changing the timing and intensity of these natural processes. For example, urbanization and roads increase impervious surfaces and change the routing of water. These conditions can increase flood peaks and landslide frequency above the range that would be expected in undeveloped conditions. Conversely, dams and other water impoundments can reduce flood peaks and interrupt sediment supply, impacting the aquatic system by limiting the creation of side-channels or delivery of spawning gravels.

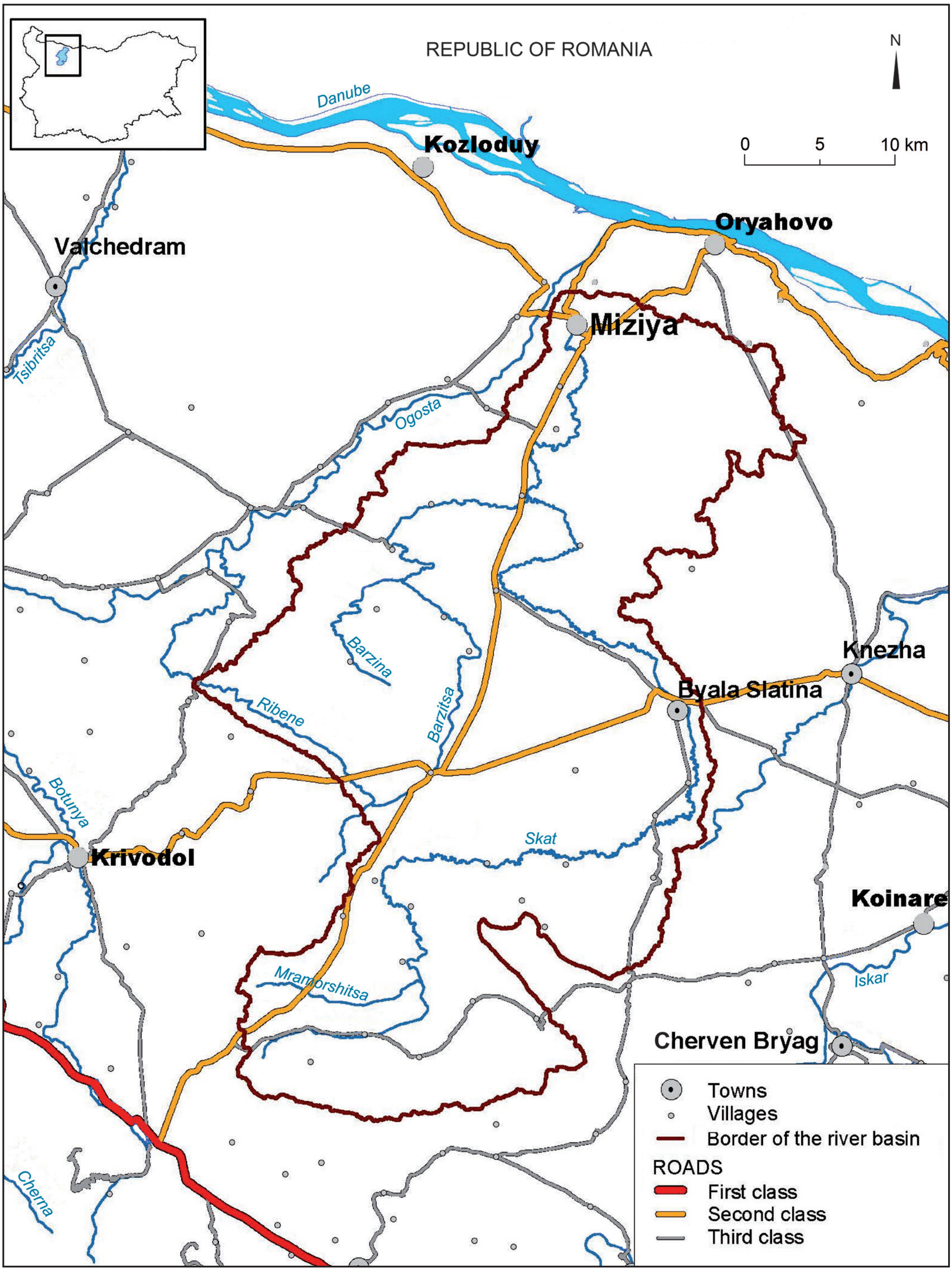

Figure 2 Geographical location of the Skat River Basin.
Source: GIS spatial data of the territory of Bulgaria and the Skat River Basin; own processing.

METHODS AND MATERIALS

Flood formation and the systemic approach have a direct relationship because both are systemic and non-linear (Ohlsson and Turton 1999). The basic principle of any systemic study is connectivity. A system is a set of elements with connections between each other. Any system is composed of subsystems; each being autonomous and open, directly interrelated and integrated with its environment (Laszlo and Krippner 1997). The systemic approach is used in this study to analyse flood formation mechanisms and improve our understanding of the complex interactions between the factors determining the formation and expression of floods. The spatial analysis method takes a central place in the examination of the flood formation factors and mechanisms, using GIS as a tool for analysis.

The following information has been used: spatial data (maps of reconstructed property, updated in 2013 – 57 maps ".zem" documents; orthophoto map of Bulgaria updated in 2011 – 129 map sheets; digital terrain model of the territory of Bulgaria in 2011 – block 2, block 7 and block 8; borders of the underground water bodies in the Skat River catchment); map materials (topographic maps of Miziya region, scale 1:5,000; geological map of the Skat River catchment, scale 1:100,000; soil map of the Skat River catchment, scale 1:200,000); hydrometeorological data (precipitation and water level values of the Skat River).

ASSESSMENT OF THE NATURAL FACTORS INVOLVED IN THE FORMATION OF THE MAXIMUM RUN-OFF AND FLOODING OF THE SKAT RIVER

Geographical location

The Skat River flows through northwestern Bulgaria and is the major tributary of the Ogosta River (Figure 2). The Skat River originates 505 m above sea level, at coordinates 43° 15' 4.139" N and 23° 37' 28,134" E. The river discharges into the Ogosta River 25 m above sea level, at coordinates 43° 43' 24,156" N and 23° 51' 44,109" E. This geographical location predetermines the unique plain structure of the river basin and has a specific moderate continental climate, unstable water regime and small run-off values (0.5–1.0 $l\ s^{-1}\ km^{-2}$). Rain water is almost exclusively lost as evaporation and only small insignificant amounts form the surface and underground waters. Simultaneously, the geographical location of the river basin determines the formation of torrential rainfall and flash floods.

Climate factors

Atmospheric circulation factors. The torrential rainfall events, which form floods and cause rivers to overflow, occur in several types of synoptic-meteorological systems: Mediterranean, Atlantic, Continental and Combined (Table 1).

Precipitation. The Skat River valley is one of the least humid areas in Bulgaria. The average annual precipitation values are insignificant, from 450-500 mm in the Danube plain up to 650-700 mm above the hilly slopes of Veslets.

The continuous rainfall in the period from 31 July to 2 August 2014 affected the whole Skat River Basin. According to data from the National Hydrometeorological Institute of the National Academy of Science and the Executive Agency "Combat hails", precipitation values for this period were between 70 and 217 mm (Figure 3). The higher precipitation values were recorded in the village areas of Malorad, Ohoden and Banitsa (167-217 mm), as well as in the southern part of the Skat River Basin (110-125 mm). The lowest recorded precipitation values are in the northern part of the basin (in the area of Miziya town 76 mm).

Maximum precipitation values were recorded between 16:00 h, 31 July 2014 and 09:00 h, 1 August 2014 (NINKS-HM Ltd. 2014).

The torrential rainfall in the period from 31 July 2014 to 1 August 2014 was assessed as extreme for the following reasons:

- Comparison of rainfall values from 1 August and 2 August 2014 with the relevant average

Table 1 Atmospheric circulation systems for formation of torrential rainfall events. Source: Zyapkov 1997; own processing.

Characteristics	Mediterranean (M)	Atlantic (A)	Continental (C)	Combined
Total number	236	218	100	56
Wind direction (%)	SW 60.2	NW 80.3	NE 2.0	
	W 38.1	W 17.4	N 69.0	
	S 1.7	N 2.3	NW 29.0	
Cyclones (%)	98.3	62.8	27.0	MAC 35.7
Anticyclones (%)	0.4	34.9	42.0	MC 37.5
Mixed (%)	1.3	2.3	31.0	MA 12.5
Cold fronts (%)	26.3	98.2	100.0	MC
Warm fronts (%)	72.7	1.8	–	Other

monthly values for the periods 1961-1990 and 1981-2010 showed that the rainfall in 2014 significantly exceeded the average monthly values of all stations, except for Ostrov. Simultaneously, the recorded rainfall in many of the stations was the maximum value ever recorded, and in other stations values were close to the absolute maximum values.

- On 1 August 2014 all measuring stations (except for Ostrov) recorded maximum daily values which exceeded the 90th percentile of the daily rainfall for August. For the stations Borovan and Galiche the precipitation values were the maximum ever registered.
- Stations with a registered maximum return period (once in 100 years) of the maximum daily precipitation were: Borovan (once in 100 years), Galiche and Mezdra (once in 50 years), Hayredin (once in 25 years) and Vratsa (once in 15 years).
- Average precipitation value in the catchment has been evaluated at 114 mm.

Geologic structure

Slightly permeable and impermeable rocks are spread across a major part of the river basin: 74% of the total area (filtration coefficient C is from 3 to 0 m day^{-1}).

Soils are represented by two types: loess complex (loess, loam) and sediment formations (made up of clays, clay limestone, marl, compacted clay rocks – shales, phyllites, marine terrigenous and terrigenous-carbonate rocks, sedimentary rocks of particle size 0.01-0.1 mm – siltstones).

Highly permeable rocks – 13% of the basin area (filtration coefficient C is from 500 to 10 m day^{-1}) – are represented by two subtypes: alluvial, proluvial, proluvial alluvial and alluvial-talus sediments which fill river terraces and valleys (as represented by blocks, boulders, gravel, etc.), with filtration characteristics which fluctuate greatly depending on their grain size and clay content; and karst and a slightly cracked variety of limestone, dolomites which are thinly spread through the region.

Rocks with an average infiltration ration – 13% of the total basin area (filtration coefficient C is from 50 to 1 m day^{-1}) – are represented by one subtype: welded, mechanically deposited sedimentary rocks, made of pieces of different sizes: conglomerates, breccias, breccia-conglomerates, arcose, sandstone, olistoliths, etc.

In conclusion, the lithological composition of the rocks in the Skat River Basin limits the deep infiltration of precipitation waters so the infiltrated precipitation water remains in the layers 2-4 m below the surface.

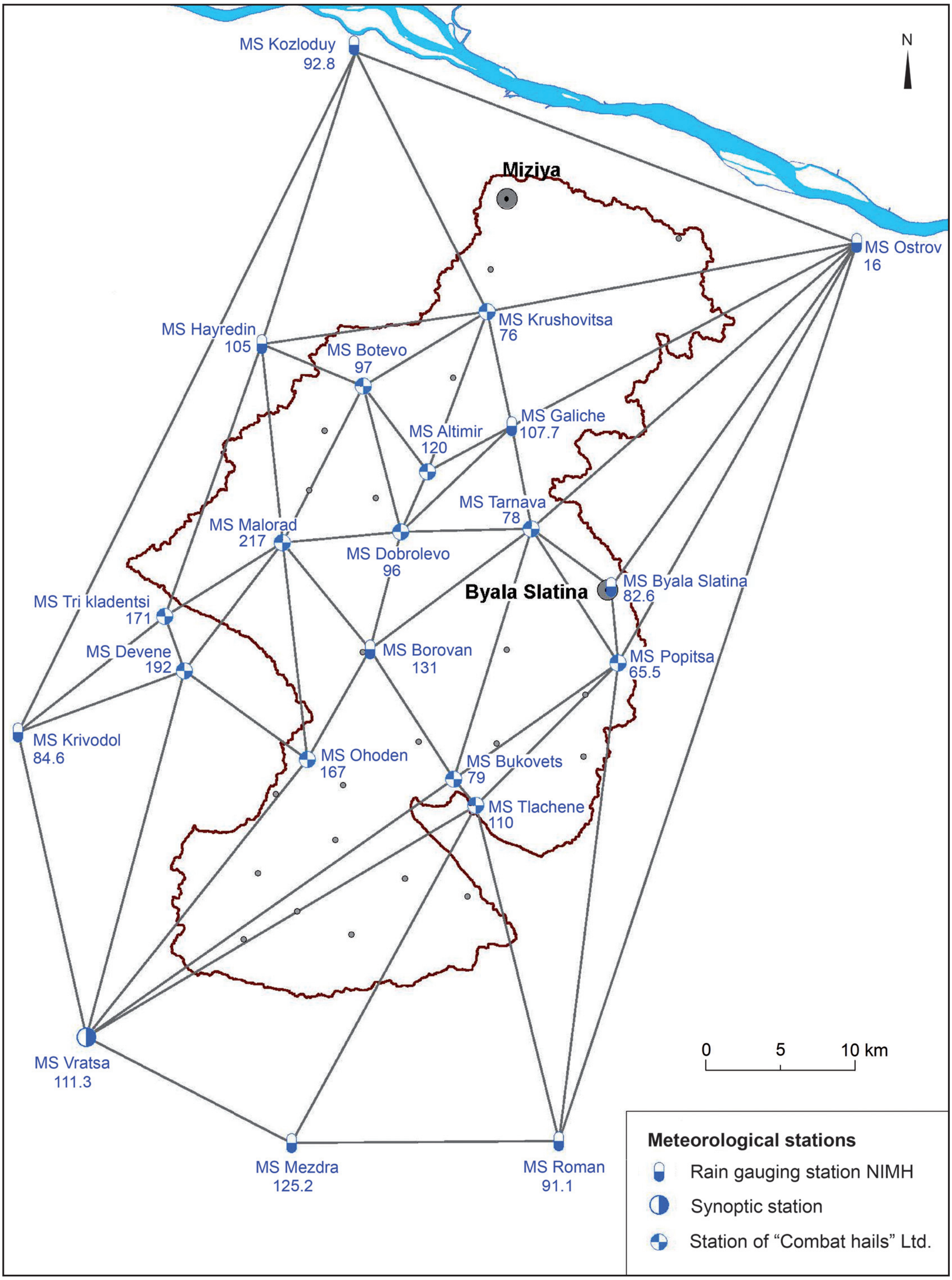

Figure 3 Location of meteorological gauges and precipitation totals (in mm) from 31 July to 2 August 2014. Source: GIS spatial data of the territory of Bulgaria and the Skat River Basin; own processing.

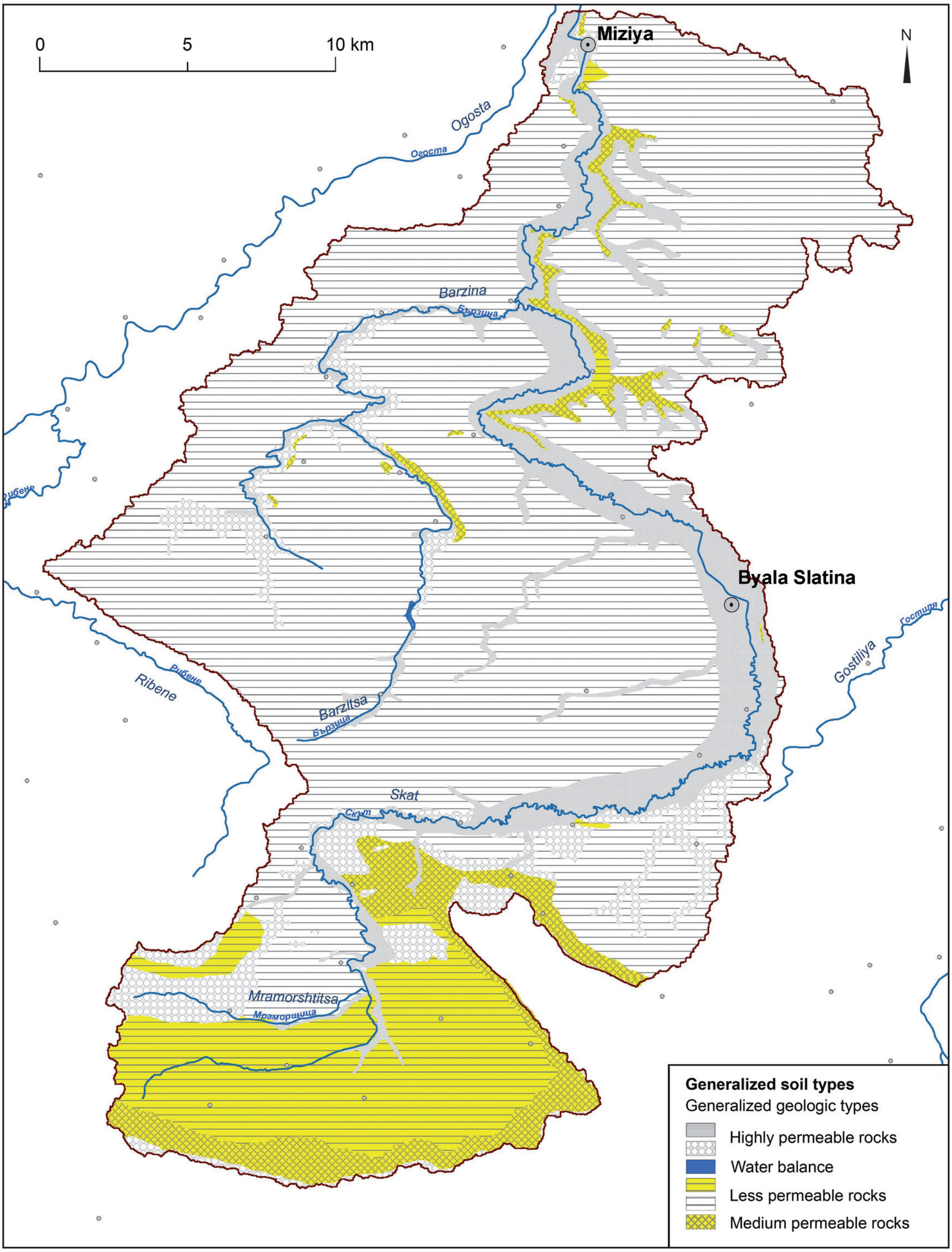

Figure 4 Geologic types, generalised by infiltration coefficient.
Source: Institute of Water Problems 2000; own processing.

Table 2 Underground water bodies formed in the Skat River Basin.
Source: Danube Water Management District (2014); own processing.

Name Code	Area (km²)	Type	Covering layers in the accumulation zone Lithological structure		
			W	**P**	**C**
Pore Quaternary waters of the Skat River BG1G0000Qal016	110	No pressure	Sandy clay deposits Gravel and sands		
			6.5	317.5	49
Pore Quaternary waters between Lom and Iskar river beds BG1G0000Qpl023	2,890	No pressure	Loess deposits Gravel-clay aggregate sands		
			25.0	13.0	2
Karst waters in the area of Lom-Pleven depression BG1G000N1bp036	6,753	Pressure	Loess deposits in the uncovered parts Western and central part – limestone		
			250.0	630.0	25
Karst waters in the Forebalkan BG1G0000K2s037	1,484	No pressure	Surface and underground karst forms Intensively cracked carbon sediments		
			.	.	.
Pore Quaternary waters in the Kozloduy valley BG1G0000Qal005	39	No pressure	Sandy clays and clays Gravel, sands, sandy clays		
			13.0	1,155.0	89
Pore waters in Ostrov valley BG1G0000Qal006	25	No pressure	Sandy loam deposits Gravel, sands, sandy clays		
			13.0	480.0	37

Notes: W – average width of the ground water basin (m); P – average porosity ($m^2\ day^{-1}$);
C – average coefficient of filtration ($m\ day^{-1}$).

Hydrogeological structure

Porous, karst and fissure rocks are spread throughout the Skat River Basin. They can be seen in groundwater basins (GWB) and are represented in Table 2.

GWB are characterized by great variety due to the complex geologic and tectonic structure of the watershed, which includes parts of the Forebalkan and Miziya plate areas. These factors determine the spatial distribution of GWB, the characteristics of the infiltration area, the accumulation and drainage conditions, and the connection with surface water bodies.

The relations between the river and ground waters formed in the alluvial deposits of the Skat River (GWB – BG1G0000Qal016) are of a complex character. The drainage of the cross-river massifs is not direct but functions through the Skat River terrace because the ground waters are hydraulically connected to the river. In periods of high water the high water position causes a temporary reverse of the hydraulic slope which causes the infiltration of river waters into the related bank areas (negative supply, according to Kudelin 1960). Together with a decrease of the high waters (decrease period), the normal slope of the ground waters recovers. The drainage capacity of the rivers recovers too and the reversion of the accumulated waters in the bank areas then begins. This bank regulation of the surface run-off is shown on the hydrograph with a gradual decrease of the ground water supply during the entering phase of the high water and the consequent increase of the decrease period.

Precipitation on chernozem soils (characterized with high infiltration capacity) quickly reaches the shallow (up to 2–3 m) ground waters in an active water circulation zone (GWB – BG1G0000Qpl023). Simultaneously, the flat terrain, the shallow river valleys with slight inclination and river network density (0.1 to 0.4 km km^{-2}) in the cross-river basin between Ogosta and Skat Rivers, are the reasons for the small drainage capacity of these lands. The lithological structure of the rocks does not contribute to the rainfall infiltration and supply of the deep ground water layers (more than 10 m). As a result, the ground water level increases and the water flows over the surface, causing swamping of the lower lands in the basin.

Karst ground waters (GWB – BG1G0000K2s037) are drained by the current river network of the Skat River. The water floods the river valleys. Because the distance between the water accumulation and drainage zones is small, the velocity of the karst waters is high, especially during heavy rains. That is why water springs in the basin have variable discharge.

In conclusion, ground waters in the Skat River Basin were a crucial factor in the formation of significant surface run-off in the period from 31 July 2014 to 2 August 2014, because:

- The aquifers were overloaded and the water level was high (as a result of intensive rainfall in the previous months) and according to information from the Danube Water Management District – Pleven Town, ground waters overflowing on the surface caused swamping.
- Due to the hydraulic connection between the waters of the Skat River and the ground waters formed in the alluvial deposits of the river, ground waters additionally increased in level and it can be easily proven that they overflowed.
- Due to the high velocity of the karst waters in the upper river basin, they were quickly transported to the lower river basin and significantly increased the level.

Geomorphologic factors

These factors reflect the landscape and indirectly influence the hydrologic system of the Skat River.

Altitude, inclination and segmentation.
The Skat River is typical of low-plain valleys in Bulgaria. The average altitude of the river basin is 183 m above sea level. The basin encompasses areas from 28 m to 781 m above sea level (Manyashki peak). The largest areas are the 200-300 m altitude lands represented by slightly hilly slopes (Figure 5).

The altitude is highest in the upper part of the basin close to Nivyanin village. It encompasses territories between 180 and 720 m above sea level from Nivyanin village to Aldemir village within the range of the middle part of the basin and is located between 100 and 180 m above sea level. The lower basin is characterised by high lands on the right bank (50-100 and 160-180 m) and a very low left bank. In the section of the Krushovitsa village – Miziya town the altitude of the river basin is less than 100 m and Miziya town is located at 20-40 m above sea level.

The hypsometry forms a typical low-plain type of water exchange with little moisture, intensive evaporation processes and a small amount of water transportation (less than 1.0 l s^{-1} km^{-2}).

Moreover, insignificant inclinations and segmentation of the slopes are typical and are the factors which determine the moisture and erosion processes. (Figure 6) The major part of the watershed (96.5%) is inclined by 0-10°, the inclinations of 11-20° represent barely 3.19% of the watershed area. Slopes with more than 21° are an insignificant area.

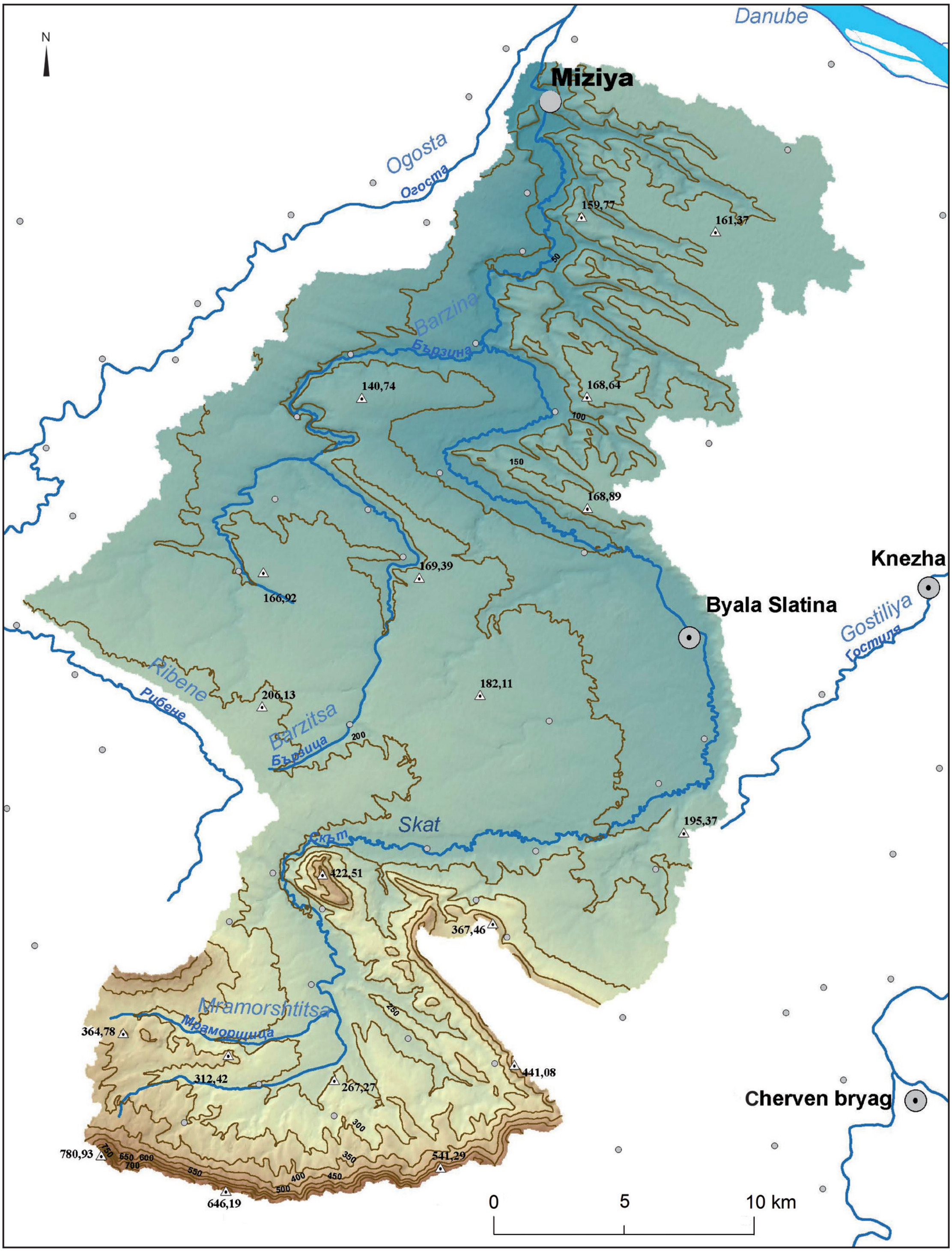

Figure 5 Relief map of the Skat River Basin.
Source: GIS spatial data of the territory of Bulgaria and the Skat River Basin; own processing.

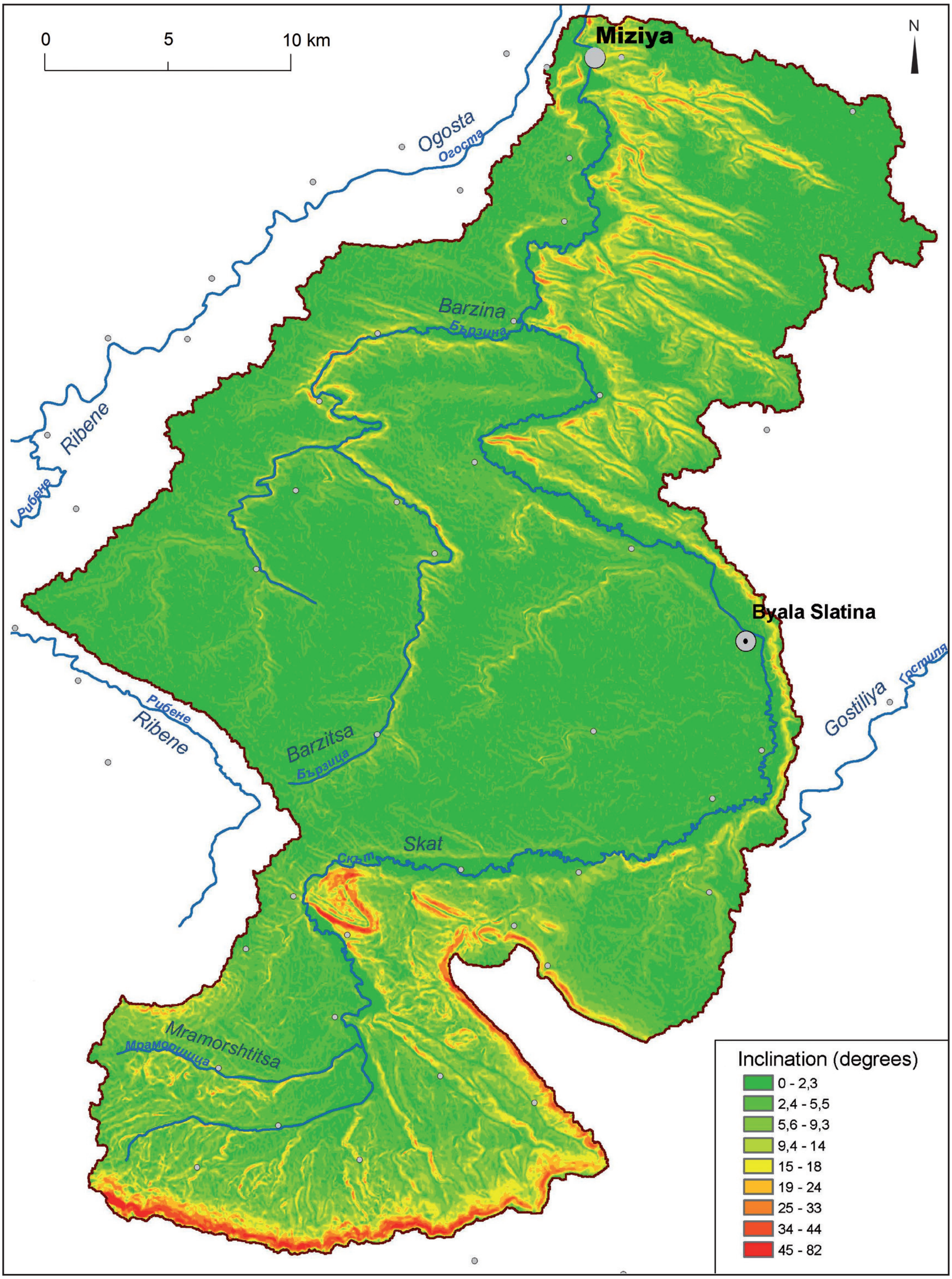

Figure 6 Inclinations in the Skat River Basin. Source: National Institute of Cartography 1983; own processing.

The least inclined (1-2°) are the slopes between the flat lands and those in the Danube plain. Inclination increases to over 39° in the hilly slopes of Veslets.

Discharge of the rainfall waters and their drainage into the ground waters also decreases due to the relatively small segmentation of the landscape: horizontal segmentation – between 0.1 and 1 m km^{-2} and vertical segmentation between 25 and 30-40 m km^{-2}.

The described features of the landscape (height above sea level, inclinations, segmentation) create specific discharge conditions in the water basin. The relief in the upper part of the basin is a precondition for faster discharge of the rainfall waters due to the high altitude and the large slopes. In the middle and largest part of the basin the rainfall discharge is significantly slower and evaporation is high. Due to the higher altitude of the lower river basin the discharge area is significantly limited. Miziya town is located in the lowest and narrowest part of the watershed, often compared to a "bottle neck" (Figure 7).

Morphology of the river bottom

The main characteristics of the river bottom which contribute to the overflows are:

- Shallow and trapezoidal asymmetric cross sections along the river.
- The right banks are high and the left ones – low and flat. Their ratio at Komarevo village is 217 : 170 m and at Miziya town 140 : 80 m.
- Sandy and unstable structure of the river bed.
- Small and longitudinal fall – 2.05 m km^{-1} and medium longitudinal inclination – 2.3‰.

Therefore, the torrential water streams in some parts of the basin destroyed the low sandy banks and flooded the related alluvial terraces (e.g. in June 1940, May 1941, March 1956, June 1957 and July 1963).

Hydrologic factors

Typical for the Skat River regime are periodic low water levels in the summer – autumn season (incl. dried river beds) and episodic torrential inflow and high waters which cause torrential-erosion processes and floods.

According to system information of the National Hydrometeorological Institute in Bulgaria, in the period 1951-1980 in the upper basin of the Skat River (Nivyanin gauging station) there were 93 torrential water inflows with maximum water amount of 30 $m^3 s^{-1}$ (run-off about 1.23 l $s^{-1} km^{-2}$) recorded. The most extreme torrential event happened on 15-17 May 1956 when the absolute water amount was calculated at about 220 $m^3 s^{-1}$ (at a run-off about 890 l $s^{-1} km^{-2}$, 270 times the average water run-off values).

Throughout the year most of the torrential events happen in the period April-June (on average more than 54% of the total number of events) and amounts of water of up to 50 $m^3 s^{-1}$ are formed during most of the events. Moreover, high waves caused by torrential rainfall events (average about 72%) prevail, while torrential events caused by snowmelt and a combination of rainfall and snowmelt (about 28%) are relatively rare. As well as these, torrential streams increase the amount of sedimentation and distort the water beds.

Torrential high waves and floods have been recorded in the past – March 1956, 1963, April 1973, May 1941, 1956, 1970, 1975, 1980 and June 1940, 1941, 1942, etc.

Hydrography

The highest flood risk zone encompasses the river mouth hydrography of the rivers Ogosta and Skat. The location of the two river beds is illustrated on the map from 1877-1878 (Figure 8).

The correction of the river beds related to the construction of the nuclear power plant Kozloduy changed the hydrography and nowadays the rivers flow as a single river after Miziya town. Information about the conductivity of the common river bed is not provided in the publication. A reliable conclusion about the correction's influence on the flood risk in Miziya town is only possible through assessment of the common bed.

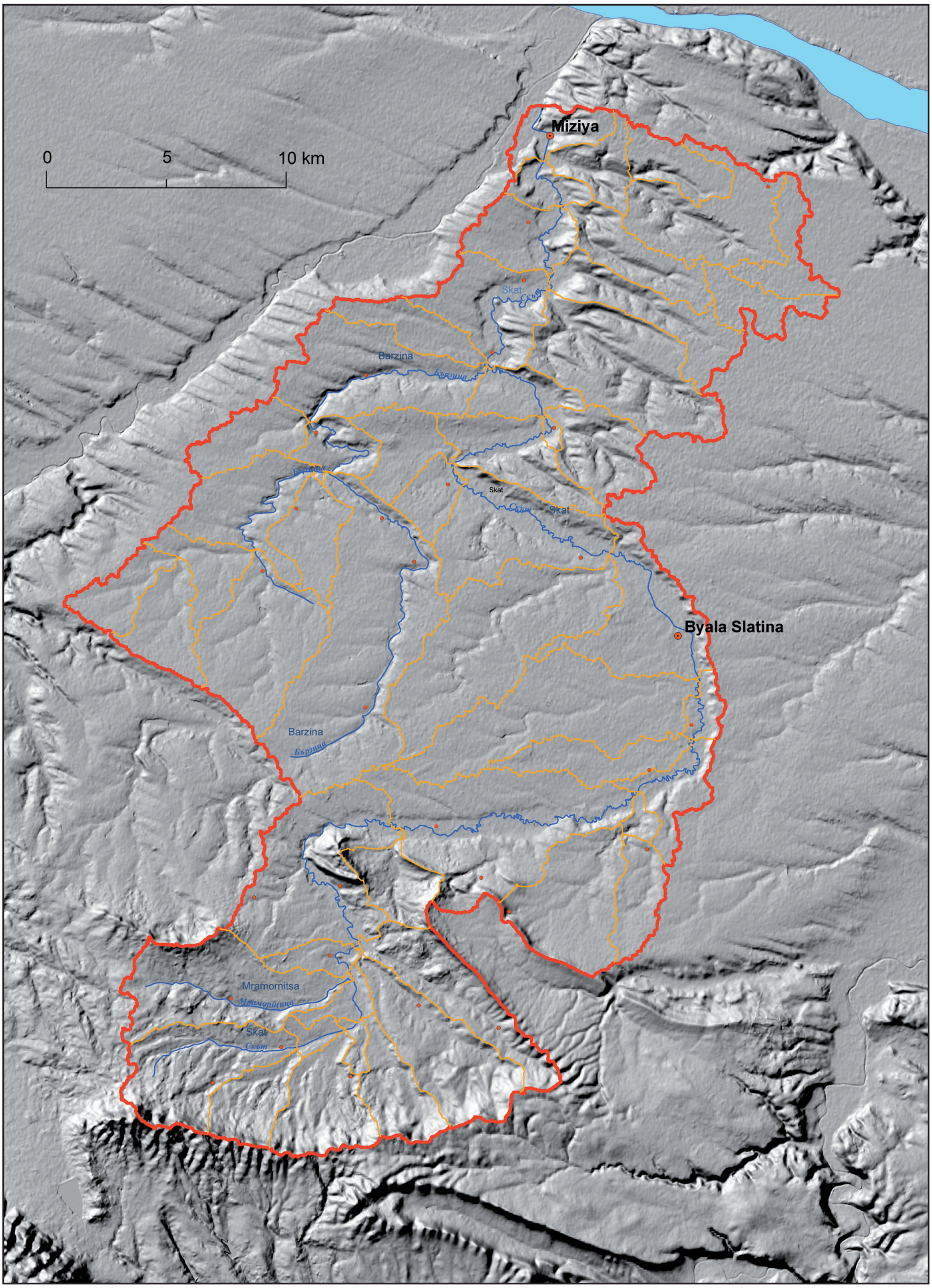

Figure 7 Digital terrain model of the Skat River Basin Landscape.
Source: National Institute of Cartography (2011); own processing..

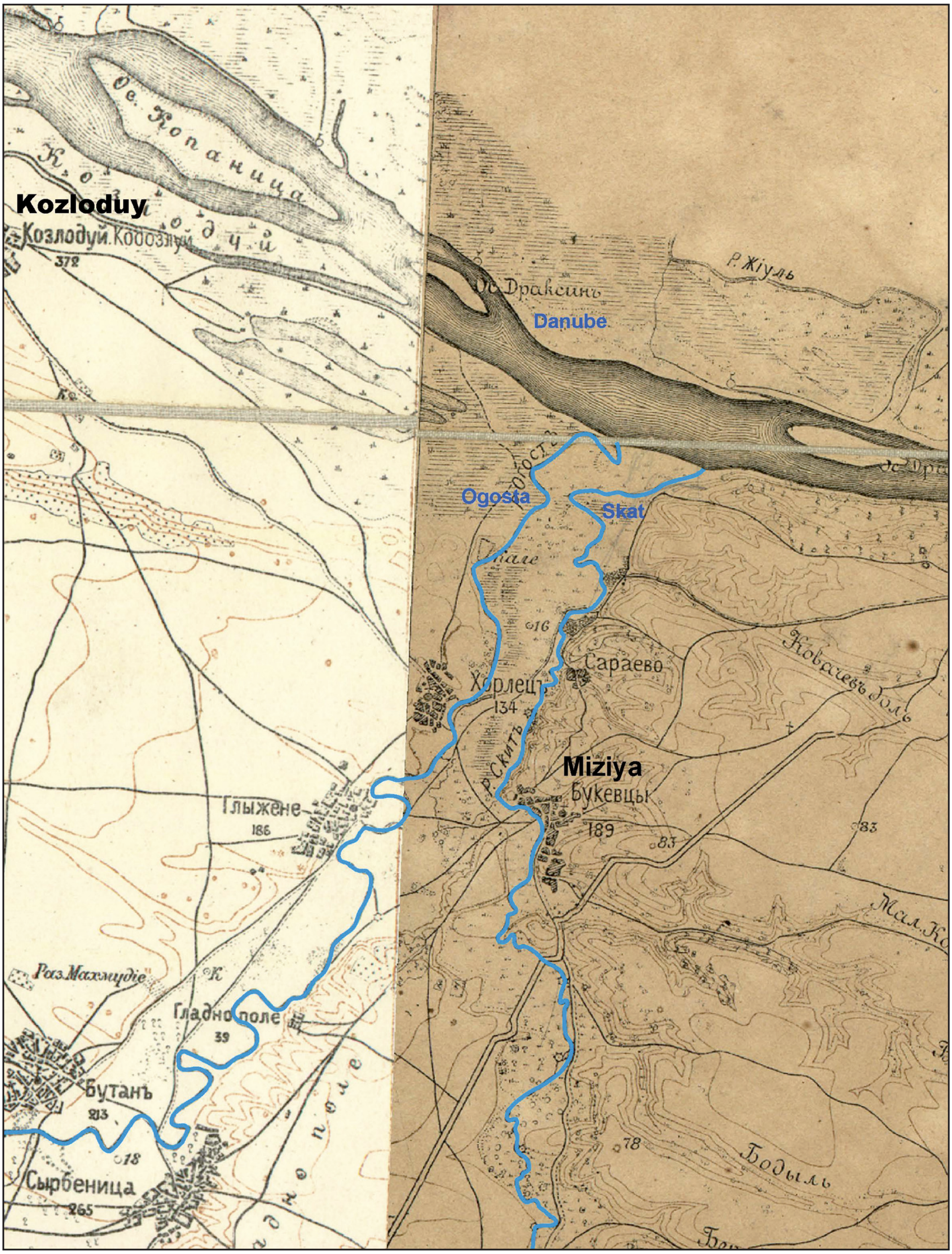

Figure 8 Old river bed of the Ogosta and the Skat rivers, 1877–1878.
Source: Russian Topographic Service and Cartography (1878); own processing.

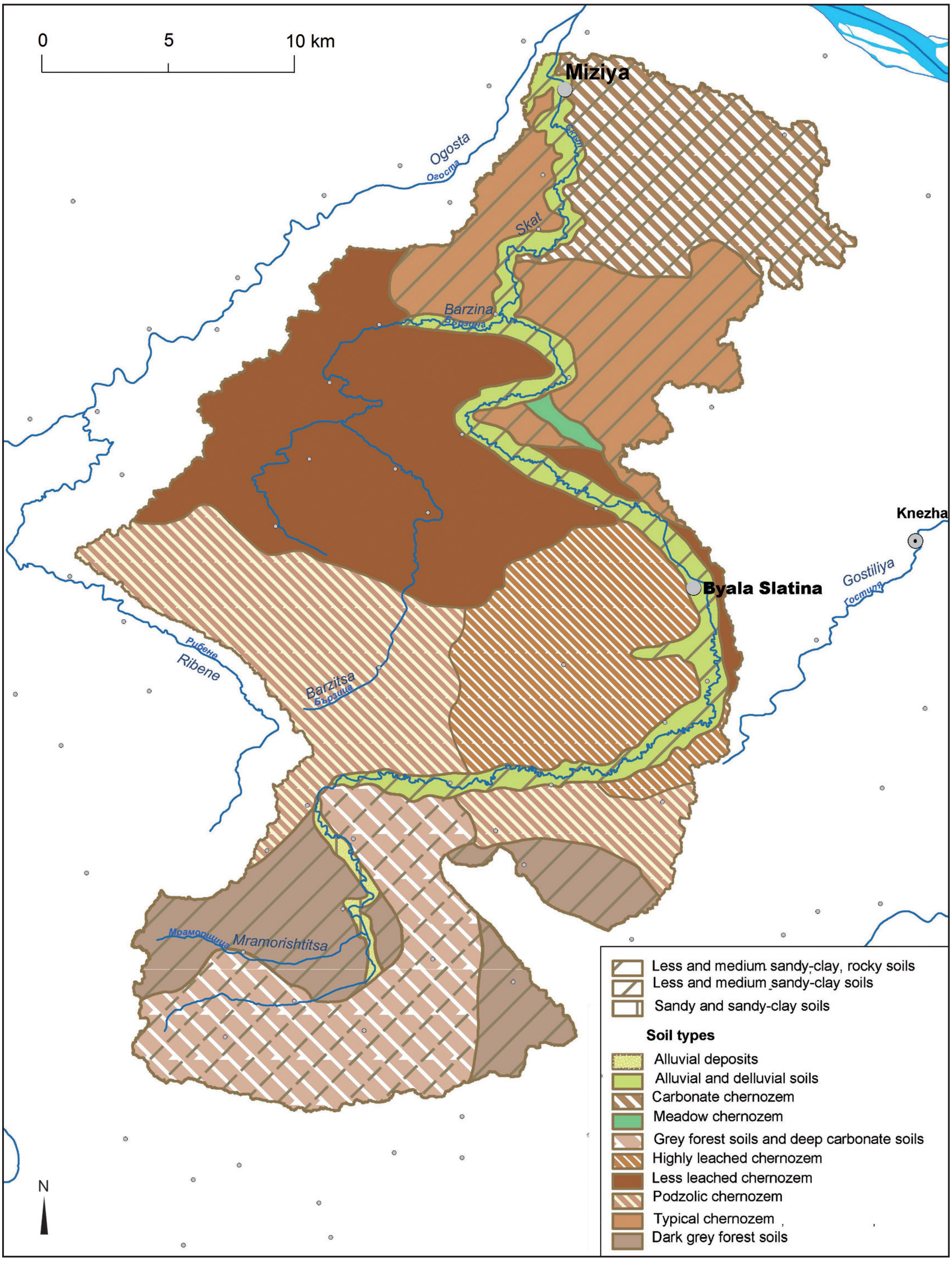

Figure 9 Soil types in the Skat River Basin.
Source: National Institute of Pedology (1957); own processing.

Soils

The Skat River watershed consists of both zonal soils (chernozem, greybrown soils) and azonal soils (alluvial and delluvial-meadow soils), see Figure 9.

The most important qualities of the soils in terms of the formation of surface run-off and high waters of the Skat River are soil moisture and more particularly the saturation ratio and permeability of the soil.

When the soil is saturated, rainfall waters cannot infiltrate and the whole amount of rainfall forms surface run-off, disregarding the other conditions and factors in the basin. There is no available information and measurement of the soil moisture before the flood. Taking into consideration that the precipitation values in April, May, June and July significantly exceeded the average monthly values, we can rather certainly conclude that the soil was in a state of absolute saturation.

The saturation ratio depends on the moisture capacity of the soil types in the Skat river basin. It is assessed by the utmost field moisture capacity (UFMC)[1]. The experimentally determined values of UFMC for the soil types distributed in the Skat River Basin are presented according to literature data (Penkov 1986). The carbonate chernozem soils are characterised with the least moisture capacity (15-25%). Gradually it increases in the typical chernozem soils (20-25%), leached chernozem soils (20-25%) and degraded chernozem soils (30-35%). The highest moisture capacity is in the degraded chernozem soils (30-35%) and the grey forest soils (30-35%).

The moisture capacity of the soils is an important factor in the fast formation of surface run-off, especially above deep soils. By increasing the moisture capacity of the soil types, their saturation ratio also increases and therefore increases the amount of the formed surface run-off. As a result, at an even state of all other flood formation factors in the basin, the generated surface run-off increases from the river mouth to the river spring and the moisture capacity of the soils increases in the same direction.

The rain waters infiltration speed depends on the permeability of the soils. The soil permeability is characterised by the filtration coefficient. Analogically to the water retention capacity of soil types, the values of the filtration coefficient decrease from north to south respectively with their permeability. The conditions which increase the surface run-off increase in the same direction.

ASSESSMENT OF THE ANTHROPOGENIC FACTORS FOR FORMATION OF THE MAXIMUM RUN-OFF AND FLOODING OF THE SKAT RIVER

Land use

Land use in the Skat River Basin is identified, based on a reconstructed property map up to date in 2013 in the ".zem" file document. Six categories of land use are defined (Figure 10, Table 3).

Agricultural land covers about 87% of the basin's area. A major part of the area is planted with grains, trees and pastures.

Forests cover small and fragmented areas (about 6%) and are composed mostly of degraded and neglected deciduous groups (e.g. oak, acacia, hornbeam, etc.). Therefore, the forests do not possess good water-protection and anti-erosion functions for the Skat River regime. The bank-strengthening forest ecosystem has more significant functions in the bank areas and consist mainly of acacia, alder tree, etc.

Assessment of the state of hydro-technical equipment in the Skat River Basin

The hydro-technical equipment built in the Skat River Basin consists of fish breeding ponds and dams. The assessment of their state and condition is based on terrain inspections conducted by representatives of local authorities, engineers from Irrigation Systems Ltd and independent experts

[1] Utmost field moisture capacity (UFMC) is the maximum amount of water the soil can retain during events of high precipitation.

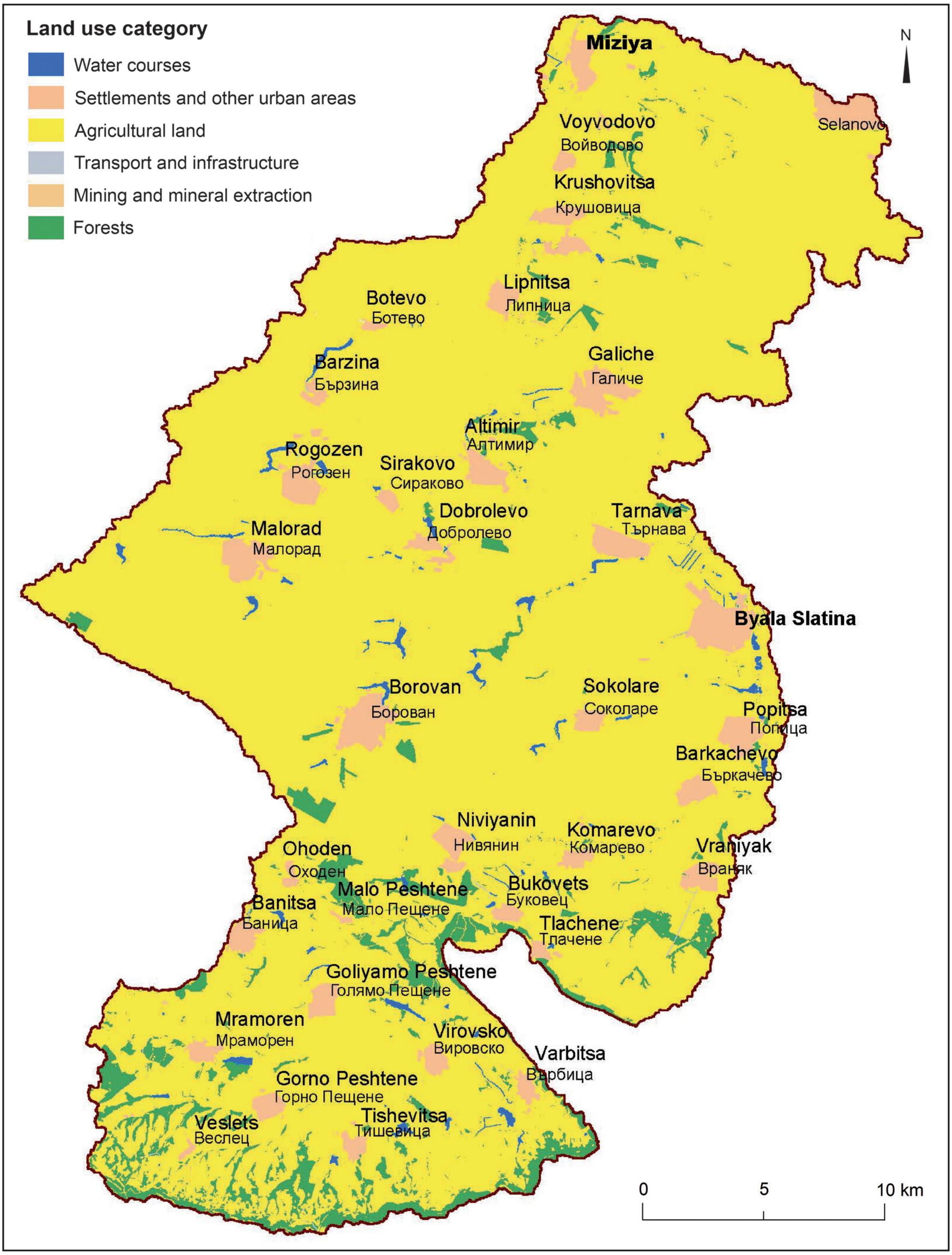

Figure 10 Land use map in Skat River Basin.
Source: National Institute of Cartography (2013); own processing.

Table 3 Ratio of land use categories in the Skat River Basin.
Source: National Institute of Cartography (2013); own processing.

Land use	**Area (km^2)**	**Share (%)**
Water courses	10.4	0.96
Settlements and other urban areas	58.0	5.38
Agricultural land	937.5	86.93
Transport and infrastructure	3.2	0.48
Mining and mineral extraction	0.2	0.02
Forests	67.2	6.23
Total area	1,078.5	100.00

immediately after the flood in Miziya town. The assessment produced the following statements.

State and condition of fish breeding ponds. The protocols attached to the flood records about the ponds located in the watershed state that they have not overflowed. Their volume is insignificant and they have practically no influence on the formation of high waves on the Skat River. No significant deformations and damages of the equipment were recorded.

State and condition of the dams. A total number of 41 dams are built in the watershed. Within the period 12-20 August 2014 inspections of the technical condition were conducted for 39 of the dams. There are no large dams whose breakage would cause flooding with the intensity of the one in Miziya in the Skat River Basin. The available water volume of all dams in the watershed is 15,971,000 m^3 – altogether 27% of the high flood wave. The dams were at about 65% of capacity – 10,400,000 m^3, and the available free volume amounts to 10% of the high wave volume. Therefore, we conclude that the dams have reduced the high wave by their retention capacity. The hydro-technical equipment has virtually received waters with volumes close or less than the designed volume for their category and class.

State of the river bed conductivity. Witnesses' statements about the flood event explicitly state that the conductivity of the river bed was significantly reduced and unable to convey large water amounts.

FLOOD FORMATION MECHANISM OF THE FLOOD IN THE TOWN OF MIZIYA

The town of Miziya was flooded as a result of three types of floods – flash floods, river floods and groundwater floods.

The source of formation of the flash floods is torrential rainfalls (with high intensity) which fall on waterlogged land cover (as a result of heavy rains in the river basin during the period April-June 2014). Due to these reasons, the rain water could not infiltrate into the soil and quickly formed surface run-off. Flash floods occurred not only in the region of Miziya town, but in the whole Skat River Basin.

As a result of the significant surface run-off, the level of the Skat River started to increase on the evening of 2 August 2014 and the natural overflow of the river flooded the town of Miziya. The water level remained unchanged until 5 August 2014. On 7 August 2014 the river resumed its normal course.

Ground waters in the Skat River Basin were a significant factor in the formation of the flood, along with the high soil moisture capacity, an increase in the level of shallow ground waters located in the area of active water exchange within the cross-basin massif of the Ogosta and the Skat rivers (GWB – BG1G0000Qpl023). The low drainage of the massif and the lithological structure of the rocks contributed to the infiltration limiting factors. We

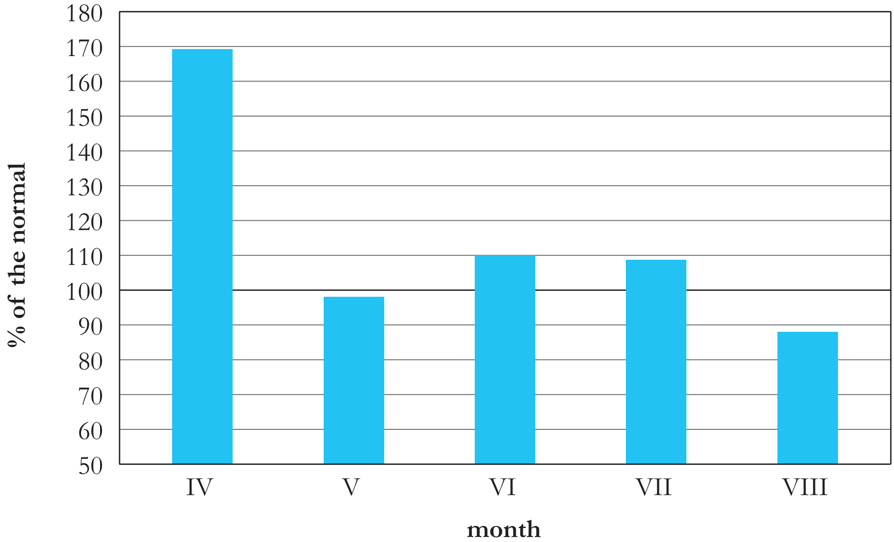

Figure 11 Water level deviations from the rates in well 033S1 – town of Miziya. Source: Measuring stations "Skat River – Nivyanin village", "Skat River – Miziya town", "Ogosta River at Glozhene village" – National Hydrometeorological Institute, branch Pleven town; own processing.

can conclude with very high certainty that ground waters overflowed on the surface and caused a so called "groundwater flood" in the period 3-5 August 2014.

Simultaneously, the river was in a state of high water due to the significant rainfall in the river basin. The process of bank regulation started, which stopped the drainage of ground waters in the alluvial deposits of the Skat River (GWB – BG1G0000Qal016) and the reverse process started – filtration of the river water in the river terrace. Underground waters in the river terrace were in a state of high water and their level reached their maximum recorded value in the town of Miziya. Positive deviations of the levels and rates of the average multiannual monthly values in July and the previous months were registered (Figure 11).

Taking into consideration that the town of Miziya is located in a cross-river massif between the rivers Ogosta and Skat, we can conclude that the groundwater level of the two river basins was additionally increased by the infiltration of fluvial waters in the river terraces and they most certainly overflowed on the surface causing a third type of flooding – groundwater flooding. According to data concerning the water level of the Skat River, the water depth in the town started to decrease on 5 August 2014 when the drainage capacity of the river was recovered (conduction of the ground waters from the river terrace to the river).

CONCLUSIONS

The flood in the town of Miziya was a natural phenomenon caused by a specific combination of natural (climate and landscape) and anthropogenic (land use) factors in the Skat River watershed. The main factors which caused the formation of the high wave in the period 2-7 August 2014 are as follows:

1. The amount, continuity and intensity of the rainfall in the Skat River Basin in the period 1-8 August 2014 were assessed as "extreme rainfalls". The calculated average precipitation for the same period is 114.3 million m^3. The run-off coefficient is 0.65.

2. Resulting from the significant rainfall in the Skat River Basin in the previous months (April, May, June and July) the land cover was waterlogged.

The water-physical characteristics of the soil types in the watershed and the rock structure were crucial factors which limited the infiltration of rainfall waters in the soil horizons and generated surface run-off.

3. Ground waters were oversaturated and the water level was high (because of intensive rainfall in the previous months). According to information from Danube Water Management District – town of Pleven, ground waters overflowed on the surface in numerous locations and caused swamping. Due to the hydraulic connection between the Skat River and the underground waters formed in the alluvial deposits of the river, groundwater levels increased through the process of bank regulation. We can most certainly conclude that ground waters overflowed on the surface during the flood event. Due to the high velocity of the karst waters located in the upper basin, the discharge is much faster in the rivers and additionally the water level increased.

4. The relief (altitude, inclination, segmentation) creates specific discharge conditions in the river basin. In the upper basin the relief is a prerequisite for fast discharge of rainfall waters due to the high altitude and inclination of the slopes. In the middle and largest part of the basin rainfall water discharges much more slowly and the evaporation ratio is higher. In the lower basin the discharge area is significantly narrowed because of the high altitude in the east part of the basin and it cannot safely receive the run-off generated in the upper and middle basin. Miziya is located in the lowest and most narrow western part, which resembles "a bottle neck".

5. The main land use categories are agricultural land (86.93%), forests (6.23%) and settlements and other urban territories (5.38%). Forests cover minor and fragmented lands (6.23%) and consist mostly of degraded deciduous forests. Therefore, they do not possess the necessary water and erosion protection functions.

6. As a result of the complex impact of the described natural and anthropogenic factors in the period from 31 July to 2 August 2014, conditions for formation of significant run-off were created.

7. The flood in Miziya was a result of three types of flooding – flash flooding, fluvial flooding and groundwater flooding.

8. Hydro-technical equipment built in the Skat River watershed has proved that the calculated load capacity is close or even less than the designed capacity for its category and type. The impact of the dams and other basins cannot be defined as major factor because their full capacity cannot cause the formation of a wave with such an enormous volume and which caused the devastating flood.

9. It is necessary to implement an integrated (holistic) approach for the protection of the whole river basin, including a combination of structural and non-structural protection measures. The specific measures should be defined in the flood risk management plans.

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Résumé

Mechanismus vzniku ničivé povodně ve městě Mizija, Bulharsko v srpnu 2014

Příspěvek se tematicky věnuje formativním faktorům a mechanismům devastujících povodní, které postihly město Mizija (Bulharsko) v srpnu 2014. Představeny jsou závěry oficiální zprávy státních institucí věnované formativním mechanismům zmíněných povodní, přičemž jsou tyto závěry dále rozpracovány autorkami příspěvku.

Povodně byly způsobeny signifikantním nárůstem vodního stavu řeky Skat v důsledku intenzivních dešťů v období 31. července až 2. srpna 2014. Některé z přítoků řeky Skat došlo taktéž k vylití vody, což způsobilo extenzivní záplavy s vážnými důsledky, včetně obětí na životech či zdemolovaných nebo vážně poškozených sídel. Potřeba vyhnout se v budoucnu škodám takového rozsahu nutně vyžaduje plánování a implementaci adekvátních protipovodňových opatření. Výsledná podoba těchto opatření nicméně záleží na detailní analýze formativních mechanismů záplav ve městě Mizija.

Koryto řeky je systém s jistým poměrem organizace, a který je dále považován nejdůležitější část krajiny v souvislosti s vodním cyklem, cyklem sedimentů a rozpouštěním geochemických a biogeochemických složek. Povodí je vědci často vnímáno jako otevřený systém. Vstupy do tohoto systému zahrnují srážky, tání sněhu a sedimentaci. Pochopení prostorové a časové variability procesů agregovaných v měřítku povodí, jejich extrémů a škálu chování je důležité pro množství aplikací jako např. odhad povodně, zmírňování sucha, analýza systému vodních zdrojů atd. (Murugesu 2005).

V příspěvku jsou využity informace z různých zdrojů: expertní hodnocení, prostorová dat, ortofoto mapy (aktualizace v roce 2011), digitální model reliéfu, data o podzemních vodách v povodí řeky Skat, mapy a hydrometeorologická data.

Provedená analýza využívá různých metod a přístupů, které zahrnují: diferencovaný přístup, komplexní přístup, geografický přístup (zahrnující chorologické a chronologické metody), metoda

prostorové analýzy (využití GIS jako analytického nástroje). Všechny formativní faktory (antropogenní i přírodní) záplav podmiňující mechanismus jejich tvorby jsou v příspěvku detailně analyzovány. Analýza přírodních faktorů neopomíjí prvky geografické (krajina) a klimatické (atmosférická cirkulace). Antropogenní složka zahrnuje hodnocení land use a provozní stav hydro-technického vybavení v povodí.

Na základě zkoumání přírodních a antropogenních faktorů formování povodňové vlny přináší příspěvek závěrů. Mezi hlavní faktory pak řadíme především:

- extrémní srážky v období 1. až 8. srpna 2014;
- výrazné srážky v povodí řeky Skat v předchozích měsících (duben až červenec 2014), v tomto důsledku vodou přesycený land cover, limitovaná infiltrace vody a intenzifikace povrchového odtoku;
- přesycené podzemní vody a jejich vysoký vodní stav. Jako důkaz prosáknutí podzemních vod na povrch lze brát zformování mokřadů v různých místech;
- zvýšená rychlost krasových vod situovaných v horním povodí a jejich rychlejší odtok do řek;
- specifické podmínky krajiny představovaly předpoklad pro rychlý odtok srážkových vod;
- limitovaná funkce vodní a erozní protekce kategorií land use nacházejících se v povodí;
- kombinace tří typů povodní: bleskové povodně, říční povodně a povodně způsobené podpovrchovou vodou;
- přehrady nacházející se v povodí nemohly způsobit zformování povodňové vlny v důsledku jejich omezené kapacity.

Doporučujeme, aby byla budoucí protipovodňová opatření v regionu založena na strukturálních a nestrukturálních analýzách. Tyto analýzy by následně měly být rozvíjeny a evaluovány v plánech protipovodňových opatření pro území s významnými potenciálními hrozbami záplav.

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