MAPPING OF CONFLUENCES OF SECOND-ORDER WATER STREAMS ON SELECTED MICRO-LOCATION IN DRINA RIVER BASIN, REPUBLIC OF SERBIA

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LIST OF ABBREVIATIONS

2G - The second generation cellular networks
3G - The third generation cellular networks
4G - The fourth generation of broadband cellular network technology
5G - The fifth generation of broadband cellular network technology
ABP - Authentication By Personalization
AC - Alternating Current
ACK - Acknowledgment
ADC - Analog-to-Digital Conversion
AES - Advanced Encryption Standard
AWS - Automatic Weather Station
BSI - Bare Soil Index
CAPEX - Capital Expenditures
COP - Computer Operating Properly (timer)
CORINE - Coordination of Information on the Environment
CSV - Comma-Separated Values
DC - Direct Current
EEE - Electronic and Electrical Equipment
EEPROM - Electrically Erasable Programmable Read-Only Memory
EMC - Electromagnetic Compatibility
EPM - Erosion Potential Model
EU - European Union
FFPI - Flash Flood Potential Index
GNSS - Global Navigation Satellite System
GPRS - General packet radio service
GSM - Global System for Mobile communication
GW - Gateway
HTTPS - Hypertext Transfer Protocol Secure
HVAC - Heating, Ventilation and Air Conditioning
HWS - Hardware and Software
ICT - Information-Communications Technology
IoS - iPhone Operating System
IoT - Internet of Things
IP - Internet Protocol
IT - Information Technology
JSON - JavaScript Object Notation
LoRaWAN – Long-Range Wide Area Networks
LPWAN - Low Power Wide Area Networks
LSB - The Least Significant Bit
LSG - Local Self Government
LTE – The Long-Term Evolution
LVD - Low Voltage Directive
M2M – Machine-to-Machine
MAC - Medium Access Control
MCD-MS - Measuring station for gathering of the meteorological and climate data
MCU - Micro-Controller Unit
MIC - Message Integrity Code
MPU - Memory Protection Unit
MQTT - Message Queuing Telemetry Transport
MSB - The Most Significant Bit
NB-IoT - Narrowband Internet of things
NFC - Near Filed Communications
OPEX - Operational Expenditures
OS - Operating System
OTA - Over-the-Air
OTAA - Over-the-Air Activation
PC - Personal Computer
PHY - Physical Layer
PoC - Proof of Concept
PoE - Power over Ethernet
PWM - Pulse Width Modulation
RAM - Random-Access Memory
Q - Discharge
RATEL - Regulatory Agency for Electronic Communications and Postal Services
RBWL-MS - Measuring station for gathering of the water level in the river bed data
RED - Radio Equipment Directive
RF - Radio-Frequency
RFID - Radio Frequency Identification
RoHS - Restriction on Hazardous Substances
ROM - Read-Only Memory
RTC - Real-Time Clock
RTU - Remote Terminal Unit
SCS - Soil Conservation Service (method)
SF - Spreading Factor
SLA - Service Level Agreement
SMS - Small Message Service
SN - Sensor Node
SSL - Secure Sockets Layer
TCP - Transmission Control Protocol
UART - Universal Asynchronous Receiver - Transmitter
UMTS - Universal Mobile Telecommunication System
UN - United Nations
UNDP - United Nations Development Programme
USB - Universal Serial Bus
UV - Ultra-Violet
VWC - Volumetric Water Content
WEEE - Waste Electrical and Electronic Equipment Directive
Wi-Fi - Wireless Fidelity
WLAN - Wireless Local Area Networks
WPAN - Wireless Personal Area Networks
WSN – Wireless Sensor Node
WTU - Watchdog Timer Unit
xDSL - Digital Subscriber Line
XML - Extensible Markup Language

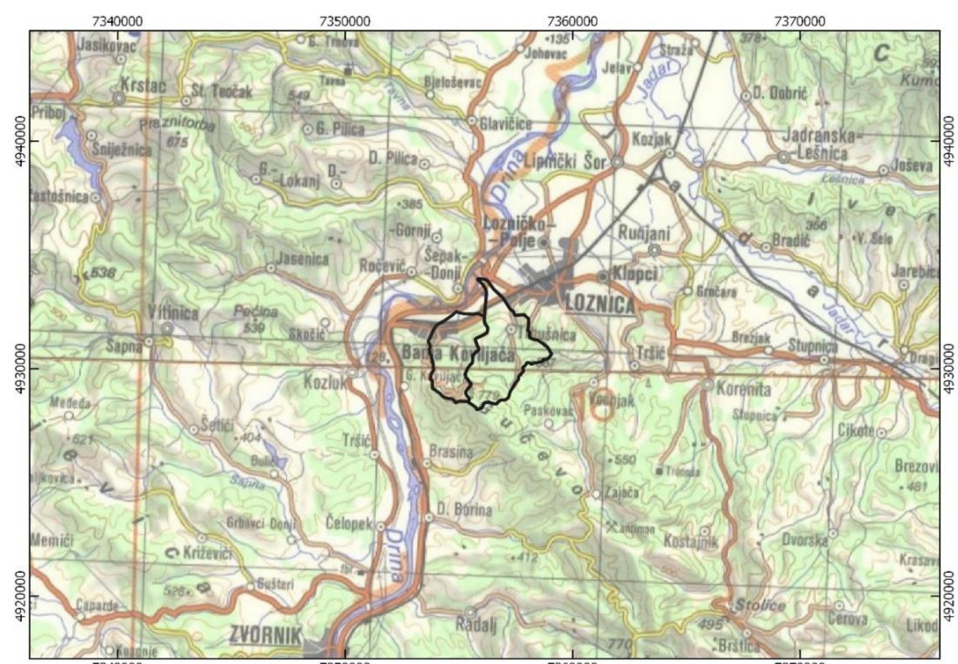
1. INTRODUCTION

In the last couple of years, torrential rains have become more common, the amount of which exceeds a third of the total average annual precipitation in 24 hours for a certain area. This type of precipitation also characterizes western Serbia, more precisely the Drina river basin. The Drina River is the largest tributary of the Sava River, both in terms of the length of the stream (346 km), the area of the basin (19,946 km^2), as well as in terms of the amount of water (average annual discharge $Q_{avg} = 395\ m^3s^{-1}$). Of the entire Sava River basin, the Drina River basin covers 20.6%. Of the total flow of the Sava River, the waters of the Drina River account for 32.6%. Within the borders of Serbia, the catchment area is 6,007 km^2. The tributaries of the Drina are mainly torrential watercourses that, with their destructive torrential waves, further threaten urban and suburban settlements on the banks of the Drina. As the formation of a flood event takes place in 2 to 4 hours, there is little time to react, and the space for the construction of protective structures is decreasing. Therefore, it is necessary to act in a timely manner and announce the arrival of a flood wave, in order to save movable and immovable property, and in some cases to evacuate the population. In this connection, a reliable announcement of a flood event is necessary. The current forecasting system is good and acceptable for larger rivers and basins, but for small torrential watercourses it is unreliable. Therefore, local self-governments are increasingly deciding to build flood early warning systems on torrential watercourses themselves, in order to have reliable data and take a timely response accordingly. One of such systems is also being developed in the Drina river basin, more precisely in 2 sub-basins.

1.1. Subject of the work

The research area is represented by the Trbušnica River basin (right in Figure 1.1), as well as the Gučevski Potok basin (left in Figure 1.1). These two watercourses are right tributaries of the Drina river and have the character of torrential watercourses.

Figure 1.1: Overview map of catchment areas



Source: Authors, based on Topographical data (Military-geographic Institute, Serbia)

1.2 Characteristics of the catchment area

The rivers Trbušnica and Gučevski potok rise on the southwestern slopes of the Gučevo mountain range.

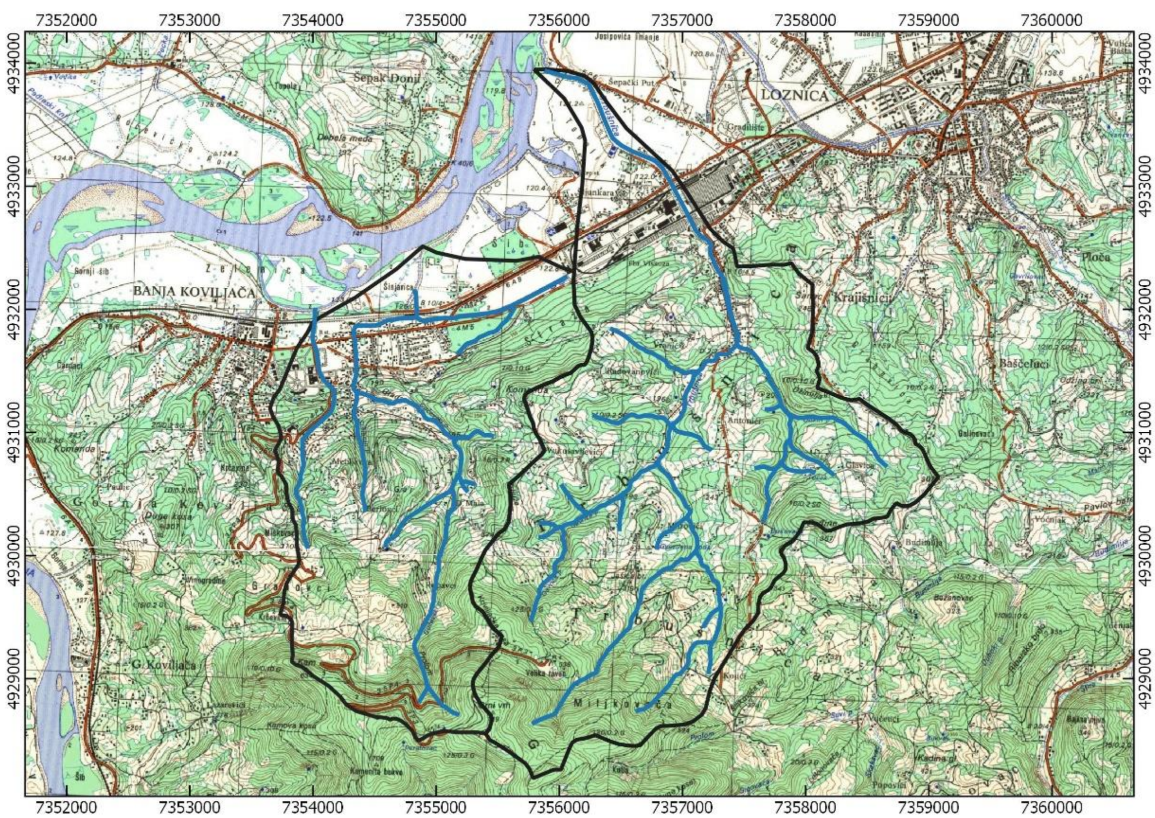
The river Trbušnica springs from under the slopes of Goli brdo, on the eastern side of Crni vrh (779 masl). The Gučevski potok springs from the western side of Crni vrh. The Gučevski potok and the Trbušnica river are tributaries of the Drina river, into which they flow downstream, that is, north-east of the settlement of Banja Koviljača. Both watercourses originate and mostly flow through the hilly and mountainous area and have no significant tributaries. The lower part of the watershed is an urbanized area, a suburban settlement. The bed of both watercourses through the urbanized zone is regulated.

1.3 Analysis of watercourses in the catchment area

The Trbušnica river basin is about 10 km^2 in size. The exact size of the catchment area is difficult to determine due to the lower part of the catchment, which is of a lowland character, where there are a large number of canals, and the terrain has been modified due to the exploitation of river sediment. The situation is the same with Gučevski potok, which has an approximate area of about 6 to 7 km^2.

Among the more important tributaries of the Trbušnica river, two streams stand out: Gavrića potok, which is the left tributary of Trbušnica, as well as Đokina potok, the right tributary of Trbušnica (Figure 1.2). Among the more important tributaries of Gučevski potok, Simana potok, the left tributary, stands out.

Figure 1.2: Watercourses in the studied area



Source: Authors, based on Topographical data (Military-geographic Institute, Serbia)

1.4. The existing flood protection system on the Drina River

On the Drina River, on its right bank, there is a protective embankment in the area of the Banja Koviljača settlement and the town of Loznica. Looking from the upstream side, the list of protective facilities is as follows (Figure 1.3):

- The right embankment along the Drina in the area of Banja Koviljača (Figure 1.3, mark "1" on the map),
  - The length of the embankment is 4.50 km,
  - Regular flood protection is carried out when the level of the Drina reaches 133.27 (masl), i.e. when the upstream station Radalj is at a height of 380 cm,
  - Emergency defense against floods is carried out when the level of the Drina reaches 134.27 (masl), that is, when it is 480 cm at the upstream station Radalj at the height of the water gauge;
- Embankment along the Drina, bypass road around Loznica (Figure 1.3, mark "2" on the map),
  - The length of the embankment is 4.42 km,
  - Regular flood protection is carried out when the level of the Drina reaches 133.27 (masl), i.e. when the upstream station Radalj is at a height of 380 cm,
  - Emergency defense against floods is carried out when the level of the Drina reaches 134.27 (masl), that is, when it is 480 cm at the upstream station Radalj at the height of the water gauge;
- Embankment along the Drina, bypass road around Loznica (Figure 1.3, mark "3" on the map),
  - The length of the embankment is 1.50 km,
  - Regular flood protection is carried out when the level of the Drina reaches 133.27 (masl), i.e. when the upstream station Radalj is at a height of 380 cm,
  - Emergency flood protection is carried out when the level of the Drina reaches 134.27 (masl), i.e. when the upstream station Radalj is at a height of 480 cm.

The existing protective system in the narrow investigation area

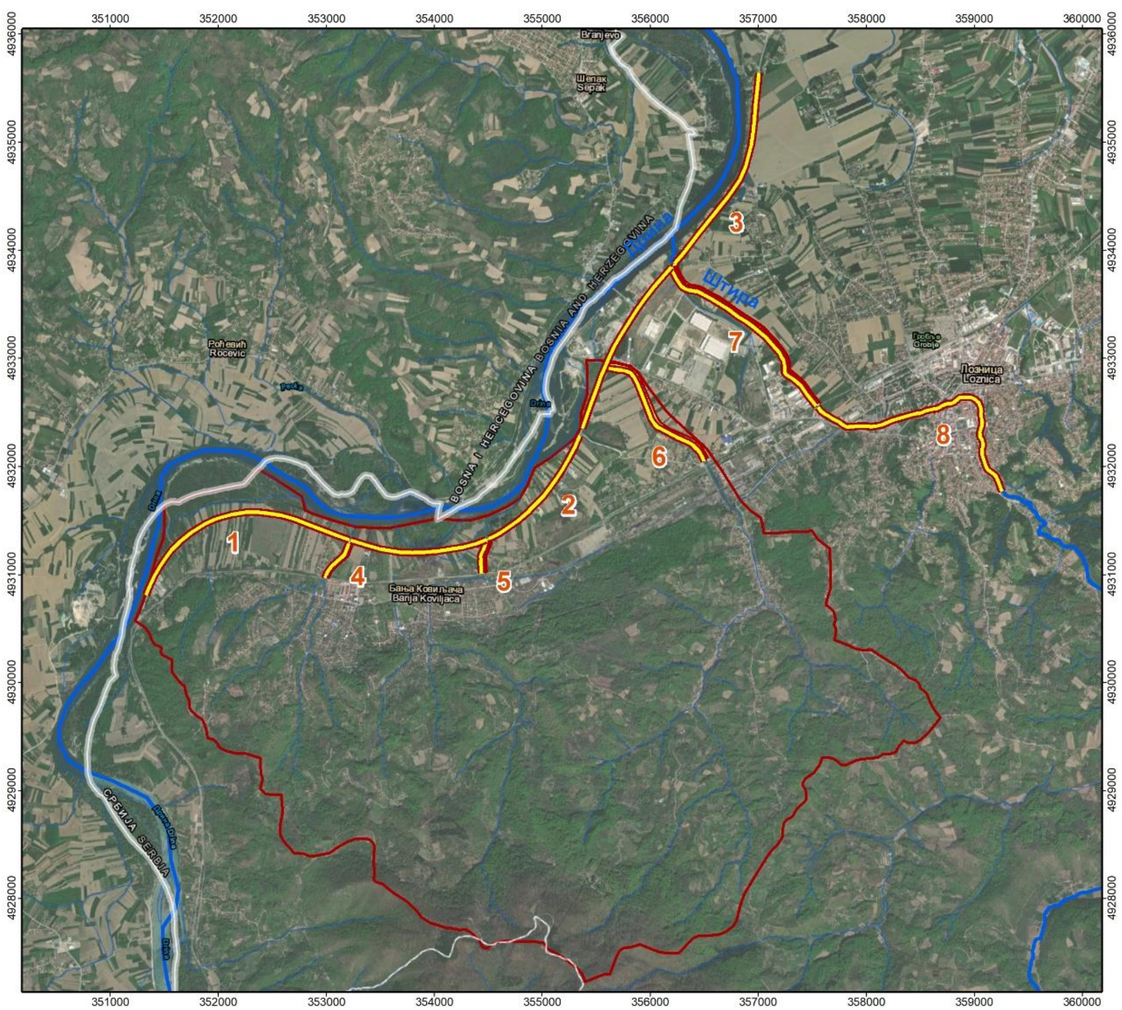
On the right tributaries of the Drina River, on the right bank, there are protective embankments in the area of the Banja Koviljača settlement and the town of Loznica. Looking from the upstream side, the list of protective objects is as follows (Figure 1.3):

- Regulated bed of Ciganski potok (Figure 1.3, mark "4" on the map),
  - The length of the regulated riverbed is 0.70 km,
  - Regular flood protection is carried out when the level of the Drina reaches 133.27 (masl), i.e. when the upstream station Radalj is at a height of 380 cm,
  - Emergency defense against floods is carried out when the level of the Drina reaches 134.27 (masl), that is, when it is 480 cm at the upstream station Radalj at the height of the water gauge;
- Regulated bed (left and right embankment) of the Simića stream (Figure 1.3, mark "5" on the map),
  - The length of the regulated riverbed is 1.16 km,
  - Regular flood protection is carried out when the level of the Drina reaches 133.27 (masl), i.e. when the upstream station Radalj is at a height of 380 cm,
  - Emergency defense against floods is carried out when the level of the Drina reaches 134.27 (masl), that is, when it is 480 cm at the upstream station Radalj at the height of the water gauge;
- The left and right embankments along Trbušnica (Figure 1.3, mark "6" on the map),
  - The length of the embankment is 3.20 km,

o Regular flood protection is carried out when the level of the Drina reaches 133.27 (masl), i.e. when the upstream station Radalj is at a height of 380 cm,
o Emergency defense against floods is carried out when the level of the Drina reaches 134.27 (masl), that is, when it is 480 cm at the upstream station Radalj at the height of the water gauge;

- The left and right embankments along Štira from the mouth of the Drina (Figure 1.3, mark "7" on the map),
  - o The length of the embankment is 4.49 km,
  - o Regular flood protection is carried out when the level of the Drina reaches 133.27 (masl), i.e. when the upstream station Radalj is at a height of 380 cm,
  - o Emergency defense against floods is carried out when the level of the Drina reaches 134.27 (masl), that is, when it is 480 cm at the upstream station Radalj at the height of the water gauge;
- Regulation of the Štira River near Loznica (Figure 1.3, mark "8" on the map),
  - o The length of the embankment is 2.50 km.

Figure 1.3: Flood protection system on the Drina River with tributaries



Source: Authors, based on Satellite data (ESRI) and data PWMC "Srbijavode"

2. DEVELOPING METHODOLOGICAL GUIDELINES FOR ESTABLISHMENT OF EARLY WARNING SYSTEM IN DRINA RIVER BASIN

Abstract: One of the most vulnerable areas to natural hazards in Serbia is the Drina River Basin with riverine and torrential floods, which are the most frequent and destructive natural disasters regarding the huge material damage and loss of human lives. In the past, during the period from 1915 to 2021, 132 torrential flood events with 9 casualties in the Drina river basin were recorded which show that this territory is extremely vulnerable to torrential floods. Based on the analysis of the registered torrential floods, it is clearly observed that during the last more than 100 years (1915-2021), the right tributaries of the Drina River that drain the slopes of the Gučevo mountain (Štira River, Trbušnica River, Gučevski potok, Simana potok, Bezimeni potok 1 and 2) more than 15 times flooded the inhabited and industrial area in the territory of Loznica and Banja Koviljača. In addition to the material damage they caused, these floods also caused the loss of human lives, and therefore it is quite justified to design the monitoring of precipitation and flowing water, with the aim of timely response and protection of people and goods in the downstream sector.

Therefore, the first step in establishing an early warning system would include a geospatial analysis of natural conditions (geological, geomorphological, hydro-meteorological, etc.) and land use mapping at targeted locations. The data collected on the susceptibility of the terrain to torrential floods (hypsometry, vertical relief dissection, slope, flash flood potential index - FFPI, etc.), in conjunction with hydro-meteorological data (precipitation, identified watercourses, their length, tributaries, attributable water capacities, etc.) provides accurate information on the locations for the installation of monitoring stations and the optimal number of devices.

Second, the second-order streams are not covered by data acquisition devices or gauging stations, so local authorities are not able to monitor, predict, or take preventive measures for the affected locations in a timely manner. Therefore, it is urgent to establish monitoring stations to collect meteo-hydrological data on precipitation amount, air temperature, soil moisture, and water level in the riverbed. Synthesis of the data obtained will allow prediction of the occurrence of torrential floods in specific microsites.

Third, for the purposes of data analysis, there is a need to develop a system of data collection, early warning, and data exchange at the local administration level with the perspective of integration along and between river basins and with the national early warning system.

Because of all above, this methodology is designed for a better understand the physical parameters needed to define the critical state of natural conditions before and during torrential floods and can be used directly in the natural disaster management process. Also, it is necessary for: identification of locations for sensor instalment, based on terrain analysis, torrential flood susceptibility assessment, meteorological and hydrological data, real-time critical situation assessment and emergency preparedness during different phases of the torrential flood management cycle, developing tools and procedures for integrating different sources of information, including monitoring data (real-time data), and the reliability of that information, defining additional parameters that will improve the precise identification of critical watercourses and critical zones for the installation of sensors (equipment for monitoring basic meteorological data and climate elements) in the most efficient and financially acceptable way.

In order to carry out an analysis of natural conditions and determine the susceptibility (predisposition of the terrain) to the genesis and occurrence of torrential floods, a complex analyis of the direct and indirect factors that cause their genesis is necessary. The analysis of recorded torrential flood events in the research area showed a clear susceptibility to the occurrence of torrential floods, and as a next step it is necessary to analyze the influence of geotopographic (geological, geomorphological, and pedological), meteo-hydrological and other factors that determine their genesis and characteristics. Natural condition analysis showed that the research area is very susceptible to the occurrence of the torrential floods. Surfaces that belong to the classes high or very high flash flood susceptibility cover around 68% of Trbušnica River basin area, and 65% of Gučevski potok basin area.

Based on the analysis of natural conditions in the research area, the best locations for setting up monitoring, which can be applied to any watershed, are presented. The proper selection of the site for the establishment of the meteorological station (precipitation station) is extremely important for the proper functioning of the early warning system for torrents. When choosing the location, the following criteria should be taken into account:

- from the aspect of hypsometry, the station should be placed in the central part of the high watershed area (headwater, head of the river), because then a representative sample (result) of the maximum precipitation for the catchment area is provided. In the specific case, the precipitation station should be located in the altitude zone of 700-800 m between the source of the Trbušnica River and the Gučevski potok.
- from the aspect of vertical relief dissection, the location of the station should be in the area of low vertical dissection of the relief, but in the immediate vicinity of the highest parts of the river basin, i.e. at the transition from low to high vertical dissection of the relief.
- from the aspect of the slope angle, the site for the monitoring station should be located in a part characterized by small slope angle, but very close to the highest parts of the basin, where the largest amount of precipitation is expected and where the water is collected for surface runoff (precipitation collection area). In addition, the site must be located in a plain, in the zone above the high vertical dissection of the relief, but also at the beginning of the significant slopes of the terrain, which condition the rapid runoff.
- regardless of the type of precipitation station installed, it is necessary to place it on a stable base; the upper edge of the receiver must be exactly at a height of 1.0 m from the base, and the area of the circular receiver should be 200 cm^2.
- around the measuring station is required free space from buildings, vegetation, etc. If the site is located in the zone of forest vegetation, a free space with a radius of at least 15-20 m is required.
- the measuring station must be placed in a place that is not endangered by various damages (vandalism), livestock, domestic animals, etc.
- it is necessary to ensure that the chosen location is easily accessible by car (transport of equipment, data collection, replacement of sensors and devices, etc.)
- the presence of a power source is important if the technical characteristics and the method of data transmission require it. This is an option because most monitoring stations have self-powered panels, which is the preferred option.
- the presence of a transmitter for the transmission of messages, i.e. registered data in real time.
- state ownership of the land where the station is to be installed is desirable, as private ownership may result in frequent relocation of the monitoring station.

Factors that were taken into account for suitability assessment of meteorological station instalment location are altitude of the terrain, the terrain slope, the land cover and the distance to roads. All factors were classified into 5 classes, with the assigned values from 1 to 5, where 5 indicates area most suitable and value 1 indicates the area least suitable for instalment of meteorological station. According to the used methodology most suitable locations for installment of the meteorological station cover 0.87 hectares in the total research area.

The proper selection of a site for the installation of the hydrological gauging station is extremely important for the proper functioning of the early warning system for torrential floods. The following criteria should be considered when selecting a major site:

- in torrential basins, the streambed water level sensor should be located in the center of the transit zone or torrential flow movement. This is a location between the zones of water and sediment accumulation and the zone of accumulation of torrential sediment.
- from the aspect of hypsometry, unlike the precipitation station, the sensor for measuring the water level should be placed in the immediate vicinity of the zone of lowest elevation and near the transition from the zone of lowest elevation to the zone of highest elevation. Thus, in this case, it would ideally be placed at the transition from the 200-300 m elevation zone to the 100-200 m zone.
- from the aspect of the vertical dissection of the relief, the location of the gauging station should be in the sector of the low vertical relief dissection, at the transition from the high to the low vertical relief dissection. Therefore, the site should be located near the steeply sloping relief energy, i.e. near or at the reference level (Rn)
- from the aspect of the slope angle, the location of the gauging station should be in the sector with small slope angle, at the transition of the last two lowest slope classes, i.e. where the kinetic energy of the river decreases.

The final selection of the location (profile in the riverbed) for the installation of the gauging station (sensor for water level measurement) will be determined by field work to select the best section of the riverbed suitable for carrying out the measurement. In order for the measurement of water level and discharge to be meaningful, the selected section of the riverbed must fulfill the following conditions:

- that the flow direction has a minimum length of 5B (B-width of the water mirror for the maximum expected flow) and that the river course is without eddies. This ensures uniform flow in the riverbed with straight-line flows whose hydraulic and morphological characteristics are representative of the longest section of the river. The riverbed should have a uniform gradient with no cascades, and there should be no large boulders or other material in the bed.
- the selected section must not have a single tributary or additional water volume
- the banks must be stable and free of vegetation (not overgrown)
- if the river course is regulated, the hydrometric profile (section) should be upstream from the cascades and rapids, far enough away not to disturb the steady flow

On the selected section, the measurement profile should be in the middle. There, an automatic gauge station is installed, i.e. a sensor that registers the change of the water level in the riverbed at each point. The sensor is placed above the riverbed at a sufficient height (in the safety zone) so that it does not come into contact with the water or with the floating sediment carried by the water during the flood wave.

The first step in establishing an early warning system would include a geospatial analysis of natural conditions (geological, geomorphological, hydro-meteorological, etc.), land use, and urban infrastructure mapping at targeted locations. The data collected on the susceptibility of the terrain to torrential floods (hypsometry, vertical relief dissection, slope, flash flood potential index - FFPI, etc.), in conjunction with hydro-meteorological data (precipitation, identified watercourses, their length, tributaries, attributable water capacities, etc.) will provide accurate information on the locations for the installation of monitoring stations and the optimal number of devices.

Second, the second-order streams are not covered by data acquisition devices or gauging stations, so local authorities are not able to monitor, predict, or take preventive measures for the affected locations in a timely manner. Therefore, it is urgent to establish monitoring stations to collect meteo-hydrological data on precipitation amount, air temperature, soil moisture, and water level in the riverbed. Synthesis of the data obtained will allow prediction of the occurrence of torrential floods in specific micro-sites.

Third, for the purposes of data analysis, there is a need to develop a system of data collection, early warning, and data exchange at the local administration level with the perspective of integration along and between river basins and with the national early warning system.

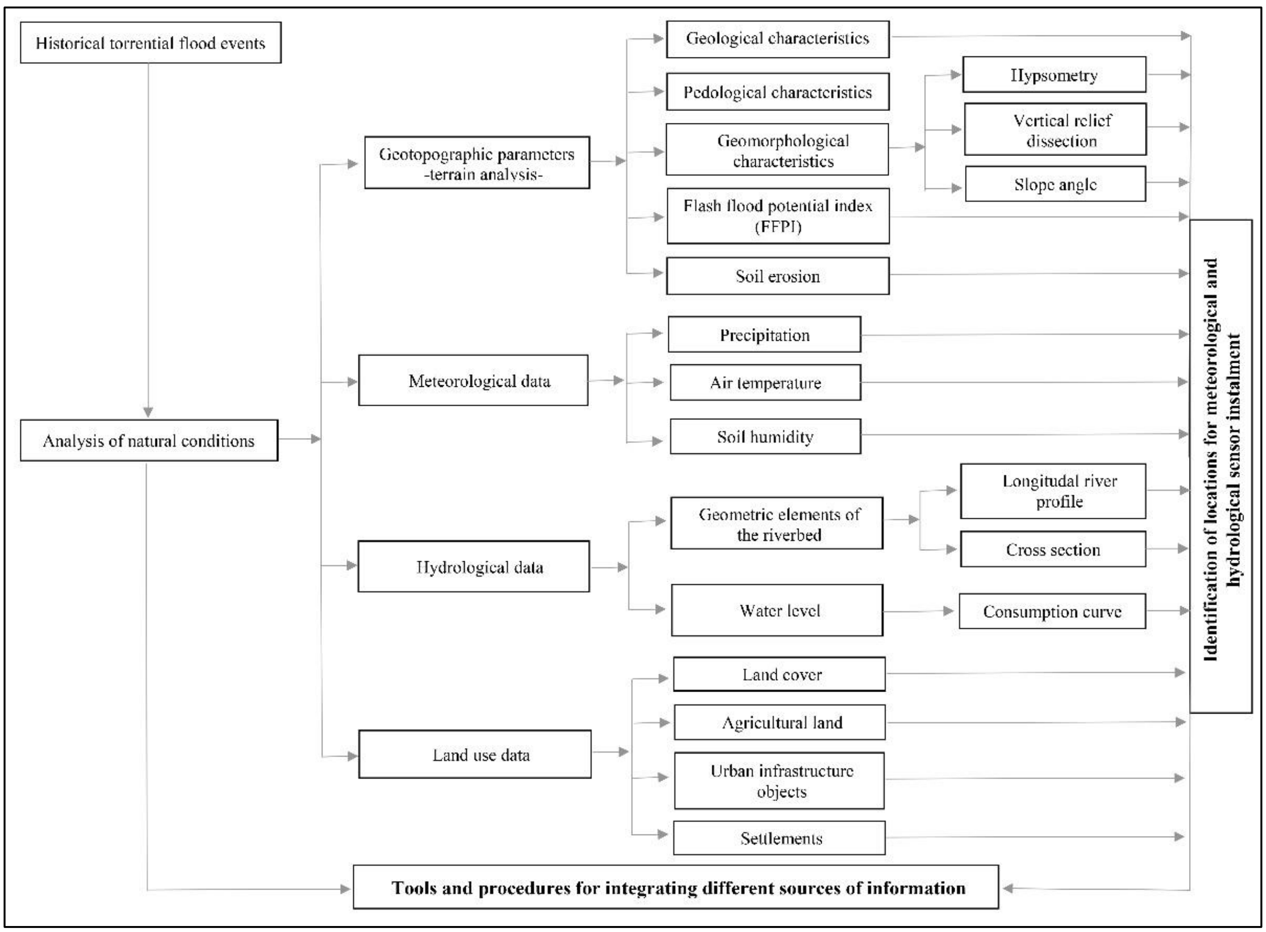
This methodology is designed for a better understand the physical parameters needed to define the critical state of natural conditions before and during torrential floods and can be used directly in the natural disaster management process.

The early warning system is the main objective of this project, which includes the following analyses to correctly determine the location for sensor placement:

- collection of data on recorded events (historical data) related to torrential floods in the research area,
- collection of all relevant data useful for assessing the state of natural conditions before and during torrential floods,
- analysis of natural conditions as determinants of torrential floods:
  1. geotopographic parameters – terrain analysis:
     - geological characteristics,
     - geomorphological characteristics - hypsometry, vertical dissection of relief, slope angles, etc.,
     - pedological characteristics,
     - flash flood potential index (FFPI), susceptibility to the genesis and occurrence of torrential floods, and
     - soil erosion intensity;
  2. meteorological data:
     - precipitation,
     - air temperature, and
     - soil humidity (moisture);
  3. hydrological data:
     - water level in the river channel, and
     - geometric elements of the riverbed at the selected locations;
  4. land use data:
     - land cover (forests, meadows and, pastures, etc.),
     - agricultural land,
     - urban infrastructure objects, and
     - settlements;

- defining additional parameters of importance for the collection and processing of data by monitoring stations to improve the management of torrential floods,
- identification of locations for sensor installment, based on terrain analysis, torrential flood susceptibility assessment, meteorological and hydrological data,
- real-time critical situation assessment and emergency preparedness during different phases of the torrential flood management cycle,
- developing tools and procedures for integrating different sources of information, including monitoring data (real-time data), and the reliability of that information,
- defining additional parameters that will improve the precise identification of critical, watercourses and critical zones for the installation of sensors (equipment for monitoring basic meteorological data and climate elements) in the most efficient and financially acceptable way.

Figure 2.1: Methodology flow chart



Source: Authors, based on available data

2.1. Historical torrential flood events in the Drina river basin

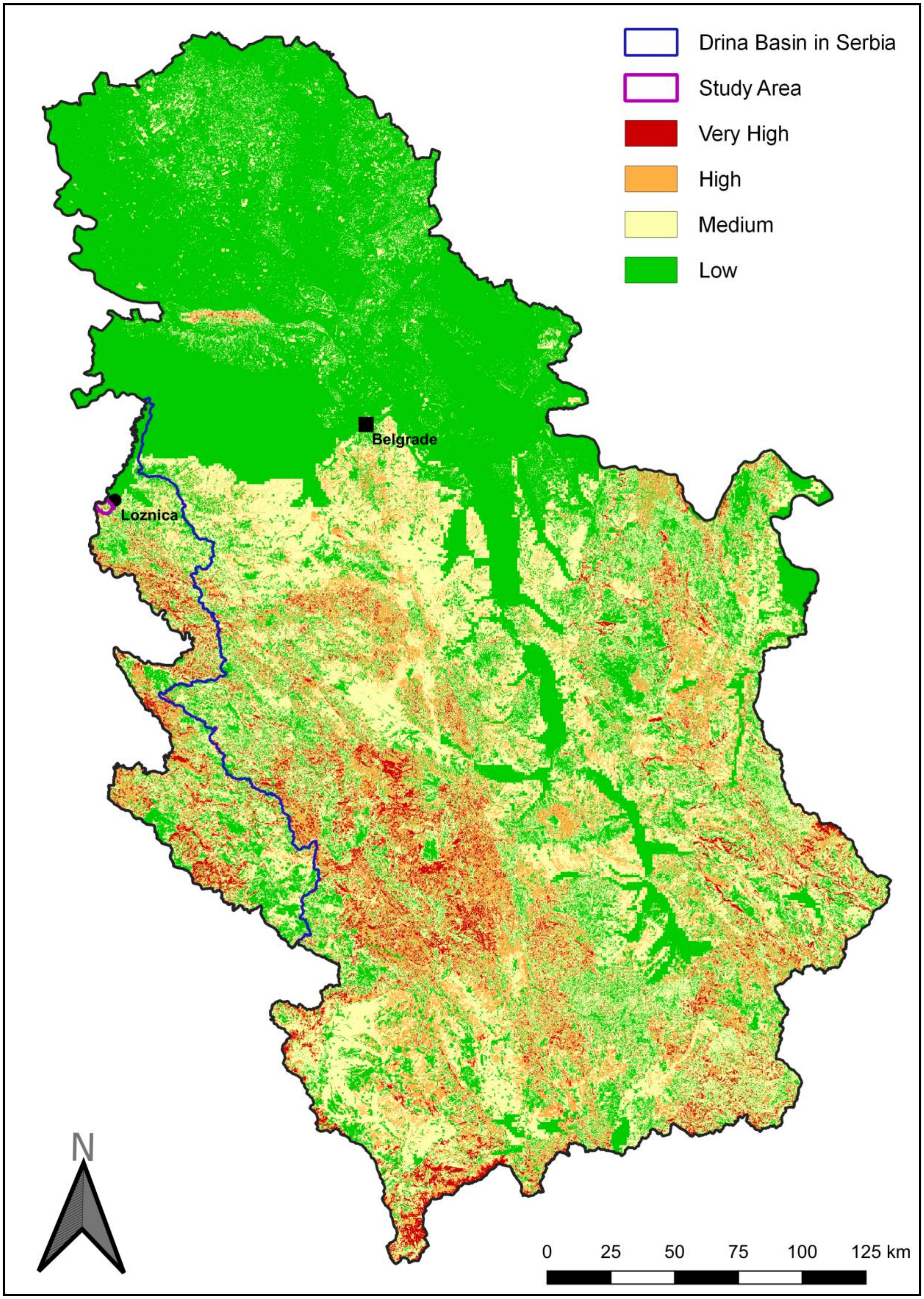
Each territory on the Earth's surface, depending on the complex of natural conditions (relief, climate, hydrological characteristics, etc.), has its own peculiarities and natural predispositions (susceptibility) to certain phenomena and processes and, consequently, to a certain type of natural disasters.

The territory of Serbia is susceptible to various types of natural hazards, and the degree of susceptibility is not uniform for the entire territory of the country, but varies depending on the type of hazard and the expected potential damage. Seismic hazards, landslides, rockfalls, floods and torrential floods, excessive erosion, droughts, and forest fires are the most important natural hazards on the territory of Serbia.

According to the number of torrential watercourses, frequency of occurrence and consequences that have occurred in the past, torrential floods are the most frequent and catastrophic natural hazards in Serbia. Their frequency, intensity and diffusion across the entire territory make them a constant threat to the ecological, economic and social spheres. The total length of watercourse on the territory of Serbia is 65,980 km, i.e. the density of the river network is 0.75 km^2. The potential floodable area for water with a return period of 100 years covers an area of 16,000 km^2, of which 500 major settlements, 515 industrial objects, 680 km of railroad lines and about 4,000 km of roads are affected. In recent years, Serbia has been vulnerable to floods caused by small watercourses, i.e. torrential floods.

To determine the vulnerability to torrential floods on the territory of the Republic of Serbia, the Flash Flood Potential Index (FFPI) method (Smith, 2003) was used. The analysis of the obtained FFPI values showed that 4.7 % of the total Serbian territory belongs to a class with very high flash flood potential, 13.6 % to a class with high potential, 36 % to a medium class, and 46 % to a class with low potential. The most vulnerable to torrential floods are the watercourses in the river basins of Zapadna Morava, Južna Morava, Kolubara, Velika Morava, Drina, Ibar, etc.

Figure 2.2: Susceptibility to torrential floods on the territory of the Republic of Serbia



Source: Authors, based on available data

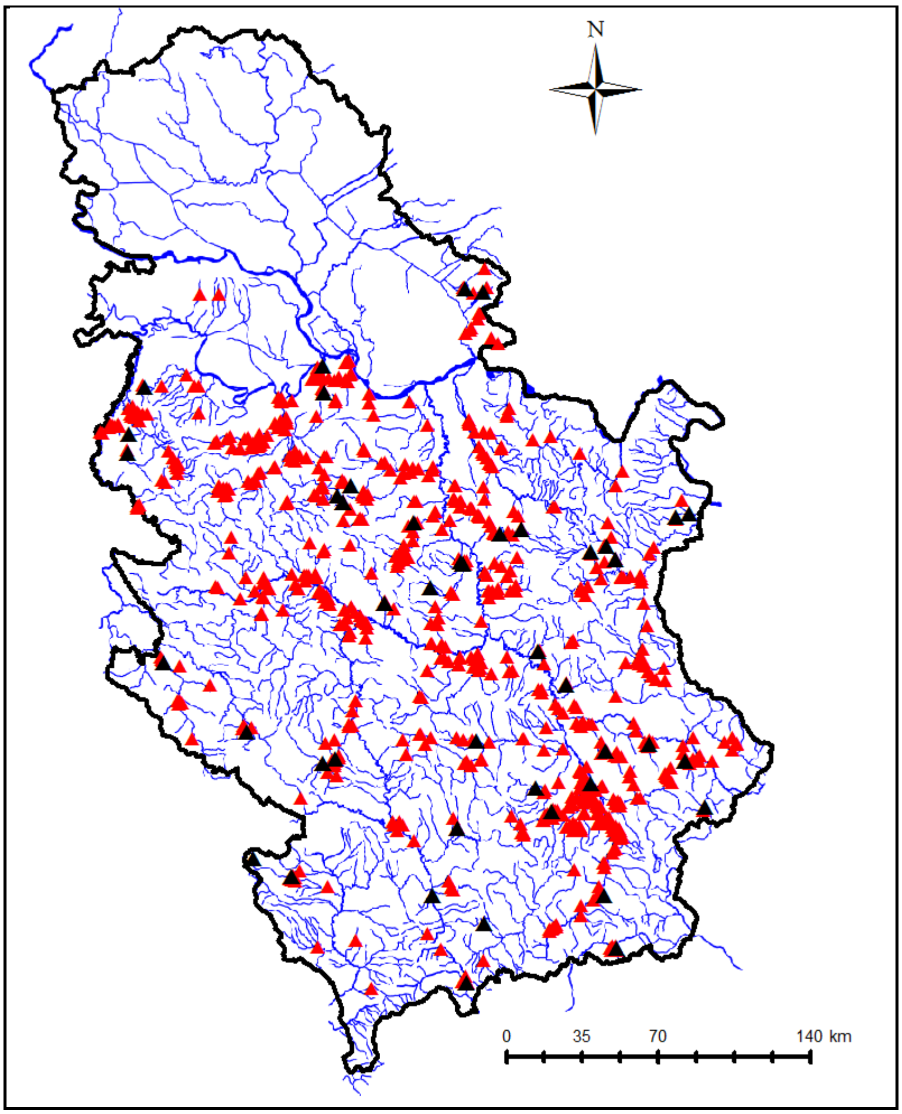
In the Inventory of torrential flood events in Serbia for the period 1915–2019 (Petrovic et al., 2014; Petrovic, 2021), the highest number of torrential floods was recorded in the Zapadna Morava River Basin (542), followed by the Juzna Morava (447), Kolubara (349), Velika Morava (226), and Drina (122) river basins.

Table 2.1: Recorded torrential flood events in Serbia for the period 1915–2019 is derived from the Inventory of torrential floods in Serbia

	River basin/ Watershed	Number of torrential flood events	Number of casualties
1.	Zapadna Morava	542	12
2.	Juzna Morava	447	>65
3.	Kolubara	349	52
4.	Velika Morava	226	13
5.	Drina	122	8

Source: Petrovic et al., 2014; Petrovic, 2021

Figure 2.2: The most destructive torrential flood events in Serbia in the period 1915-2019. (▲ - casualties & material damage, ▲ material damage)



Source: Petrovic et al., 2014

One of the most vulnerable areas to natural hazards in Serbia is the Drina River Basin with riverine and torrential floods, which are the most frequent and destructive natural disasters regarding the huge material damage and loss of human lives. In the past, during the period from 1915 to 2019, 122 torrential flood events with 8 casualties in the Drina river basin were recorded which show that this territory is extremely vulnerable to torrential floods.

Table 2.2: Recorded torrential flood events in the Drina River basin

Date	Watercourse	River basin/ Watershed	Place	Number of casualties
12-05-1931.	Postenjska reka	Drina	Postenje	
12-05-1931.	Rakovica	Drina	Cikot	1
12-05-1931.	Simanin potok	Drina	Banja Koviljača	
12-05-1931.	Gučevski potok	Drina	Banja Koviljača	
25-05-1938.	Štira	Drina	Loznica, Zajača	1
25-05-1938.	Lešnica	Drina	Joševa, Milina, Jadar. Lešnica	
25-05-1938.	Jadar	Drina	-	
25-05-1938.	Kamenica	Drina	-	
27-03-1940.	Lim	Drina	Prijepolje	
16-05-1965.	Lim	Drina	Priboj	
24-05-1967.	Jadar	Drina	-	
24-05-1967.	Lešnica	Drina	-	
24-05-1967.	Štira	Drina	Loznica	
10-01-1970.	Drina	Drina	Loznica, B. Koviljača	
10-01-1970.	Štira	Drina	Loznica	
10-01-1970.	Jadar	Drina	Put Loznica -Lešnica	
10-04-1973.	Jablanica	Drina	Sjenica	
10-04-1973.	Uvac	Drina	Sjenica	
10-04-1973.	Grabovica	Drina	Sjenica	
10-04-1973.	Vapa	Drina	Sjenica	
10-04-1973.	Lim	Drina	Brodarevo, Prijepolje	
18-11-1979.	Drina	Drina	Ljubovija	
18-11-1979.	Lim	Drina	Put B. Polje-Prijepolje, Priboj	2
20-11-1979.	Mileševka	Drina	Prijepolje	
20-11-1979.	Seljašnica	Drina	-	
20-11-1979.	Grabovica	Drina	Sjenica	
12-07-1982.	Štira	Drina	Loznica	
12-07-1982.	Trbušnica	Drina	Banja Koviljača	
12-07-1982.	Gučevski potok	Drina	Banja Koviljača	
12-07-1982.	Simanin potok	Drina	Banja Koviljača	
23-06-1985.	Jadar	Drina	Osečina	
23-06-1985.	Pecka	Drina	Pecka	
30-08-1985.	Ostružanjska reka	Drina	Osečina	
30-08-1985.	Ljubovida	Drina	Ljubovija	
17-07-1986.	Štira	Drina	Loznica	
07-05-1987.	Jadar	Drina	Straža, Gornji Dobrić, Kozjak	
07-05-1987.	Štira	Drina	Loznica	2
07-05-1987.	Žeravija	Drina	Klupci	
07-05-1987.	Lešnička reka	Drina	Jadarska Lešnica, Donji Dobrić	
22-05-1987.	Pecka	Drina	Pecka	

Date	Watercourse	River basin/ Watershed	Place	Number of casualties
20-08-1989.	Radaljska reka	Drina	Mali Zvornik	
20-08-1989.	Štira	Drina	Loznica	
20-08-1989.	Trbušnica	Drina	Banja Koviljača	
20-08-1989.	Gučevski potok	Drina	Banja Koviljača	
20-08-1989.	Simanin potok	Drina	Banja Koviljača	
14-10-1992.	Jadar	Drina	Gornji Dobrić, Bradić	
11-09-1993.	Štira	Drina	Loznica	
11-09-1993.	Trbušnica	Drina	Banja Koviljača	
11-09-1993.	Gučevski potok	Drina	Banja Koviljača	
11-09-1993.	Simanin potok	Drina	Banja Koviljača	
22-06-2001.	Štira	Drina	Loznica	
22-06-2001.	Jadar	Drina	Gornji Dobrić, Kozjak, Jelav	
22-06-2001.	Korenita	Drina	Korenita	
22-06-2001.	Žeravija	Drina	-	
22-06-2001.	Ostružanjska reka	Drina	Osečina	
22-06-2001.	Pecka	Drina	Gunjaci	
22-06-2001.	Ljuboviđa	Drina	Ljubovija	
22-10-2003.	Štira	Drina	Loznica	
22-10-2003.	Trbušnica	Drina	Banja Koviljača	
22-10-2003.	Gučevski potok	Drina	Banja Koviljača	
18-06-2005.	Jadar	Drina	Osečina, Plužac, Komirić	
18-06-2005.	Sirdijska reka	Drina	Sirdija	
18-06-2005.	Viška reka	Drina	Dragijevica	
18-06-2005.	Rakovica	Drina	Belotić	
18-06-2005.	Ostružanjska reka	Drina	Ostružanj	
13-03-2006.	Jadar	Drina	Bradići	
08-03-2009.	Lešnica	Drina	Jadarska Lešnica	
08-03-2009.	Jazina	Drina	Jadarska Lešnica	
08-03-2009.	Korenita	Drina	Korenita	
12-10-2009.	Štira	Drina	Loznica	
12-10-2009.	Trbušnica	Drina	Banja Koviljača	
12-10-2009.	Gučevski potok	Drina	Banja Koviljača	
12-10-2009.	Simanin potok	Drina	Banja Koviljača	
08-11-2009.	Jablanica	Drina	Sjenica	1
08-11-2009.	Vapa	Drina	Sjenica	
08-11-2009.	Grabovica	Drina	Sjenica	
08-11-2009.	Jadar	Drina	Bradić, Draginac, Slatina	
08-11-2009.	Lim	Drina	Priboj, Prijepolje	
08-11-2009.	Zlošnica	Drina	Nova Varoš	
08-11-2009.	Kratovska reka	Drina	Kratovo	
08-11-2009.	Mileševka	Drina	Prijepolje	
20-04-2010.	Mileševka	Drina	Prijepolje	
23-06-2010.	Jadar	Drina	Zavlaka	
02-12-2010.	Lim	Drina	Brodarevo	
22-05-2011.	Mileševka	Drina	Prijepolje	
25-05-2012.	Jadar	Drina	Zavlaka	
14-03-2013.	Mileševka	Drina	Prijepolje	

Date	Watercourse	River basin/ Watershed	Place	Number of casualties
25-04-2014.	Jadar	Drina	Zavlaka	
14-05-2014.	Ljubovića	Drina	Ljubovija	
14-05-2014.	Milešievka	Drina	Prijepolje	
15-05-2014.	Jadar	Drina	Zavlaka	
15-05-2014.	Čađavica	Drina	Krupanj	2
15-05-2014.	Kržava	Drina	Krupanj	
15-05-2014.	Brštica	Drina	Krupanj	
15-05-2014.	Boranjska reka	Drina	D. Tresnica	
15-05-2014.	Borinska reka	Drina	Borina	
15-05-2014.	Radalj	Drina	Radalj	
15-05-2014.	Rogačica	Drina	Rogačica	
15-05-2014.	Štira	Drina	Loznica	
15-05-2014.	Trbušnica	Drina	Banja Koviljača	
15-05-2014.	Gučevski potok	Drina	Banja Koviljača	
15-05-2014.	Simanin potok	Drina	Banja Koviljača	
07-06-2014.	Štira	Drina	Loznica	
07-06-2014.	Trbušnica	Drina	Banja Koviljača	
07-06-2014.	Gučevski potok	Drina	Banja Koviljača	
07-06-2014.	Simanin potok	Drina	Banja Koviljača	
05-08-2014.	Štira	Drina	Loznica	
05-08-2014.	Simanin potok	Drina	Banja Koviljača	
05-08-2014.	Bezimeni bujični p. 1	Drina	Banja Koviljača	
05-08-2014.	Bezimeni bujični p. 2	Drina	Banja Koviljača	
05-08-2014.	Gučevski potok	Drina	Banja Koviljača	
02-12-2014.	Lim	Drina	Prijepolje	
07-03-2016.	Pilica	Drina	Bajina Bašta	
07-03-2016.	Rogačica	Drina	Rogačica	
07-03-2016.	Derventa	Drina	Dub	
15-07-2016.	Trbušnica	Drina	Banja Koviljača	
15-07-2016.	Gučevski potok	Drina	Banja Koviljača	
15-07-2016.	Simanin potok	Drina	Banja Koviljača	
08-11-2016.	Grabovica	Drina	Sjenica	
08-11-2016.	Uvac	Drina	Sjenica	
08-11-2016.	Vapa	Drina	Sjenica	
12-11-2016.	Mileševka	Drina	Prijepolje	
19-04-2017.	Kržava	Drina	Krupanj	
23-05-2017.	Likodra	Drina	Krupanj	
23-05-2017.	Kržava	Drina	Krupanj	
03-06-2019.	Bogoštica	Drina	Loznica	
03-06-2019.	Likodra	Drina	Krupanj	
23-06-2019.	Brštica	Drina	Brštica	
10-05-2021.	Štira	Drina	Loznica	
10-05-2021.	Trbušnica	Drina	Banja Koviljača	
10-05-2021.	Gučevski potok	Drina	Banja Koviljača	
10-05-2021.	Simanin potok	Drina	Banja Koviljača	

Source: Petrovic et al., 2014; Petrovic, 2021

Based on the analysis of the registered torrential floods, it is clearly observed that during the last more than 100 years (1915-2021), the right tributaries of the Drina River that drain the slopes of the Gučevo mountain (Štira River, Trbušnica River, Gučevski potok, Simana potok, Bezimeni potok 1 and 2) more than 15 times flooded the inhabited and industrial area in the territory of Loznica and Banja Koviljača. In addition to the material damage they caused, these floods also caused the loss of human lives, and therefore it is quite justified to design the monitoring of precipitation and flowing water, with the aim of timely response and protection of people and goods in the downstream sector.

Table 2.3: Research area

Research area [km^2]	Total	Trbušnica river	Gučevski potok
	23.41	10.18	6.71

Source: Authors, based on available data

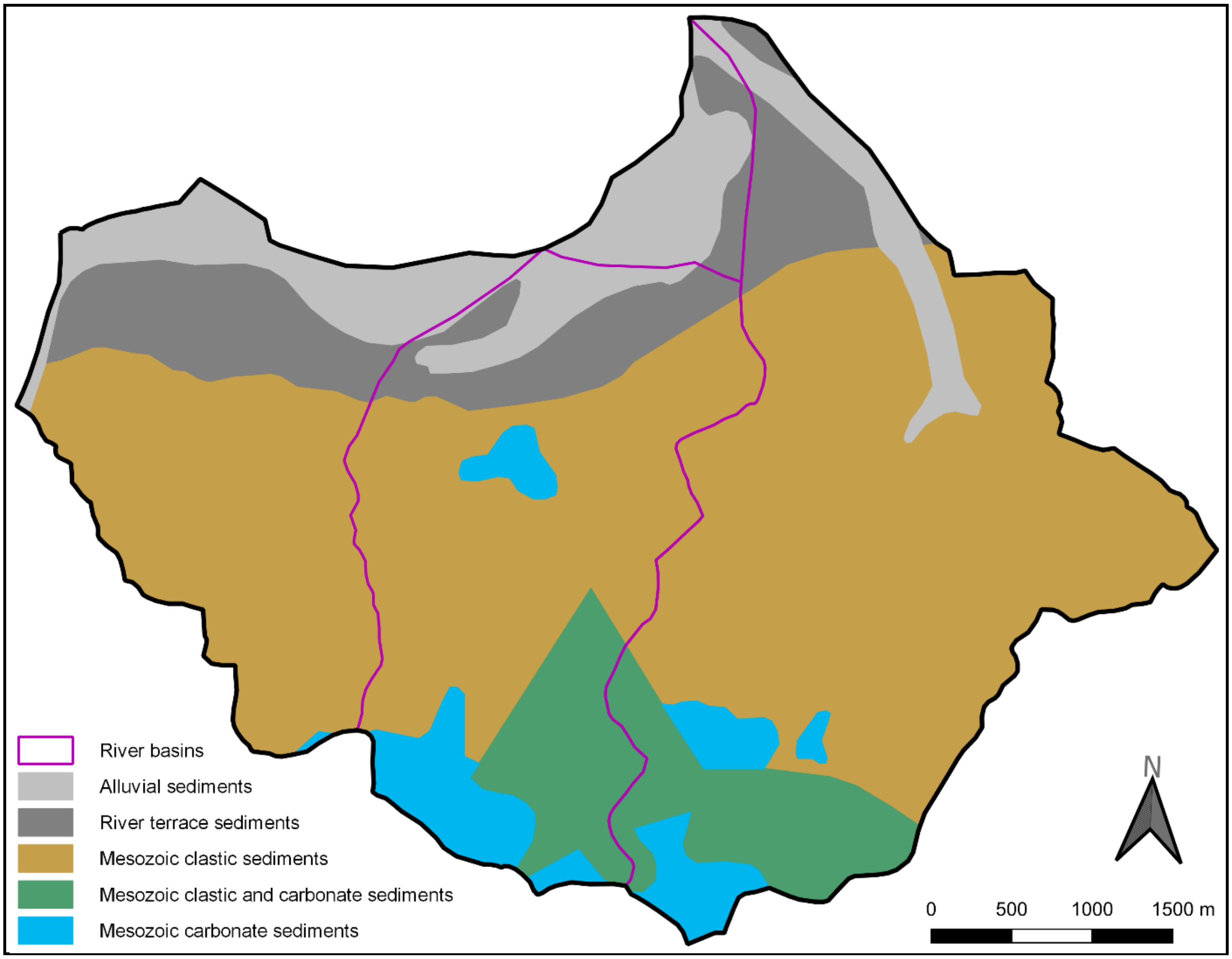
2.2. Analysis of natural conditions as determinants of torrential floods

In order to carry out an analysis of natural conditions and determine the susceptibility (predisposition of the terrain) to the genesis and occurrence of torrential floods, a complex examination of the direct and indirect factors that cause their genesis is necessary. The analysis of recorded torrential flood events in the research area showed a clear susceptibility to the occurrence of torrential floods, and as a next step it is necessary to analyze the influence of geotopographic (geological, geomorphological, and pedological), meteo-hydrological and other factors that determine their genesis and characteristics.

2.2.1 Geological characteristics

The Trbušnica River, Gučevski Potok and Simića Potok flow through different geological formations and this diversity is reflected in the geological structure and age of certain parts of the river basins. The geological base in which the basins of the mentioned watercourses were formed consists of Mesozoic and Cenozoic sedimentary rocks. The existing geological formations enable surface runoff and rapid drainage of rainwater. Water-permeable rocks must be present in the water collection zone, because if the geological formations are very cracked or in an advanced stage of decay, they are very permeable to water, so that after rainfall there is a significant infiltration of water, which reduces surface runoff.

Figure 2.3: Geological formations in the research area



Source: Authors, based on available data

Table 2.4: Geological formations in the research area

Geological formations	Total		Trbušnica river		Gučevski potok	
	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]
Alluvial sediments	2.82	12.06	0.60	5.91	0.42	6.32
River terrace sediments	2.92	12.46	0.65	6.41	0.87	12.93
Mesozoic clastic sediments	14.07	60.13	7.12	69.88	3.65	54.38
Mesozoic clastic and carbonate sediments	2.26	9.67	1.26	12.39	1.00	14.93
Mesozoic carbonate sediments	1.33	5.68	0.55	5.40	0.77	11.44
Total	23.41	100.00	10.18	100.00	6.71	100.00

Source: Authors, based on available data

2.2.2 Pedological characteristics

Alluvium covers an area of 1.01 km^2 (9.88 %) in the Trbušnica River Basin, and 1.39 km^2 (20.74 %) in the Gučevski potok basin. This soil type occurs in the valleys of these watercourses and is represented in three layers of different thickness (up to 100 cm).

Layer I (0-25 cm) is, according to its granulometric composition, loamy sand characterized by an undefined structure, water permeability and light brown color. The layer II (25 to 60 cm) is similar to layer I in its mechanical composition and has a dark brown color. The layer III extends from 60-100 cm, has a gray color and is loamy sand according to the granulometric composition. Below 100 cm is the groundwater.

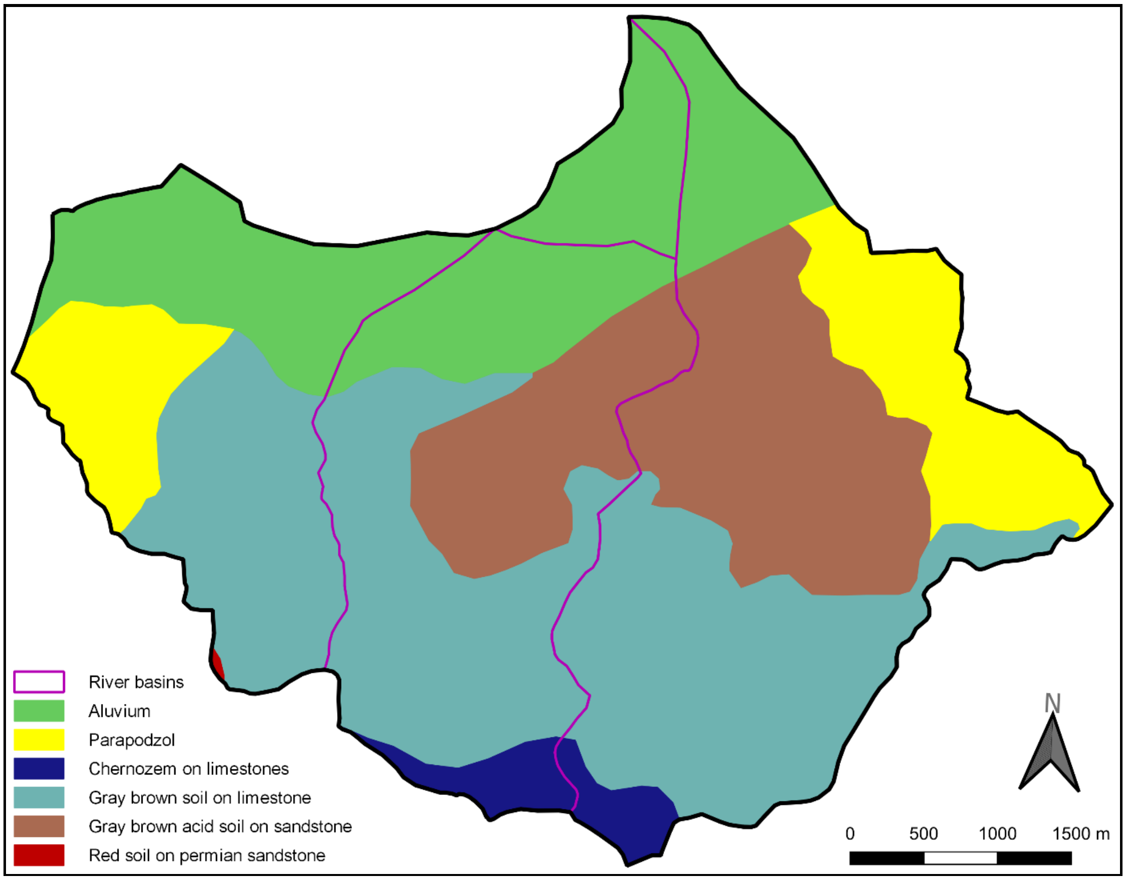
Parapodzol covers an area of 1.86 km^2 (18.3 %) in the Trbušnica River Basin. According to the morphological characteristics, the following horizons are distinguished: A_1, A_2, B and C. The A_1 horizon has a gray-brown color. The profiles under the forest contain more organic matter, which is why their color is darker, and in some cases an A_0 horizon (humus-accumulative horizon) appears. The thickness of the horizon ranges from 0 to 20 cm. Its composition is powdery clay. The A_2 or B_1 horizon has a light gray color, which often has a yellowish tint. Its thickness ranges from 21 to 46 cm. The transition horizon AB represents an impermeable part of the profile, where the upper groundwater is retained. It is characterized by an ash-gray color and a thickness of 47-68 cm. The B horizon is dark brown in color. Its composition is impermeable clay with a thickness of 68-108 cm. The C horizon has a rusty brown color and a thickness of 108-140 cm. This type of soil has very unfavorable water-air properties and is therefore susceptible to erosion processes.

Chernozem on limestones covers an area of 0.31 km^2 (3.04 %) in the basin of the Trbušnica River and 0.39 km^2 (5.74 %) in the basin of the Gučevski potok. The following horizons are represented: A, AC and C. The A horizon has a black color and a depth of 0-40 cm. The horizon AC has a dark and grayish color and a thickness of 40-70 cm. Horizon C has a yellowish color and is 70-100 cm thick. It has unfavorable physical properties.

Gray-brown acid soil on sandstones is widespread in the hilly-mountainous part of these basins and covers an area of 3.22 km^2 (31.65 %) in the Trbušnica River Basin and 1.83 km^2 (27.3 %) in the Gučevski potok basin. According to its morphological composition, it has the following horizons: A, AC and C. Horizon A extends in profile from 0-14 cm, has dark brown color, weakly pronounced granular structure, light mechanical composition and is well porous and water permeable. Horizon AC goes has a thickness of 14-27 cm and is brown in color. The sandstone is decomposed, weathered and suitable for plant root penetration. The transition to undecomposed sandstone is gradual. Horizon C is below 27 cm. There are sandstone blocks with some fine soil distributed between them. According to the mechanical composition, this type belongs to light and medium loam soils. Since the soil is shallow after the rains, it can absorb very little water, everything else flows into the hydrographic network on the surface, which favors the occurrence of flood waves.

Gray brownsoil on limestones is found in these river basins at higher elevations, above the previous soil type, and covers an area of 3.78 km^2 (37.13 %) in the Trbušnica River Basin and 3.1 km^2 (46.21 %) in the Gučevski potok basin. According to its morphological composition, it has the following horizons: A1, B and C. At the surface there is the humus-accumulative horizon A1, then follows the horizon B, which lies on the geological substrate C. Horizon A1 extends from 0-15 cm, has a brown color and its granulometric composition is clayey. It abruptly passes into horizon B, which is characterized with a thickness of 15-30 cm, gray brown color. According to the granulometric composition, it is clayey loam. Horizon C is the geological substrate for the limestone. This soil is also shallow, and after the rain it can absorb very little water, everything else flows into the hydrographic network on the surface, which favors the occurrence of flood waves.

Figure 2.4: Soil types in the research area



Source: Authors, based on available data

Table 2.5: Soil types in the research area

Soil types	Total		Trbušnica river		Gučevski potok	
	Area [km²]	Share of total area [%]	Area [km²]	Share of total area [%]	Area [km²]	Share of total area [%]
Aluvium	5.44	23.25	1.01	9.88	1.39	20.74
Parapodzol	3.03	12.92	1.86	18.30	0.00	0.00
Chernozem on limestones	0.70	2.97	0.31	3.04	0.39	5.74
Gray brown soil on limestone	9.17	39.16	3.78	37.13	3.10	46.21
Gray brown acid soil on sandstone	5.06	21.60	3.22	31.65	1.83	27.30
Red soil on permian sandstone	0.02	0.10	0.00	0.00	0.00	0.00
Total	23.41	100.00	10.18	100.00	6.71	100.00

Source: Authors, based on available data

2.2.3 Geomorphological characteristics

Apart from the analysis of the pluviometric and hydrological regimes as direct factors that cause the flooding of the terrain, it is necessary to analyze the indirect causes in more detail, and the most important are the geomorphological characteristics of the terrain. The initial relief represents the basic natural state, which makes it a significant factor and modifier of the intensity of other natural conditions and processes. The analysis of geomorphological characteristics (hypsometry, vertical dissection of the relief, and slope angle) represents the necessary basis for the analysis of the relief conditions as the dominant factor in the occurrence of torrential floods on the research area. In this way, their quantitative interpretation, performed through quantitative geomorphological maps, with the application of numerical indicators, provides a basis for assessing the impact of the relief on geomorphological processes and various human activities.

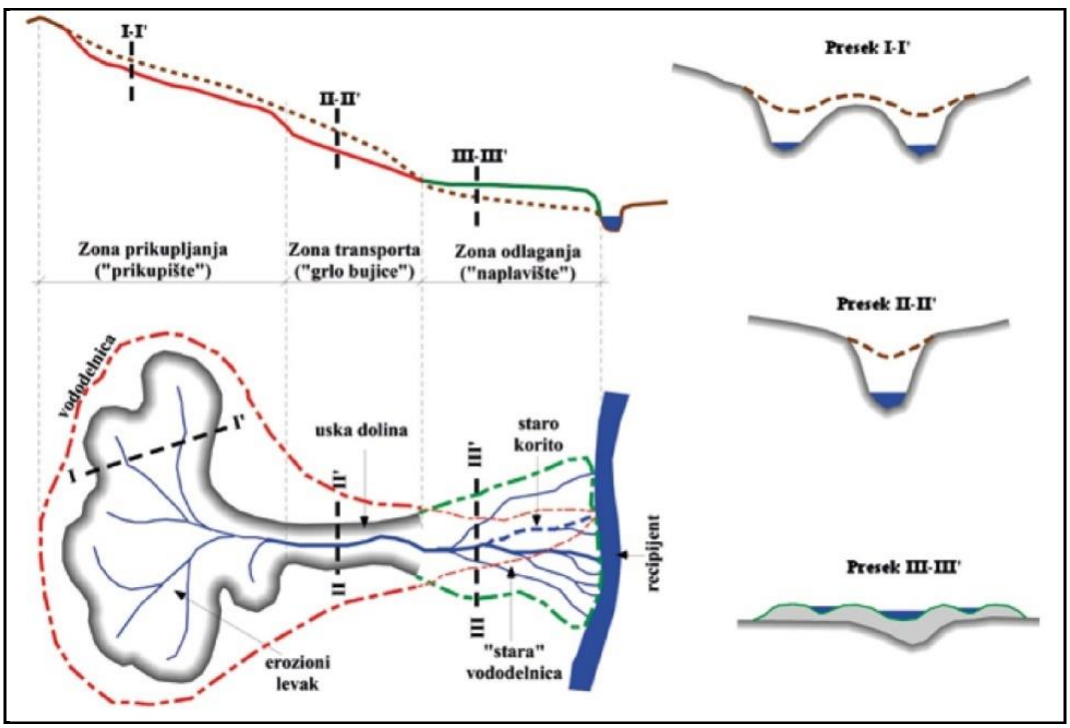
Previous geomorphological research has shown that the most important characteristics of the relief, which have the greatest influence on the genesis of torrential floods, are the relative height difference between the maximum and minimum elevation of the watershed (distance from the reference level Rn), then the mean slope of the watershed (Isr), and areas with a terrain slope greater than 15°.

The torrent basin consists essentially of 3 basic geomorphologic units in which torrent floods originate, develop, and occur:

- emergence zone (origin zone) of torrents or collection zone (headwaters),
- transit zone or zone of torrent movement, which is also called a gorge, and
- zone of deposition of torrent sediments (alluvial fans).

For the purposes of this study, a methodology was developed to clearly distinguish these zones as they include locations for the installation of sensors to monitor precipitation, water levels, and runoff.

Figure 2.5: Schematic representation of the torrent course with longitudinal and transverse profiles



Source: Stefanović et al., 2014

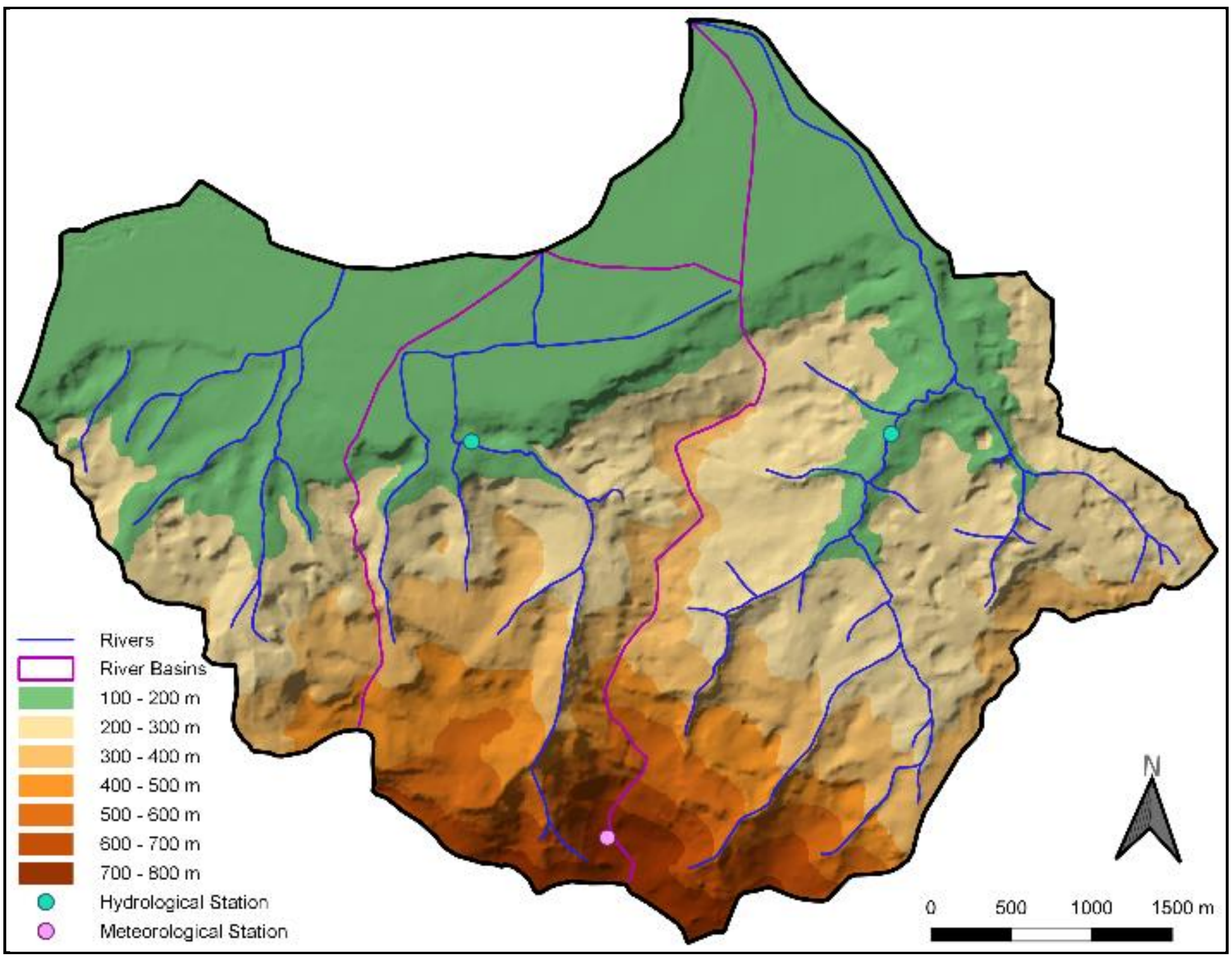
Hypsometry

The research of a torrential river basin usually begins with the analysis of topographic maps and digital elevation models (DEM), on the basis of which morphometric parameters and indices are defined. Their interpretation can explain the susceptibility of the river basin to torrential floods, because the morphometric characteristics of the basin have a strong influence on the relationship between precipitation and surface runoff in the river basin area. Therefore, the morphometric parameters quantitatively reflect the geomorphology of the river basin (watershed), which controls the hydrological response in the event of intensive rainfalls.

The hypsometric characteristics of the relief represent the basis for all further research and enable a more complete picture of the terrain we are analyzing. On the basis of them, we come to know whether it is a plain, hill-mountainous or mountainous relief, and depending on the altitude of the terrain, the possibilities of its planning and proper use also arise. The mean altitude of the terrain represents important data in calculating the intensity of erosive processes, water discharge, sediment discharge and retention, and enters into the structure of a large number of empirical formulas for calculating the intensity of erosion.

Determining the hypsometric characteristics of the relief is indispensable in the analysis of the influence of the orographic characteristics of the terrain on the circulation of air masses and the climatic conditions of some areas. Namely, the elevation of the relief (hypsometry) is one of the essential factors that determine the climate conditions of a certain area (via the amount of precipitation and air temperature). Therefore, this type of hypsometric analysis is first step of determining the location and installation of the precipitation monitoring station.

Figure 2.6: Hypsometry map of research area



Source: Authors, based on available data

Table 2.6: Hypsometry of research area

Altitude zone [m]	Total		Trbušnica river		Gučevski potok	
	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]
100-200	9.45	40.35	2.56	25.17	2.17	32.39
200-300	7.16	30.58	4.36	42.86	1.57	23.47
300-400	3.20	13.66	1.54	15.14	1.20	17.86
400-500	1.40	5.98	0.56	5.49	0.71	10.63
500-600	1.04	4.45	0.50	4.96	0.54	8.00
600-700	0.68	2.90	0.36	3.52	0.32	4.77
700-800	0.48	2.07	0.29	2.86	0.19	2.89
Total	23.41	100.00	10.18	100.00	6.70	100.00

Source: Authors, based on available data

The analysis of the hypsometric characteristics of the research area shows that 40.35 % (9.45 km^2) of its area is below 200 masl whereas 50.22 % (11.76 km^2) is located between 200 and 500 masl. Therefore, 90.58 % of the research area is situated up to 500 masl (21.20 km^2), and 9.42 % (2.21 km^2) between 500 and 800 masl. Based on these data, the average elevation of the research area has been calculated to be 264 masl. The hypsometric structure shows that the most common elevation in the study area is between 200 and 500 masl, i.e. hilly area.

When it comes to choosing the location of the rain gauge station for the torrential river basin, the rain gauge should be placed approximately in the central part of the high watershed area (headwater, head of the river), because it then gives a representative result of the largest amount of precipitation for that basin. In this specific case, the rain gauge station should be in the altitude zone of 700-800 m, at the watershed between the headwaters of the Trbušnica River and Gučevski Potok. The selected location is marked on the map with a red point as an ideal location proposal.

Unlike the station for measuring precipitation, the sensor for measuring the height of water in the riverbed should be placed in the lowest altitude zone, near the transition from the lowest to the next, higher altitude zone. So, in this case, it would ideally be installed at the transition from the height zone of 200-300 meters to the zone of 100-200 meters. The selected location is marked with a green point as an ideal location proposal.

Vertical dissection of relief

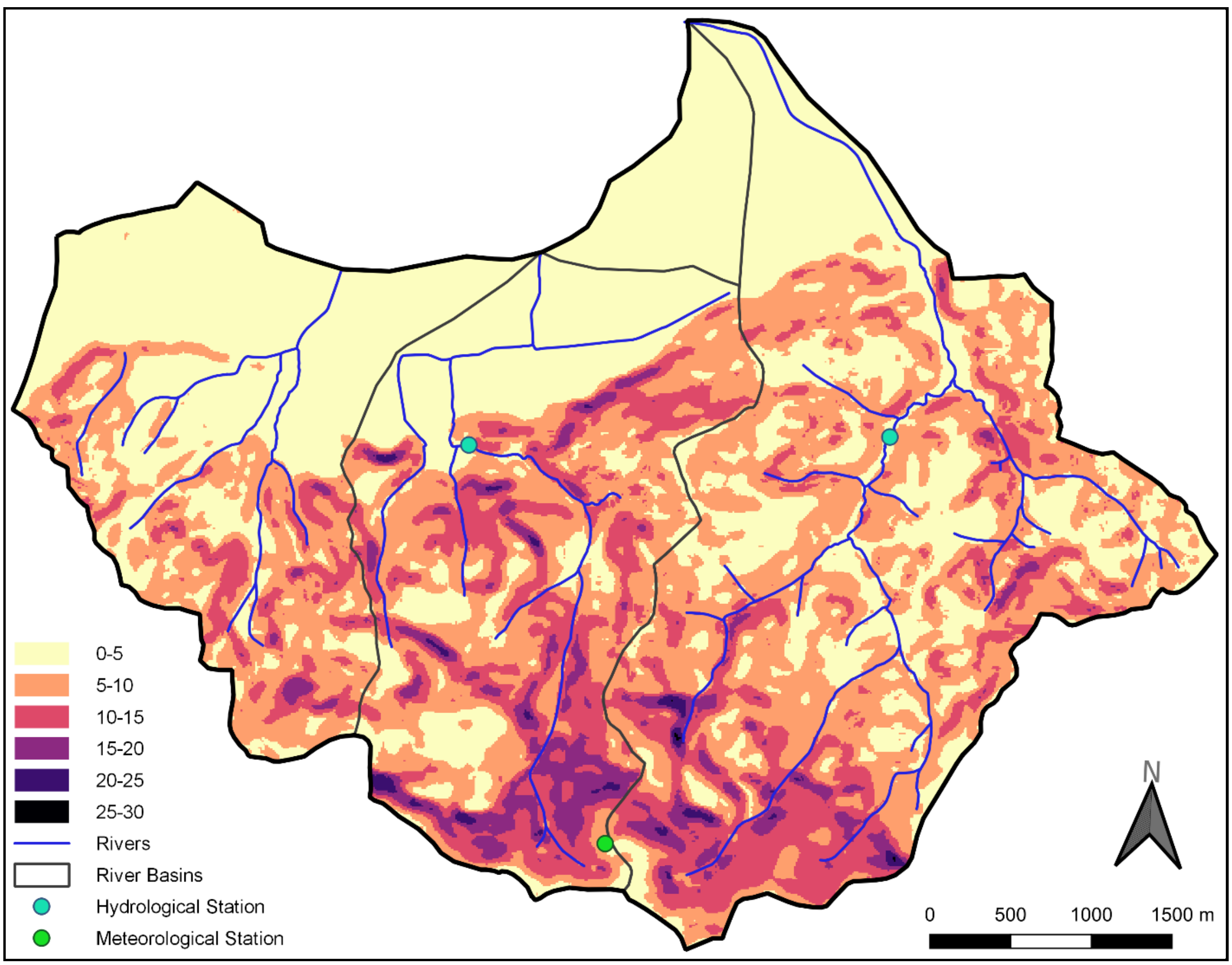
The term vertical relief dissection represents the potential energy of a certain terrain (part of the Earth's surface) defined by the height difference of the highest and lowest point within the observed unit area, grid area or river basin (Δh). Where the terrain is highly vertically dissected, there is often a high density of the river network and in that area the watercourses have a high sediment concentration in the water (sediment discharge). The interpretation of the obtained results is very simple, because surface area with positive values has a good susceptibility (predisposition) for the appearance of erosive processes, while negative values indicate areas of possible accumulation of previous eroded material. Areas of maximum and minimum vertical relief dissection are located by isolines. These are at the same time the most vulnerable and unstable parts of the terrain, i.e. the areas with the highest concentration of sediment.

Vertical dissection of relief, terrain slopes and excessiveness of water discharges clearly show the endangerment of the research area by torrential floods. Also, torrential floods in a basin occur as the consequence of intensive precipitations or sudden thawing of snow and they are characterized by a fast formation of torrential waves. The main property of these waves is that the water is highly concentrated with debris; they last a short period of time, and cause significant damage. Unlike medium and large streams where the duration of great waters is of prolonged intensity, which enables timely reaction and flood control, torrential floods are something quite different. Because of the great speed of formation and occurrence of a flood wave there is little time for a preventive action (regular flood control is practically disabled and the emergency flood control starts) and therefore monitoring is very important step in torrential flood control.

When choosing a location for setting up a precipitation monitoring station, it should be in a part of a small vertical dissection of the relief, but very close to the highest parts of the river basin, with a pronounced (very high) vertical dissection of the relief. In any case, the location should be near the highest parts of the watershed, where the highest amount of precipitation is expected. The selected location is marked on the map with a green point as an ideal location proposal.

When choosing a location for setting water level sensor, it should be in a part of a small vertical dissection of the relief, at the transition from high to low vertical dissection of the relief. In any case, the location should be near the sudden decrease in relief energy, that is, at the reference level (Rn). The selected location is marked on the map with a blue point as an ideal location proposal.

Figure 2.7: Map of the vertical dissection of the relief



Source: Authors, based on available data

Table 2.7: Vertical dissection of the relief of research area

Vertical dissection	Total		Trbušnica river		Gučevski potok	
	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]
0-5	10.31	44.06	3.66	36.00	2.25	33.53
5-10	8.29	35.44	4.41	43.28	2.29	34.15
10-15	3.79	16.19	1.74	17.13	1.57	23.40
15-20	0.92	3.94	0.32	3.17	0.55	8.23
20-25	0.09	0.37	0.04	0.40	0.05	0.68
25-30	0.002	0.01	0.002	0.02	0.00	0.00
Total	23.41	100.00	10.18	100.00	6.70	100.00

Source: Authors, based on available data

Slope of the terrain (slope angle)

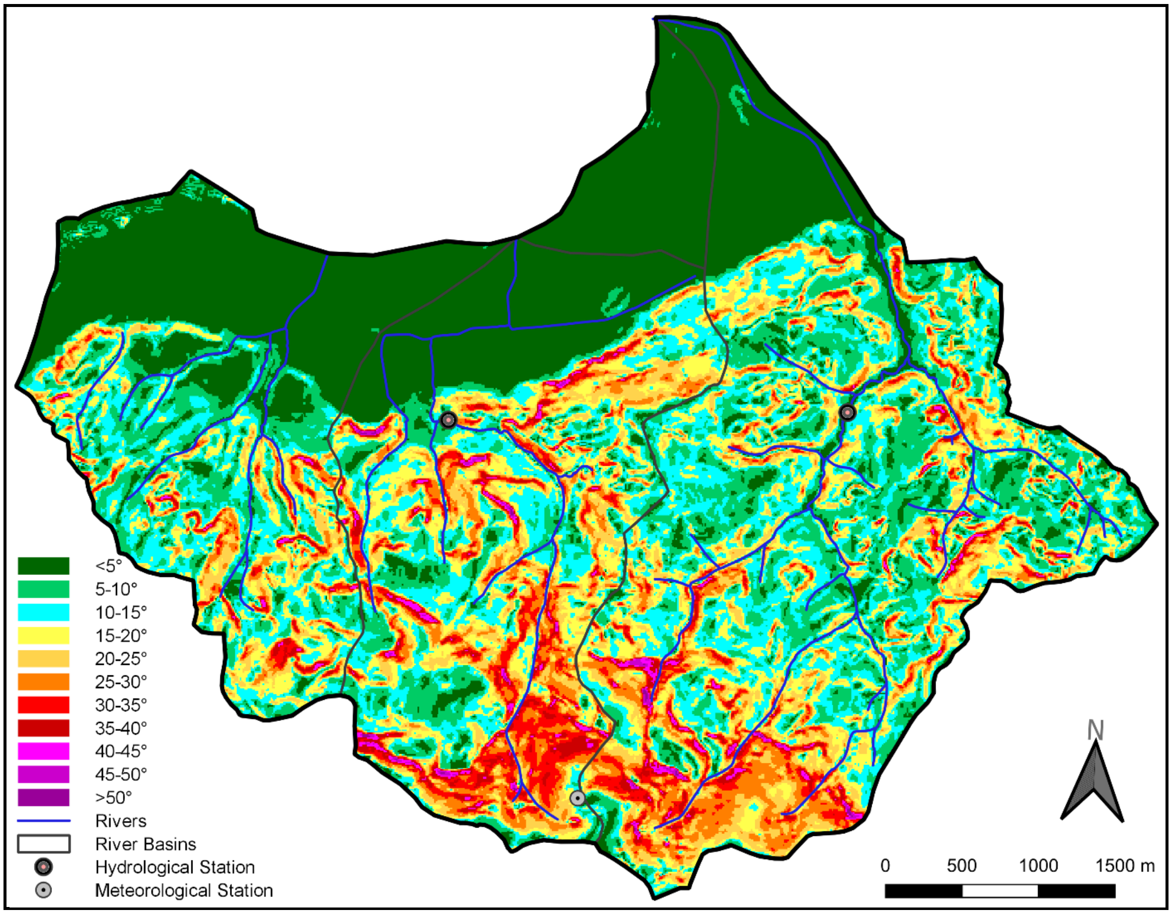
The slope of the terrain represents the vertical angle that overlaps the surface of the terrain with the horizontal plane, and is an excellent indicator of geomorphological processes (erosive or accumulative landforms). The erosive landforms and linear water erosion largely depend on the slope angle and previous research has shown that surface (sheet) erosion is dominant on slopes up to 5° (as well as around on high areas in the watersheds), and with the increase of slope angles, the density of linear erosion features and river network increases. This is conditioned by the fact that as the slope of the terrain increases, the kinetic energy of the water flowing down the slope also increases. The previous consideration is largely of theoretical importance, because in the field it can happen that in addition to the existence of a large slope angle, the intensity of erosion processes has no significant value. For example, if the terrain with a large slope is covered with very dense vegetation (forest), erosion intensity can be within the limits of tolerance, in contrast to the less slop angle, but non-protective parts of the topographical surface (without vegetation).

Table 2.8: Slope angle of the research area

Slope [°]	Total		Trbušnica river		Gučevski potok	
	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]
<5	6.48	27.68	1.56	15.32	1.54	23.01
5-10	3.96	16.92	2.16	21.19	0.81	12.02
10-15	4.32	18.46	2.28	22.41	1.12	16.65
15-20	3.09	13.20	1.56	15.35	0.98	14.57
20-25	2.27	9.69	1.14	11.24	0.79	11.85
25-30	1.72	7.34	0.84	8.29	0.68	10.21
30-35	0.97	4.13	0.39	3.82	0.48	7.13
35-40	0.41	1.76	0.16	1.55	0.21	3.15
40-45	0.15	0.63	0.06	0.63	0.07	1.06
45-50	0.04	0.16	0.02	0.17	0.02	0.30
>50	0.01	0.03	0.004	0.04	0.004	0.05
Total	23.41	100.00	10.18	100.00	6.70	100.00

Source: Authors, based on available data

Figure 2.8: Map of the slope angle



Source: Authors, based on available data

In the research area slope angles up to 5° cover 27.68 % of territory, while slope angles from 5° to 10° cover 16.92 % of the basin. Slope angles from 10° to 15° cover 18.46 % of the research area, and greater than 15° cover 39.94 %. The average slope angle is 12.8°.

When choosing a location for setting up a precipitation monitoring station, it should be in a part of a small slope angle, but very close to the highest parts of the river basin. In any case, the location should be near the highest parts of the watershed, where the highest amount of precipitation is expected and where water is collected for surface runoff (water collection area). Also, the location must be close to the high vertical dissection of the relief, but also where the high slope angles begin. The selected location is marked on the map with a grey point as an ideal location suggestion.

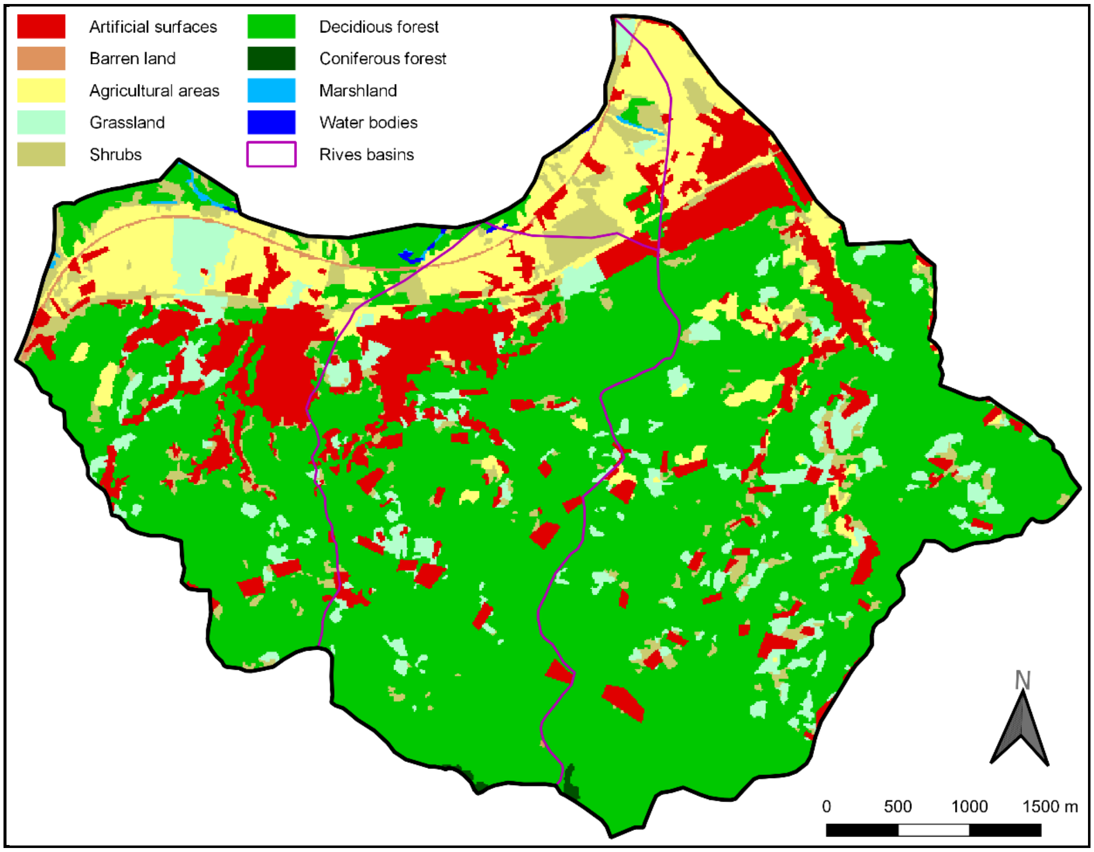
When choosing a location for setting water level sensor, it should be in a part with a small slope angle of relief, in places where the kinetic energy of the river flow decreases. The selected location is marked on the map with a dark grey point as an ideal location proposal.

2.2.4 Land use

The analysis of the land cover database shows that deciduous forests dominate and cover 63.58 % of the entire study area, more than 70 % in the Trbusnica and Gucevski potok river basins. Considering that a large part of the river basins is covered by deciduous forests, this represents a significant predisposition to the development of intense water erosion processes in certain periods of the year (outside the growing season).

Artificial surfaces cover 13.42 % of the total study area (11 % in the Trbusnica Riber Basin and 14.5 % in the Gucevski potok River Basin). Agricultural land occupies 10 % of the total study area (about 7 % in the Trbusnica River Basin and 5.8 % in the Gucevski potok River Basin), which is a significant area from the point of view of erosion protection.

Figure 2.9: Map of the land use in the research area



Source: Authors, based on available data

Table 2.9: Land use in the research area

Land use	Total		Trbušnica river		Gučevski	
	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]
Artificial surfaces	3.14	13.42	1.13	11.12	0.97	14.53
Barren land	0.10	0.42	0.00	0.03	0.02	0.24
Agricultural areas	2.39	10.22	0.69	6.80	0.39	5.82
Grassland	1.47	6.28	0.70	6.83	0.33	4.87
Shrubs	1.33	5.67	0.42	4.17	0.27	4.00
Deciduous forest	14.88	63.58	7.22	70.88	4.71	70.29
Coniferous forest	0.03	0.14	0.02	0.17	0.01	0.21
Marshland	0.04	0.15	0.00	0.00	0.00	0.00
Water bodies	0.03	0.12	0.00	0.00	0.002	0.03
Total	23.41	100.00	10.18	100.00	6.70	100.00

Source: Authors, based on available data

2.2.5 Flash flood potential index (FFPI)

In order to determine the degree of torrential flow of different watercourses in the Trbusnica River Basin and Gucevski potok river basin, the susceptibility of the basins to the occurrence of torrential floods was determinate. The method used to determine this phenomenon is the *Flash Flood Potential Index* (FFPI) which allowed identification of areas in the River Basin that are susceptible to torrential floods, i.e., that have a strong or very strong potential for the torrential floods.

So, susceptibility to the occurrence of torrential flood is obtained on the basis of Flash Flood Potential Index (FFPI). This method is based on the fact that there is an unbreakable bond between this disaster and certain physical-geographical characteristics of the territory on which it occurs. The soil structure and texture define the water retention and infiltration. Slope and basin geometry determine the speed and concentration of runoff. Vegetation and canopy structure equalize the entering of the atmospheric water in the surface. Land use has an important role in the infiltration of water, concentration and behavior of runoff. Together, these rather static qualities provide information on the possibility of a torrential flood in a certain area. The value of the proposed index is in the spatial representation of the areas with a flash flood risk, therefore, giving possibility to prevent the negative effects. Calculation of FFPI is performed according to the formula:

$$FFPI = \frac{a_1 \cdot M + a_2 \cdot S + a_3 \cdot L + a_4 \cdot V}{\sum_{n=1}^{4} a_n},$$

where: M – slope index; S – soil type index; L – land use index; V – vegetation density index; a_n – sum of weightings. Index values are within the range 1 to 10 (from least to most susceptible). In this case all weightings had value of 1, which means that the next formula is used:

$$FFPI = \frac{M + S + L + V}{4}.$$

The slope index is calculated according to the following formula:

$$M = 10^{n/30},$$

where: n – slope in %. If n is greater or equal to 30%, then M value is 10.

Considering the fact that there are no soil structure and texture data available for investigated river basin, to calculate soil type index, values from 1 to 10 were given to certain soil types, based on their characteristics which are significant for the development of torrential floods. Land use index is calculated on the basis of Map of the base Landcover (RGA), where values from 1 to 10 were given to certain types of land cover, depending on the characteristics important for torrential processes. Vegetation density index is obtained by analysis of multispectral images from the Sentinel-2 satellites, TOA-radiance corrected, and calculating BSI (Bare Soil Index). Due to the fact that the vegetation density index is ranging from 1 to 10, the correlation with BSI values is performed, and the resulting formula is:

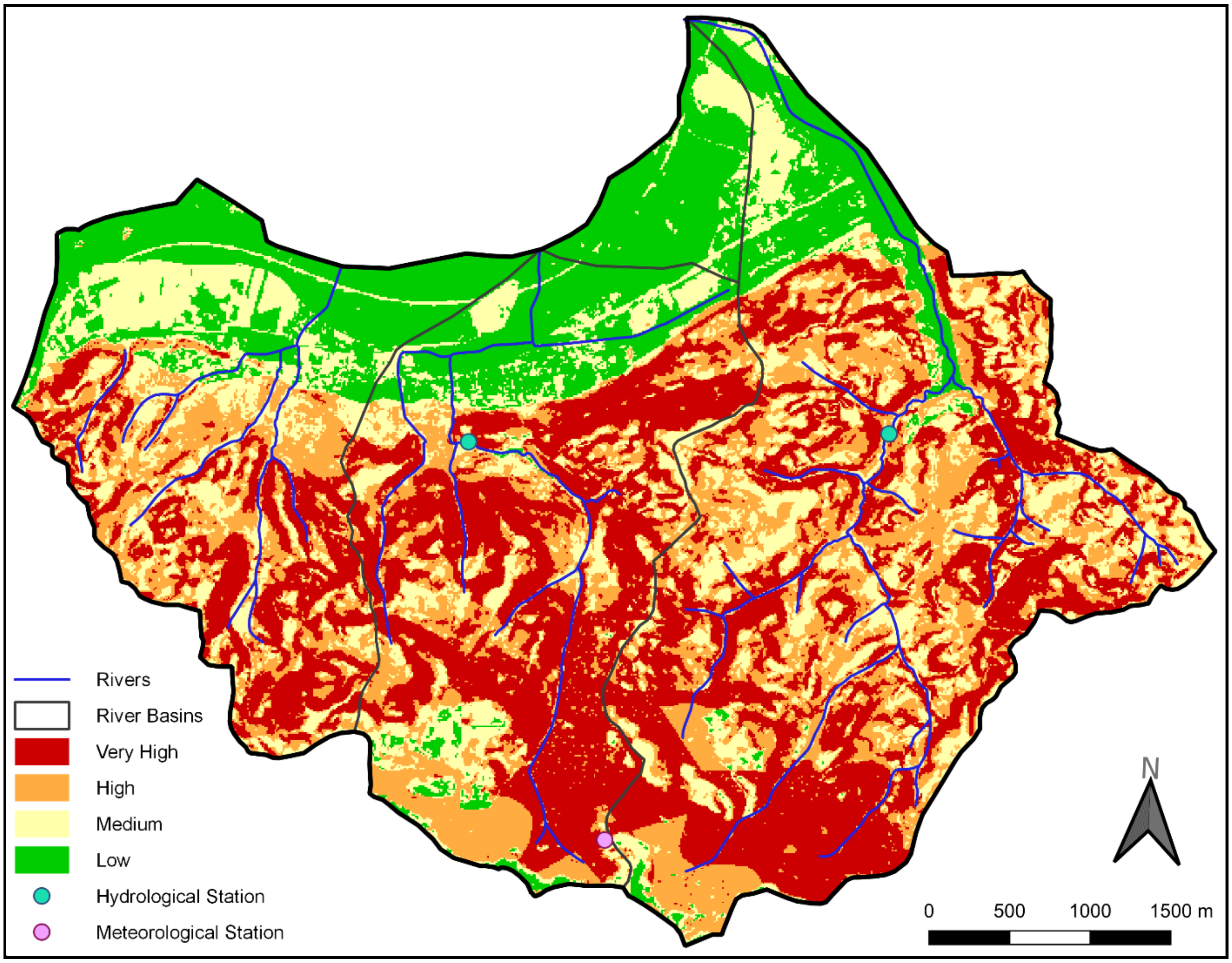
$$V = 7.68 \cdot ln(BSI + 1) + 8.$$

After FFPI calculation, the classification of results on the four classes of susceptibility to torrential floods was carried out (very high, high, medium and low susceptibility).

FFPI assessment in the research area

Analysis of the obtained FFPI values revealed that the class of very high susceptibility to torrential floods is registered on 33.71 %, and class of high susceptibility on 25.32 % of the total research area. This shows that 59.03 % of the research area is highly susceptible to torrents which indicate that this data should be seriously taken into consideration. The medium susceptibility class occupies 23.18 % while 17.79 % of the total river basin area belongs to low class. Therefore, less than 20 % of the research area is not significantly threatened by torrential floods.

Figure 2.10: Map of susceptibility to torrential floods in the research area



Source: Authors, based on available data

When choosing a location for setting up a precipitation monitoring station, it should be very close to the highest parts of the river basin, with low or medium FFPI class. The selected location is marked on the map with a pink dot as an ideal location suggestion.

Table 2.10: Susceptibility to torrential floods in the research area

FFPI	Total		Trbušnica river		Gučevski potok	
	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]
Very high	7.89	33.71	3.80	37.37	2.83	42.18
High	5.93	25.32	3.10	30.50	1.55	23.18
Medium	5.43	23.18	2.39	23.46	1.29	19.30
Low	4.16	17.79	0.88	8.67	1.03	15.35
Total	23.41	100.00	10.18	100.00	6.70	100.00

Source: Authors, based on available data

2.2.6 Soil erosion intensity

Torrential floods are closely related to the intensity and spatial distribution of erosion processes in the research area. It is of great importance to point out the recent state of soil erosion intensity, because it represents a significant factor of sediment production and transport through torrents, and also a condition for torrential floods occurrence and damage to the infrastructure.

Research of the erosion intensity and susceptibility of torrential floods include the following activities: study of natural characteristics of the river basin, analysis of vegetation cover and creation of land use map, analysis of the soil erosion intensity and creation of soil erosion map with Erosion Potential Model (EPM), susceptibility assessment of basins from torrential floods with Flash Flood Potential Index (FFPI).

The analytical equation for calculation of the annual volume of detached soil (gross erosion)due to water erosion is:

$$W_{year} = TH_{year}\pi\sqrt{Z^3}F\ ,$$

where W_{year} is average annual gross erosion (m^3/year), T is temperature coefficient in form: $T = (0.1t + 0.1)^{0.5}$, where t is the mean annual air temperature (°C), H_{year} is the average yearly precipitation (mm), F is the river basin area (km^2), and Z is the erosion coefficient.

The soil erosion coefficient (Z) can be estimated using corresponding tables or can be calculated from the following equation:

$$Z = YX\left(\phi + \sqrt{I}\right)\ ,$$

where: Y is the soil erodibility coefficient, X is soil protection coefficient, ϕ is erosion and stream network developed coefficient and ϕ is average slope steepness of the basins in degree.

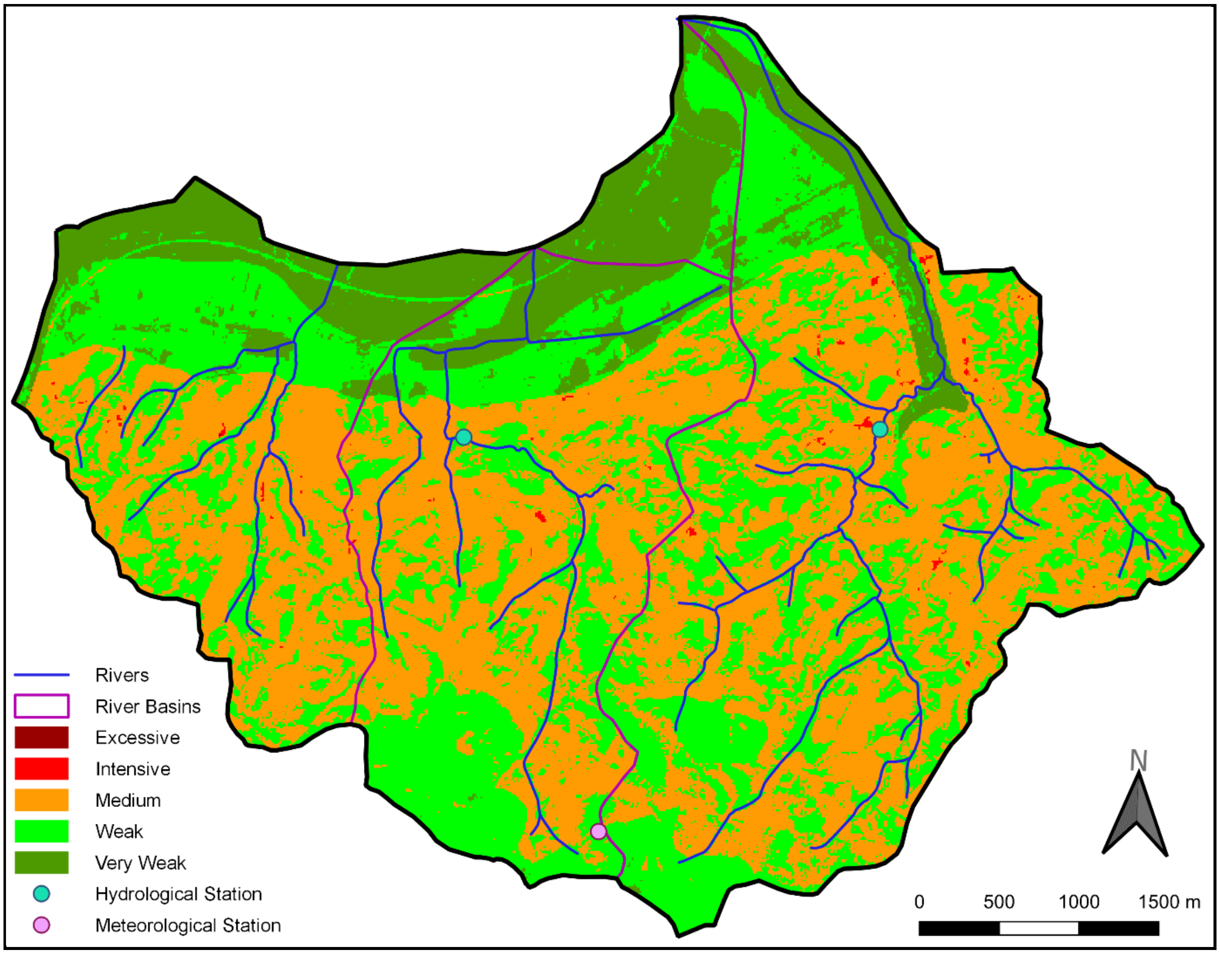
The quantitative values of the erosion coefficient (Z) have been used to separate erosion intensity to classes or categories. The calculation of the erosion coefficient (Z) enables observations of changes in the soil erosion intensity since the formula includes the parameters which have been changed by the performed erosion control work.

Soil erosion intensity assessment in the research area

As we know, torrential floods occur in the hilly-mountainous regions in Serbia, endangered by intensive soil erosion processes. The emphasized phenomenon of torrential floods in the Trbusnica River Basin and Gucevski potok are explained by intensive erosion processes, and by a pronounced imbalance of small, medium and large peak of high flood wave. Erosion processes, as the basic determinants of the occurrence of torrential floods, are hazardous phenomena and represent a factor endangering the safety of residents, road network, economic activities and environment.

The erosive processes in the Trbusnica River Basin belong to the medium erosion ($Z_{av} = 0.38$), which represents the third category of devastation. More than a half of the basin is in the category of very weak and weak erosion, but also the category of medium erosion is geospatial dominant (53.06%).

Figure 2.11: Soil erosion intensity map in the research area



Source: Authors, based on available data

Table 2.11: Soil erosion intensity in the research area

Erosion category	Total		Trbušnica river		Gučevski potok	
	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]	Area [km^2]	Share of total area [%]
Excessive	0.002	0.01	0.00	0.00	0.00	0.00
Intensive	0.57	2.41	0.03	0.27	0.01	0.11
Medium	14.89	63.60	5.40	53.06	3.35	49.98
Weak	5.06	21.61	4.11	40.34	2.71	40.49
Very veak	2.89	12.36	0.64	6.34	0.63	9.42
Total	23.41	100.00	10.18	100.00	6.70	100.00

Source: Authors, based on available data

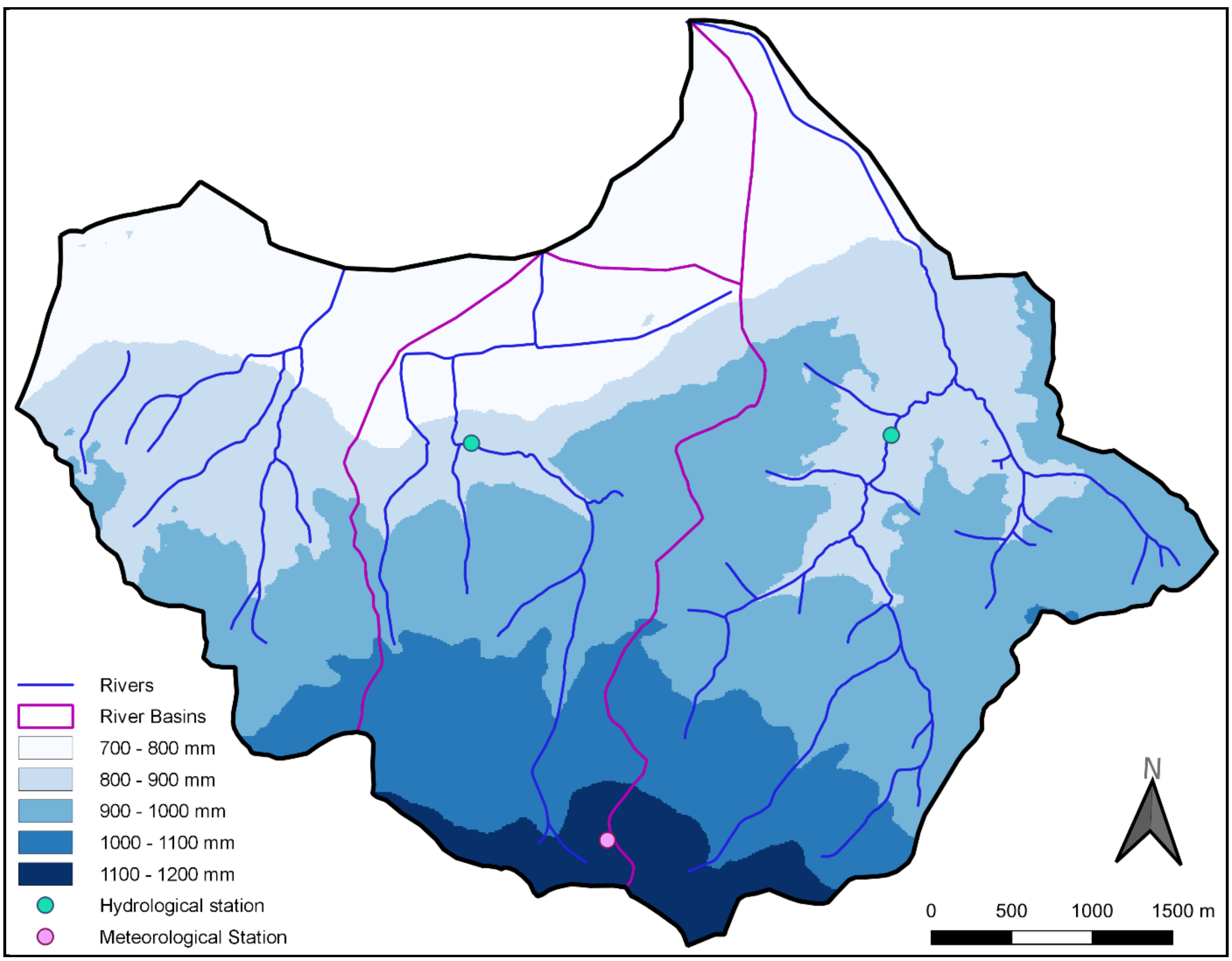
Medium erosion category is connected to the areas of the Trbusnica basin with the prominent vertical dissection of relief on significant terrain inclinations and also in the areas with the precipitation quantities above the average for the river basin. Such a distribution of medium erosion category provides conditions for generating, i.e. production of sediment which would increase torrential properties in the existing water streams.

2.2.7 Climatological characteristics (precipitation)

Climatological characteristics are one of the most important factors determining the intensity and nature of erosion and torrential processes. The influence of climatological variability on the occurrence of floods must be considered as the total state of all factors and not only the amount of precipitation during a year. The most important climatological parameters for the development of erosion processes and the occurrence of torrential floods are precipitation in the form of rainfall (daily maximum, monthly and annual average), air temperature (monthly and annual average) and relative humidity. For this analysis, meteorological data from the most representative meteorological station in the studied area, MS Loznica (44º 32' N, 19º 14' E, 121 m above sea level), were used. Due to the insufficiency of data for the defined time interval, data from other precipitation stations near the study area were not used.

Since rainfalls are the most important factor for the genesis and creation of water runoff, its evaluation was the central part of the analysis. In particular, the importance of the precipitation distribution during the year, i.e., the pluviometric regime, is emphasized. A time series of 60 years (1962-2021) was chosen as the reference period for the study of precipitation characteristics.

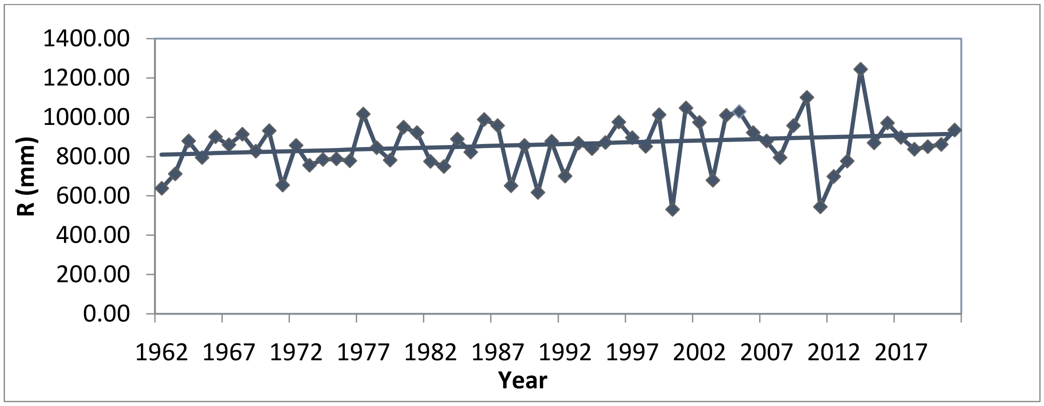
Figure 2.12: Precipitation map of the research area



Source: Authors, based on available data

In the given period, the average *annual precipitation* on MS Loznica was 853 mm. However, if we analyze the trend of changes in the value of annual precipitation during the reference period, it can be stated that the annual precipitation increased at a significance level of 0.1 ($Z = 1.85$). Of particular note are the seven years in which the annual precipitation exceeded 1,000 mm (five of them in the last 20 years). The highest annual precipitation was recorded in 2014 with 1,243 mm (32 % more than the average value for the entire period). It is also interesting to note the period 2004-2005, when the recorded precipitation value exceeded 1,000 mm for two consecutive years.

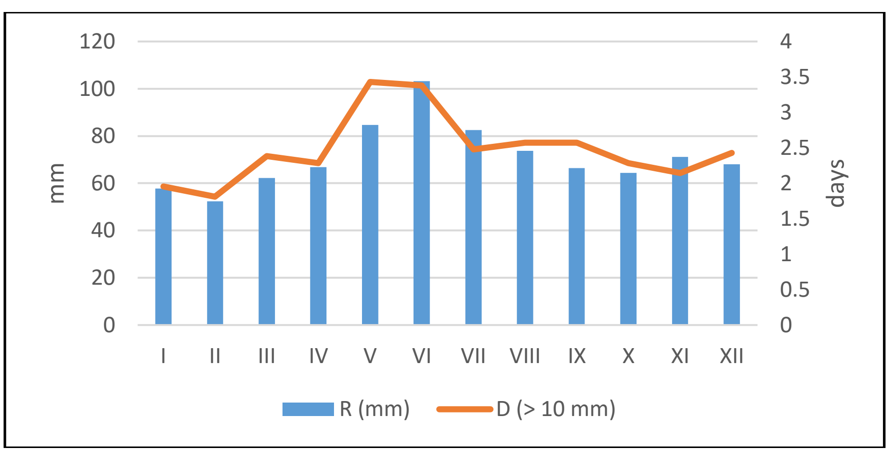
Figure 2.13: Trend of annual precipitation values in the period 1962–2021 (MS Loznica)



Source: Authors, based on available data

The analysis of *monthly precipitation* during the reference period showed that June was the rainiest month, with an average of 103 mm, followed by May (84.7 mm) and July (82 mm). Thus, 32 % of the total precipitation fell in three months, indicating an unfavorable pluviometric regime in the area. The lowest values were recorded in the winter months (January: 58 mm, February: 52 mm). Significant changes in the increase of monthly precipitation were recorded in three months (June, October and January) (Z between 1.68 and 1.86). The number of days with daily precipitation exceeding 10 mm is an important indicator for precipitation analysis. The results showed that on average there were 29.7 days with more than 10 mm of precipitation, especially in May (3.4 days) and June (3.3 days).

Figure 2.14: Ratio between monthly precipitation (R) and number of days with more than 10 mm of precipitation (D)



Source: Authors, based on available data

Analysis of the *maximum daily precipitation* values is critical for researching and monitoring the intensity and occurrence of torrential floods. According to this analysis, precipitation with shorter duration but higher intensity (1 mm/min) has the greatest impact on floods. In the defined 60-year period, maximum daily precipitation varied from 23 mm (1962) to 110 mm (2014). They occurred most frequently in the summer months (June-August), i.e., 57 % of the time (June: 14 years, July: 12 years, and August: 8 years). No maximum daily precipitation values were measured in March and April during the studied period. In Table 2.12, the maximum daily precipitation values exceeding 50 mm are highlighted at MS Loznica. The highest value was recorded on May 15, 2014, with 110 mm of precipitation in 24 hours, which corresponds to 13 % of the total precipitation in an average year (1962-2021). Considering that the amount of precipitation on the day before (May 14) and on the day after (May 16) was more than 50 mm, it can be concluded that in May 2014, on three days, a quarter of the annual precipitation of an average year fell. Such extreme precipitation influenced the devastating effects of torrential flooding in the study area. Also noteworthy were October 23, 2003, with a daily precipitation of 92 mm, and September 12, 1993, with 86 mm. The recorded values indicate a completely unfavorable pluviometric regime, as 2003 and 1993 were characterized as drier years in the 60-year study period.

Table 2.12: Maximum daily precipitation of more than 50 mm (1962-2021)

Date	R_{min} $[mm]$	Date	R_{max} $[mm]$
05-11-2021.	67.6	30-07-1999.	64.2
16-06-2020.	58.0	26-07-1997.	60.4
27-06-2016.	55.0	12-09-1993.	86.0
16-07-2016.	61.4	21-08-1989.	77.1
14-05-2014.	50.6	07-05-1987.	59.3
15-05-2014.	110.0	18-07-1986.	62.8
16-05-2014.	52.6	18-05-1986.	59.6
06-08-2014.	67.6	07-08-1986	51,4
25-05-2012.	55.8	28-08-1985.	63.6
01-06-2010.	56.6	07.10.1984.	51.5
13-10-2009.	64.2	18-09-1983.	59.6
05-09-2007.	51.0	13-07-1982.	80.1
23-10-2003.	92.3	22-07-1977.	56.7
20-05-2002.	70.2	15-07-1972.	58.9
21-06-2001.	62.7	01-06-1971.	50.3
01-07-1999.	53.0	20-12-1968.	52.4

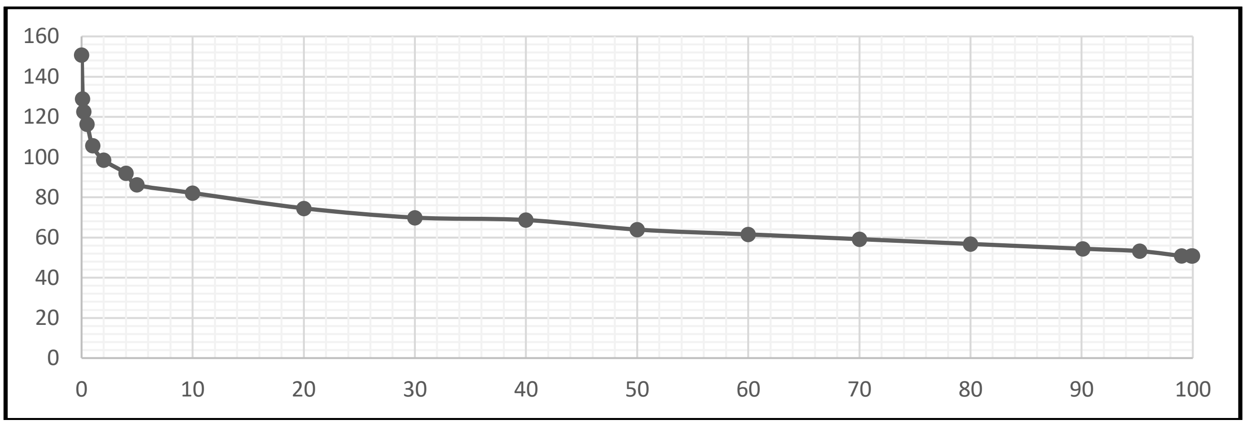
Source: Authors, based on available data

Based on the values of the maximum daily precipitation, an analysis of the *probability of occurrence of extreme precipitation* was performed. The choice of the previous method was based on the possibility of determining return periods for extreme meteorological conditions. The final goal is to predict the future dynamics of the occurrence of extreme values by creating a probability curve (Figure 2.15). The results show that the centennial precipitation (1%) is characterized by values greater than 106 mm and was recorded once during the reference period (1962-2021), on May 15, 2014. Also important are the extreme events with a return period of 20 years (5%), which were registered twice, on October 23, 2003 and on September 12, 1993, because the precipitation value exceeded 86 mm (the defined precipitation threshold).

In addition to the three events mentioned above, which caused torrential floods in the study area, such events were also recorded during less extreme meteorological conditions. For example, at the beginning of August 2014 (August 5-6), torrents were recorded at Gučevski and Simanski Potok, Trbušnica and Štira. Daily precipitation values amounted to 68 mm, with a return period of 2.5-3 years (40% probability). Prior to this event, floods of this magnitude were recorded in 2001 (June 22) and 1986 (July 17). Significant consequences can also result from precipitation with a return period of 2 to 2.5 years or a 50% probability (e.g., May 7, 1987). It should be noted that due to the peculiarities of the monitoring procedure at meteorological stations, there is often a "discrepancy" between the exact date of heavy rainfall and the date of registration of the flood. The floods are registered at the moment they occur, while the daily rainfall is recorded over a 24-hour period.

From a brief analysis of the precipitation, it can be concluded that the studied period is characterized by an unfavorable pluviometric regime and the occurrence of daily maximum precipitation exceeding 50 mm, which causes the formation of torrential floods and indirectly has significant consequences for the population and its activities. Therefore, it is essential to study the increasing trend of occurrence of extreme daily precipitation (recorded nine times in the last 10 years). This condition also necessitates more comprehensive precipitation monitoring to prevent extreme impacts.

Figure 2.15: Probability of precipitation of different intensity (1962-2021)



Source: Authors, based on available data

Table 2.13: Calculation of total (gross) precipitation for the research area

Total (gross) precipitation P_{br} $[mm]$
$P_{br0.2} = 122.6\ mm$
$P_{br1} = 105.6\ mm$
$P_{br2} = 98.4\ mm$
$P_{br5} = 86.2\ mm$
$P_{br10} = 82.1\ mm$

Source: Authors, based on available data

2.3. Identification of locations for sensor installment

In order to establish an early warning system for the occurrence of torrential floods, it is necessary to choose the most appropriate location for the installation of the sensors for monitoring the main parameters. In this case, *the meteorological station* is of particular interest, which will collect data on the amount and intensity of precipitation as primary data and air temperature as secondary data. For monitoring the water level and river discharge of torrential watercourses (Trbušnica and Gučevski potok) it is necessary to install sensors in the riverbed.

2.3.1 Selection of the location for establishment of the meteorological station

The proper selection of the site for establishment of the meteorological station (precipitation station) is extremely important for the proper functioning of the early warning system for torrents. When choosing the location, the following criteria should be taken into account:

- from the aspect of hypsometry, the station should be placed *in the central part of the high watershed area (headwater, head of the river)*, because then a representative sample (result) of the maximum precipitation for the catchment area is provided. In the specific case, the precipitation station should be located in the altitude zone of 700-800 m between the source of the Trbušnica River and the Gučevski potok;
- from the aspect of vertical relief dissection, the location of the station should be in *the area of low vertical dissection of the relief, but in the immediate vicinity of the highest parts of the river basin, i.e. at the transition from low to high vertical dissection of the relief*;
- from the aspect of the slope angle, the site for the monitoring station should be *located in a part characterized by small slope angle, but very close to the highest parts of the basin, where the largest amount of precipitation is expected and where the water is collected for surface runoff (precipitation collection area)*. In addition, the site must be located in a plain, in the zone above the high vertical dissection of the relief, but also at the beginning of the significant slopes of the terrain, which condition the rapid runoff;
- regardless of the type of precipitation station installed, it is necessary to place it on a stable base; the upper edge of the receiver must be exactly at a height of 1.0 m from the base, and the area of the circular receiver should be 200 cm^2;
- around the measuring station is required free space from buildings, vegetation, etc. If the site is located in the zone of forest vegetation, a free space with a radius of at least 15-20 m is required;
- the measuring station must be placed in a place that is not endangered by various damages (vandalism), livestock, domestic animals, etc;
- it is necessary to ensure that the chosen location is easily accessible by car (transport of equipment, data collection, replacement of sensors and devices, etc.);
- the presence of a power source is important if the technical characteristics and the method of data transmission require it. This is an option because most monitoring stations have self-powered panels, which is the preferred option;
- the presence of a transmitter for the transmission of messages, i.e. registered data in real time;
- state ownership of the land where the station is to be installed is desirable, as private ownership may result in frequent relocation of the monitoring station.

2.3.2 Suitability assessment of meteorological station installment location

Factors that were taken into account for suitability assessment of meteorological station installment location are altitude of the terrain, the terrain slope, the land cover and the distance to roads. All factors were classified into 5 classes, with the assigned values from 1 to 5, where 5 indicates area most suitable and value 1 indicates the area least suitable for installment of meteorological station. Following table shows the distribution of values on different classes of used parameters.

Table 2.14: Parameters for suitability assessment of meteorological station installment location

Value	Altitude [m]	Land Cover	Slope [°]	Distance from roads [m]
5	$(H_{min} + 0.8 \times \Delta H) - H_{max}$	Grassland; Barren land	0 - 5	0 - 100
4	$(H_{min} + 0.6 \times \Delta H) - (H_{min} + 0.8 \times \Delta H)$	Agricultural areas; Artificial surfaces	5 - 10	100 - 200
3	$(H_{min} + 0.4 \times \Delta H) - (H_{min} + 0.6 \times \Delta H)$	Shrub; Orchards; Vineyards	10 - 15	200 - 300
2	$(H_{min} + 0.2 \times \Delta H) - (H_{min} + 0.4 \times \Delta H)$	Forest; Marshland	15 - 25	300 - 500
1	$H_{min} - (H_{min} + 0.2 \times \Delta H)$	Water bodies	> 25	> 500

Source: Authors, based on available data

Calculation of suitability is then performed according to the formula:

$$Suitability = \frac{a_1 \cdot A + a_2 \cdot S + a_3 \cdot L + a_4 \cdot Dr}{\sum_{n=1}^{4} a_n},$$

where: A – altitude index; S – slope index; L – land cover index; D_r – distance from roads; a_n – weight coefficients. Since altitude is most important factor for suitability assessment, in this weighted coefficient 2 was given to this factor, and all other factors had coefficient 1, which means that the next formula is used:

$$Suitability = \frac{2A + S + L + Dr}{5}.$$

After calculation, the classification of results on the three classes of suitability for meteorological station installment location was carried out according to following table.

Table 2.15: Classes of suitability for meteorological station installment location

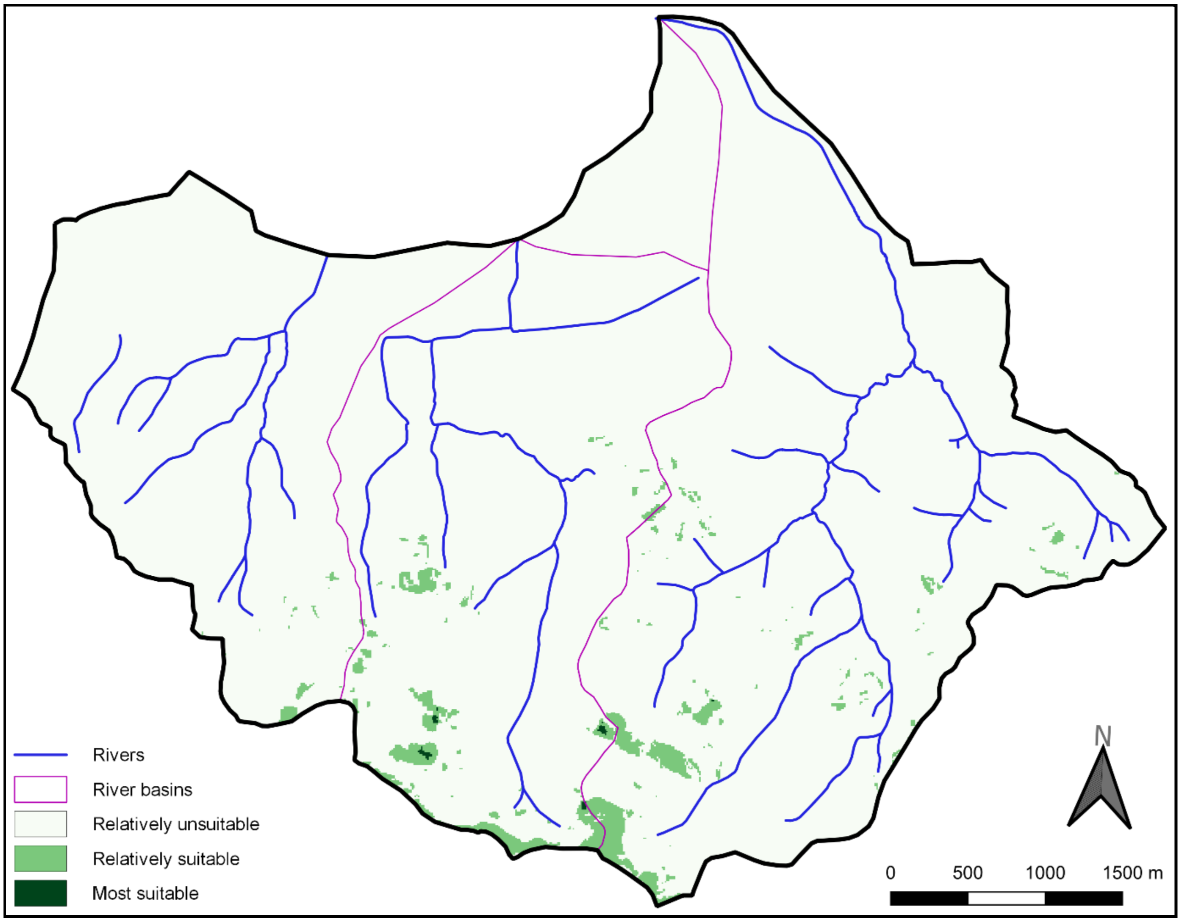
Suitability	Values
Relatively unsuitable	1 - 4
Relatively suitable	4 - 4.5
Most suitable	4.5 - 5

Source: Authors, based on available data

Meteorological station installment location suitability assessment in the research area

Areas that have been determined to be the most suitable are the ones where the meteorological station should be installed. Precedence should be given to the location at the highest altitude and closest to the watershed boundary. In this case that is location close to WWI monument at Gučevo Mt summit. Nevertheless, if on all the locations that were determined as most suitable, for some reason meteorological station could not be installed (inaccessibility, lack of electrical installations, private property etc.), areas that were marked as relatively suitable should be taken into account.

Figure 2.16: The locations that were determined as most suitable for meteorological station



Source: Authors, based on available data

Table 2.16: Suitability for meteorological station installment location in the research area

Suitability	Area [ha]	Share in total area [%]
Relatively unsuitable	2289.00	97.78
Relatively suitable	51.13	2.18
Most suitable	0.87	0.04

Source: Authors, based on available data

2.3.3 Collection of meteorological data

In the meteorological (precipitation) station, precipitation is recorded throughout the year using the installed sensors for recording precipitation and air temperature. The following meteorological data are collected:

- precipitation with an accuracy of 0.5 mm, and
- air temperature.

The measuring sensors of the station are wirelessly connected to a central processor, which processes and stores the data on the observed values. The automatic station reads the data every 15 minutes (or optionally 5 minutes if needed) and stores the observed values in the internal memory of the device and sends them to the operators at regular intervals (the interval is determined according to the final calculations). The reading interval can be set for the specific case of the Trbušnica and Gučevski potok rivers during precipitation, and the report is sent every 15 minutes.

From the point of view of monitoring the torrent basins and the erosion processes characteristic for them, the following parameters are analyzed:

- precipitation structure,
- intensity of precipitation, and
- torrential or excessive rainfall.

In the analysis of *precipitation structure*, all precipitation should be divided into four classes to better identify the frequency of precipitation levels:

- the class: 0.10-10.0 mm;
- the class: 10.1-20.0 mm;
- the class: 20.1-30.0 mm; and
- the class: more than 30 mm.

The percentage frequency of days with precipitation by class is determined and presented in a diagram to better illustrate the relationship.

It should be noted that the majority of class 1 precipitation (0.1-1 mm) does not cause runoff or soil erosion when forest vegetation is prevalent. Since these are small amounts, they can be neglected when determining the runoff coefficient. The only exception is heavy rainfall.

In Class 2, where rainfall is 10.1-20.0 mm, the data show that some of these rains may cause minor water runoff, while the amounts of erosive sediment are still small and negligible.

From the point of view of runoff and erosion intensity, class 3 precipitation (20.1-30.0 mm) mainly causes erosion processes on cropland and clover land. On the forest areas, even precipitation of this magnitude rarely causes soil erosion.

Precipitation greater than 30 mm most often leads to runoff and soil erosion, especially when it coincides with the snow cover melting.

Therefore, different warning levels can be programmed based on these classes, but they will be explained and defined in detail after calculating the effective amount of precipitation for each catchment.

However, everything depends on the rainfall intensity, because sometimes even the short precipitation with high intensity provides high runoff. In addition to rainfall intensity, an extremely important factor in the occurrence of lower or higher runoff is the previous precipitation index. Namely, if it rained every day during the previous week, even a lower rainfall will provide a higher runoff on the eighth day. Therefore, when analyzing the precipitation and runoff regime of an area, it is necessary to consider the previous precipitation index.

Measuring range, desired resolution, measuring procedure, reporting dynamics

For the selected river basins (Trbušnica and Gučevski potok), one station is sufficient to collect meteorological data (with a specific micro-site), that is:

- It will allow observation and reporting all year round (24 × 7), registration of precipitation in the form of rain or snow using a precipitation station with an accuracy of 0.5 mm. The sensor must be placed at a distance of 1 m from the surface (ground);
- The station (sensors) must support two working models (measurement methods): regular and periodic or emergency (urgent) reporting;
- Under regular conditions, the reporting period is every 60 minutes;

- Under emergency conditions, the reporting period is every 15 minutes. When it starts raining, the first notification (alarm) must be activated when 10 mm of rain falls within 15 minutes;
- Fixed values for certain alarm levels;
- Automatic sending of reports after detection of increased probability of flooding (this event is detected by the central system as well as rain classes 1-4);
- Throughout the year (24 × 7), the detection of air temperature is ensured with an accuracy of 0.1°. Required data on daily average, maximum and minimum values. Reporting once a day or with shorter period if the snow cover suddenly melts;
- Throughout the year (24 × 7), soil moisture must be recorded with 5% accuracy. Required data on daily averages, maximum and minimum values. Reporting once per day; and
- Additional meteo-climatological data will be downloaded from the existing GMS in Loznica.

Air temperatures are registered during 24 hours at an automatic station with an accuracy of 0.1°C. Data on average daily, maximum and minimum temperatures are collected. Average monthly and annual values are processed.

The meteorological station should therefore contain the following sensors:

- Sensor for the amount of precipitation,
- Sensor for air temperature, and
- Sensor for measuring soil moisture (option: fork sensor, which measures temperature and soil moisture at one depth).

2.3.4 Selection of a location for the establishment of a gauging station

The proper selection of a site for the installation of the gauging station is extremely important for the proper functioning of the early warning system for torrential floods. The following criteria should be considered when selecting a major site:

1. in torrential basins, the streambed water level sensor should be located in *the centre of the transit zone or torrential flow movement*. This is a location between the zones of water and sediment accumulation and the zone of accumulation of torrential sediment;
2. from the aspect of hypsometry, unlike the precipitation station, the sensor for measuring the water level should be placed *in the immediate vicinity of the zone of lowest elevation and near the transition from the zone of lowest elevation to the zone of highest elevation*. Thus, in this case, for the chosen micro-location, it would ideally be placed at the transition from the 200-300 m elevation zone to the 100-200 m zone;
3. from the aspect of the vertical dissection of the relief, the location of the gauging station should be in *the sector of the low vertical relief dissection, at the transition from the high to the low vertical relief dissection*. Therefore, the site should be located near the steeply sloping relief energy*, i.e. near or at the reference level* (R_n); and
4. from the aspect of the slope angle, the location of the gauging station should be in *the sector with small slope angle, at the transition of the last two lowest slope classes*, i.e. where the kinetic energy of the river decreases.

The final selection of the location (profile in the riverbed) for the installation of the gauging station (sensor for water level measurement) will be determined by field work to select the best section of the riverbed suitable for carrying out the measurement. In order for the measurement of water level and discharge to be meaningful, the selected section of the riverbed must fulfil the following conditions:

1. that the flow direction has a minimum length of 5B (B - width of the water mirror for the maximum expected flow) and that the river course is without eddies. This ensures uniform flow in the riverbed with straight-line flows whose hydraulic and morphological characteristics are representative of the longest section of the river. The riverbed should have a uniform gradient with no cascades, and there should be no large boulders or other material in the bed;
2. the selected section must not have a single tributary or additional water volume;
3. the banks must be stable and free of vegetation (not overgrown); and
4. if the river course is regulated, the hydrometric profile (section) should be upstream from the cascades and rapids, far enough away not to disturb the steady flow.

On the selected section, the measurement profile should be in the middle. There, an automatic gauge station is installed, i.e. a sensor that registers the change of the water level in the riverbed at each point. The sensor is placed above the riverbed at a sufficient height (in the safety zone) so that it does not come into contact with the water or with the floating sediment carried by the water during the flood wave.

Except for sensors, a manually water gauge is placed on the selected measurement profile for measurement control. If the gauging station is located in a natural, unimproved bed, a marker (benchmark) should be placed on the selected section to monitor elevation changes on the hydrometric profile after the passage of flood waves. In addition to the aforementioned marker, a control marker should also be placed.

All profiles on the survey section (downstream, midstream and upstream) should be well anchored in the ground and their coordinates should be recorded. They should be fixed with stone or concrete markers and, if none are available, with well-buried stakes.

After creating the hydrometric section, it is necessary to survey the section to obtain a site plan at a scale of 1:500. It is necessary to record the transverse and longitudinal profiles of the selected section.

The river is determined on the basis of the water level in the bed (depth), the water level gradient and the cross-section using the Shezi equation for the mean profile water velocity and the continuity equation for the discharge.

2.3.5 Hydrological characteristics on the selected gauge station locations in the research area

River discharge calculation at the gauging station on Trbušnica River

For the hydrological station, the profile on the regulated section of the Trbušnica River in the Trbušnica settlement was chosen, which meets the adopted criteria. The profile is marked with two stakes in the river banks. The coordinates of the stakes on the right bank are (EPSG: 6316):

$$X - 7\ 357052$$
$$Y - 4\ 931357$$

The regulation is embedded in the ground, the bed is not lined. It has the shape of an irregular trapezoid. The banks are overgrown with grass, as well as the right slope. The left bank borders the local asphalt road leading from Loznica to Gučevo. In the settlement there are private houses and the post office, and it is understandable that there is a source of electricity nearby.

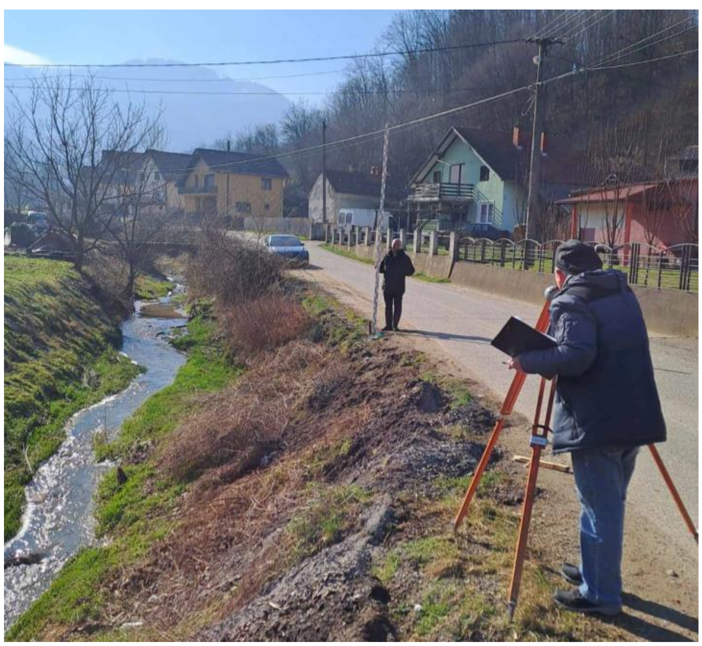
Since the regulation is in the ground, there is likely to be a change in the hydrometric profile after large flood waves. Therefore, a marker (benchmark) should be placed (buried) on this selected section to help monitor elevation changes in the hydrometric profile after the passage of flood waves. In addition to this marker, a control marker should also be placed.

It is very important that the selected section of the Trbušnica riverbed (minimum 40 m upstream and 20 m downstream from the measuring profile) is kept constantly clean, in order not to reduce the flow profile. Various types of municipal waste, branches, stones, etc. must not be allowed to remain in the riverbed. Also, the slopes of the banks must be cleaned from the emergence of vegetation. Only low grass is permitted.

Figure 2.17: Location of the gauging station installment in the bed of the Trbušnica River

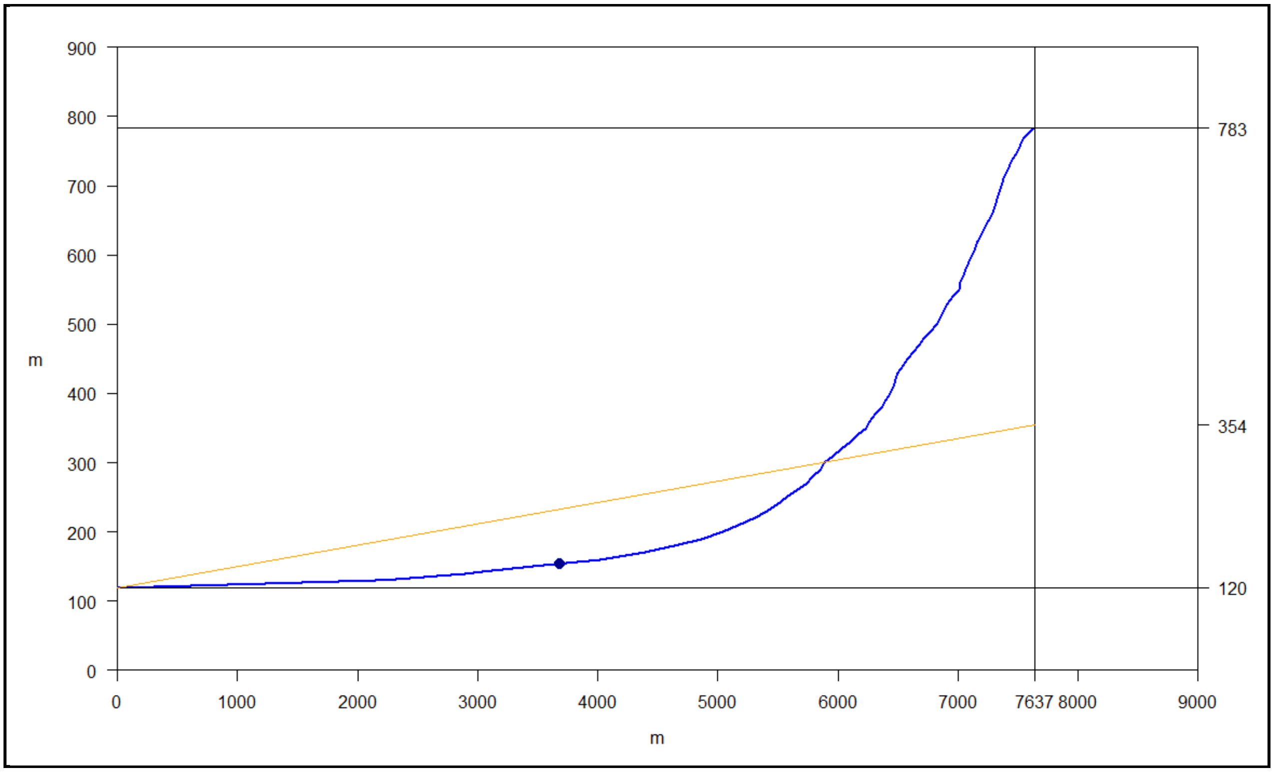
Source: Authors

Figure 2.18: Geodetic survey of the selected section for the installation of the gauging station in the Trbušnica riverbed



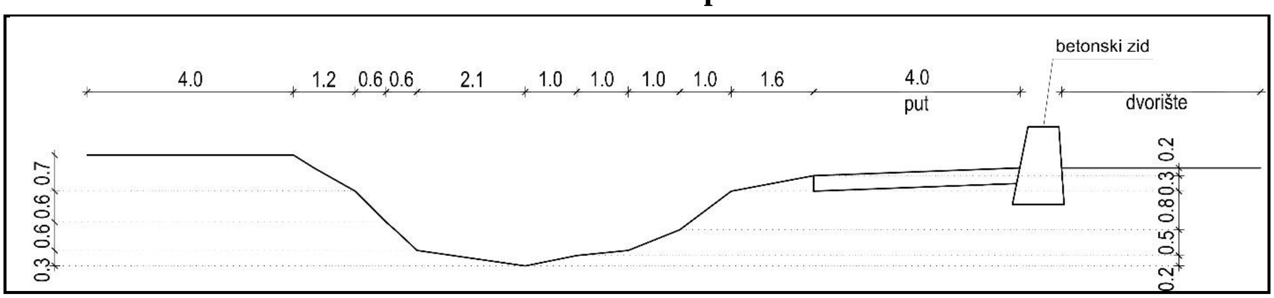
Source: Authors

Figure 2.19: The locations that were determined as most suitable for hydrological station in Trbusnica river profile



Source: Authors, based on available data

Figure 2.20: Cross section of the most suitable profile (point) for hydrological station in Trbusnica river profile



Source: Authors, based on available data

In order to determine the location for sensors in the riverbed, it is necessary to record the following parameters at the location of the future gauging station: cross section, which together with the water depth gives a cross section of the watercourse – A; wetted perimeter of the watercourse – X; water level gradient – I.

- Cross section of the water course $A[m]$,
- Wetted perimeter of the watercourse – $X[m^2]$,
- The hydraulic radius - $R[m]$:

$$R = A/X \ [m] \,,$$

- Water level gradient – $I[\%]$:

$$I = \frac{\Delta h}{l},$$

where: $\Delta h[m]$ is the height difference between upstream and downstream profile and $l[m]$ is a distance between profiles in $[m]$.

- Hydraulic roughness - n_{sr},
- Water velocity coefficient – C:

$$C = \frac{1}{n_{sr}} \cdot R_{sr}^{1/6},$$

- Average water velocity - $v_{sr}[ms^{-1}]$:

$$v_{sr} = K \cdot C \cdot \sqrt{RI},$$

where: K is the coefficient of torrential flow (according to the river basin erosion), $Q[m^3s^{-1}]$ is river discharge:

$$Q = v_{sr} \times A_{sr}[m^3s^{-1}].$$

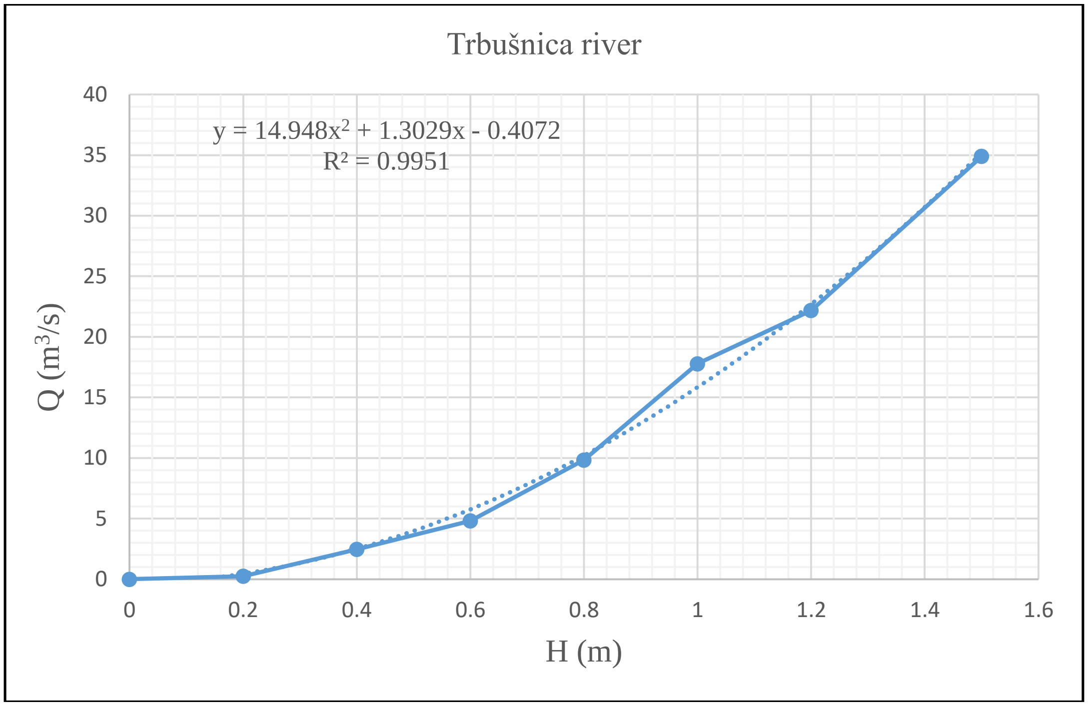
River discharge is determined based on the water level in the riverbed (depth), water level gradient, and the cross section using the Shezi equation for mean profile water velocity and the continuity equations for discharge.

Calculated river discharges for different depths, to form the consumption curve $Q = f(H)$:

Depth $[\boldsymbol{m}]$	**River discharge** $[\boldsymbol{m^3s^{-1}}]$
0.2	0.24
0.4	2.46
0.6	4.81
0.8	9.84
1.0	17.78
1.2	22.18
1.5	34.90

By calculating the discharge value for different water depths, a consumption curve of dependence $Q = f(H)$ is obtained. Later, the discharge for each water depth can be derived based on the depth registered by the sensor.

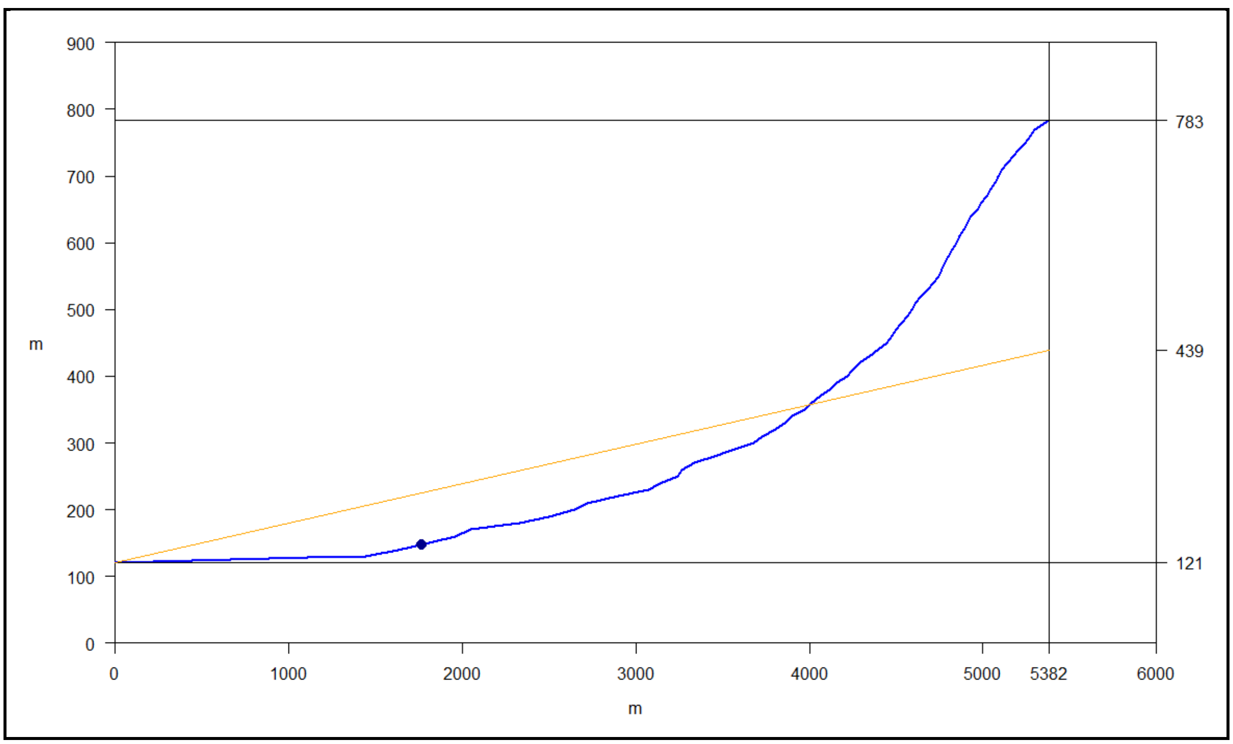
Figure 2.21: Consumption curve for the Trbušnica River



Source: Authors, based on available data

River discharge calculation at the gauging station on Gučevski potok

Figure 2.22: The locations that were determined as most suitable for hydrological station in Gučevski potok profile



Source: Authors, based on available data

Figure 2.23: Location of the gauging station installment in the bed of the Gučevski potok

Source: Authors

For the hydrometric profile, the spillway of check dam No. 1 in the Gučevski potok riverbed was chosen as the most favourable option according to the assumed criteria. The check dam was built in the late 1960s with the aim of stopping erosion of torrent bed and reducing the destructive force of flood waves that caused damage to the settlement and Banja Koviljača. In the lower course through the settlement itself, regulation was carried out, the aim of which is to direct the flood waves through the stream bed without causing flooding. Of course, other facilities were planned upstream of check dam No. 1, as well as earlier works in the catchment area, but they were not carried out.

Check dam No. 1 was constructed of stone masonry and retained large amounts of sediment, significantly reducing the riverbed fall, which in turn reduced the speed and destructiveness of flood waves that occur after heavy rains.

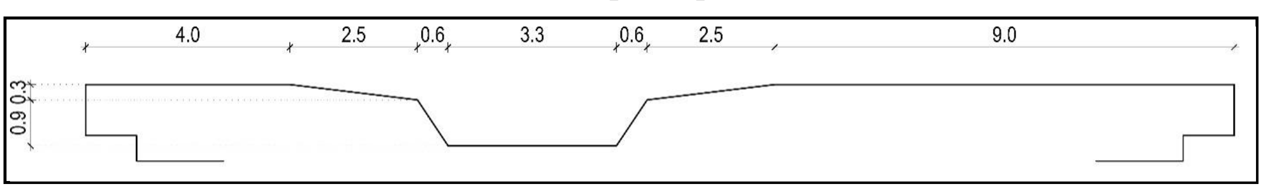
The spillway of check dam No. 1 is very suitable to be used as a measuring profile, but it is necessary to keep it absolutely clean, without deposits and other waste on it. Also, on the section about 40 m upstream of the spillway, the watercourse bed must be cleared of sediment (up to the level of the lower edge of the spillway), and upstream section should also be cleared of vegetation. In this way, it is ensured unhindered flow of water to the spillway, where the water level and thus the water discharge are registered.

The sensor for detecting the water level and determining the river discharge should be placed on the console at a height of at least 3.0 m above the top of the check dam. The console is concreted into the right bank on check dam wing.

The hydrometric profile is easily accessible by car, and on the right bank there is the yard of an inhabited house, so there is electricity nearby.

The river discharge is calculated according to the well-known and worldwide used empirical method of Weissbach.

Figure 2.24: Cross section of the most suitable profile (point) for hydrological station in Gucevski potok profile



Source: Authors, based on available data

The spillway is prismatic shape:

$$Q = \frac{2}{3} \cdot \mu \cdot b \cdot \sqrt{2 \cdot g} \cdot \left[(H + k)^{3/2} - k^{3/2}\right] [m^3/s] \,,$$

where: $Q[m^3 s^{-1}]$ is discharge through the spillway ($m^3 \cdot s^{-1}$), $b[m]$ is the average width of the spillway, g is the gravity acceleration $g = 9.80665\, ms^{-2}$, $H[m]$ is depth 3H upstream of the edge of the spillway, μ is the spillway coefficient $\mu = 0.6 - 0.7$; adopted $\mu = 0.65$, and k is velocity height:

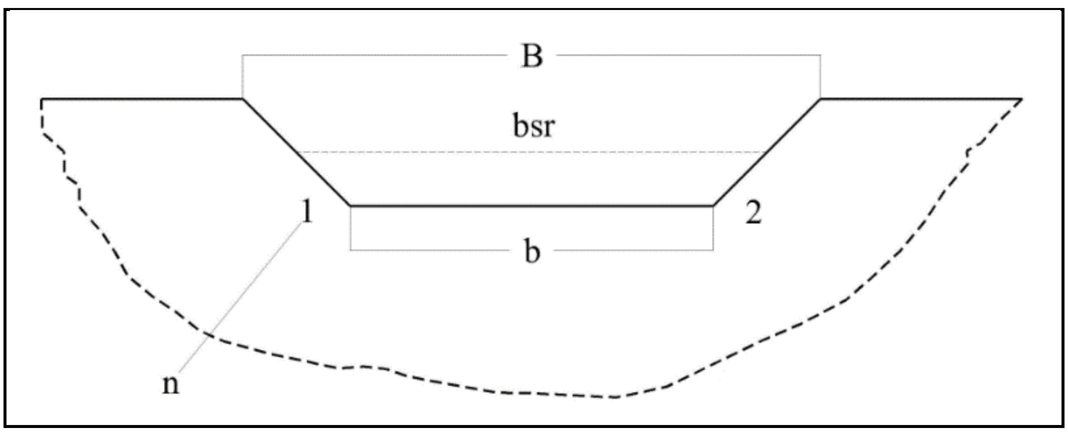
$$k = \frac{V_0^2}{2 \cdot g} \,,$$

where: $V_0[ms^{-1}]$ *is* arriving velocity:

$$V_0 = \frac{Q}{A} \,,$$

where: $A[m^2]$ is the cross section of the water course upstream of the check dam.

Figure 2.25: Cross section of the check dam



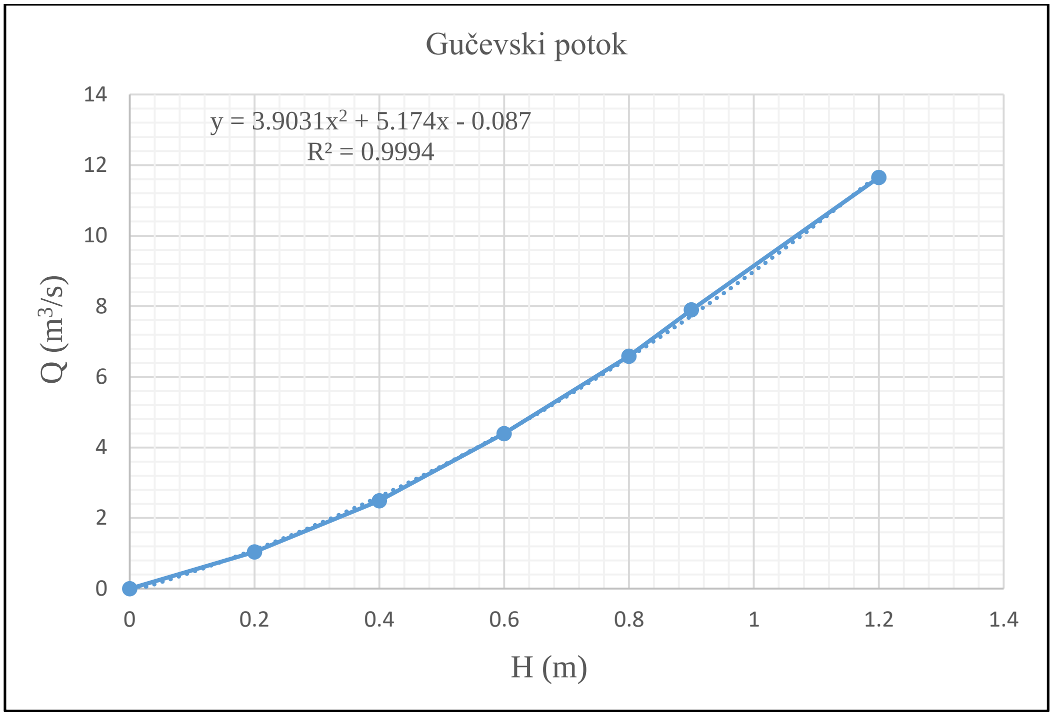
Source: Authors, based on available data

By calculating the discharge value for different water depths, a consumption curve of dependence $Q = f(H)$ is obtained. Later, the discharge for each water depth can be derived based on the depth registered by the sensor.

Calculated river discharges for different depths, to form the consumption curve $Q = f(H)$:

Depth $[m]$	**River discharge** $[m^3 s^{-1}]$
0.2	1.04
0.4	2.49
0.6	4.40
0.8	6.59
0.9	7.90
1.2	11.65

Figure 2.26: Consumption curve for the Gučevski potok



Source: Authors, based on available data

Necessary data for calculation the maximum discharge for the catchment areas of the rivers Trbušnica and Gučevski potok

The main task of high-water hydrological analysis is to determine the characteristics of high water for a part of the basin upstream from the profiles intended for the construction of the water measuring stations. For this hydrological analysis it is necessary to calculate the maximum discharge for a frequency of 1 %, 2 %, 5 % and 10 %, i.e. for return periods of 100, 50, 20 and 10 years.

It is important to emphasize that hydrological observations and measurements have not been previously performed on these watercourses, so the methods used for hydrologically unstudied watersheds were applied.

The parameters given in the Table 2.17 are necessary for this calculation, where:

- $\boldsymbol{A}[\boldsymbol{km^2}]$ is the Watershed area,
- $\boldsymbol{H_{sr}}[\boldsymbol{m}]$ is the Mean altitude,
- $\boldsymbol{H_{ur}}[\boldsymbol{m}]$ is the Attitude of central point of the watershed,
- $\boldsymbol{H_{max}}[\boldsymbol{m}]$ is the Peak point of the watershed (river basin),
- $\boldsymbol{H_{min}}[\boldsymbol{m}]$ is the confluence point of the watershed (river basin),
- $\boldsymbol{D}[\boldsymbol{m}]$ is the Mean altitude difference, $\boldsymbol{D = H_{sr} - H_{min}}$,
- $\boldsymbol{L}[\boldsymbol{km}]$ is the River length,
- $\boldsymbol{L_C}[\boldsymbol{km}]$ is the River length until the central point of the watershed,
- $\boldsymbol{I_{ur}}[\%]$ is the Mean slope of river bed, $\boldsymbol{I_{ur} = (H_{ur} - H_{min})/L}$, and
- $\boldsymbol{I_{sr}}[\%]$ is the Absolute slope of river bed.

Table 2.17: Parameters necessary for the calculation

River	A	H_{sr}	H_{ur}	H_{max}	H_{min}	D	L	L_C	I_{ur}	I_{sr}
Trbusnica	10.18	291	354	783	120	171	7.63	4.46	3.07	8.69
Gucevski potok	6.71	309	439	783	121	188	5.38	3.02	5.91	12.30

Source: Authors, based on available data

The maximum river discharge in the study area is calculated using a combined procedure that includes:

- SCS (Soil Conservation Service, 1972) procedure (method) to separate the effective precipitation P_e (which form direct runoff) and total precipitation (gross precipitation P_{br}); and
- The synthetic unit hydrograph theory to determine the peak ordinates of runoff q_{max}.

By using the combined method, the maximum river discharge of a certain probability of occurrence $Q_{\text{max}}(\%)[\text{m}^3\text{s}^{-1}]$.is obtained as:

$$Q_{max}(\%)[m^3 s^{-1}] = q_{max} \cdot P_e(\%) \, .$$

The calculation procedure from the beginning includes the following calculations:

$$t_p[h] = 0.751 \cdot \frac{(L \cdot L_C)^{0.336}}{\sqrt{I_u}} \, ,$$

where: t_p is the lag time, time from the middle of the hydrograph of effective precipitation to the moment of occurrence of the peak ordinate of the synthetic unit hydrograph (lag time of the basin).

The above relationship was determined on the basis of representative surveys for Serbia:

- $T_p[h]$ – the time to peak:

$$T_p[h] = \frac{T_k}{2} + t_p \, ,$$

- $T_k[h]$ - the duration of the relevant effective precipitation:

$$T_k[h] = 2(T_C)^{1/2} + t_p,$$

- $T_C[h]$ - the time of concentration:

$$T_C[h] = 0.0195 \cdot K^{0.77},$$

- $K[\text{h}]$ – the factor of water concentration:

$$K[h] = L/I_{sr}^{1/2},$$

- $T_r[h]$ – the time of recession:

$$T_r[h] = k \cdot T_p,$$

- k - the hydrograph shape coefficient:

$$k = T_p/T_k \, .$$

Relevant rain (precipitation)

The maximum daily precipitation with a certain probability of occurrence H (24 h, P) is obtained by processing the data from the nearest meteorological station or precipitation station (by extracting the maximum daily precipitation for the reference period and applying some theoretical probability distribution functions). In calculating the maximum discharge, it is assumed to have the same probability of occurrence as the precipitation that caused it. The maximum daily precipitation with a certain probability of occurrence H (24 h, P) was determined on the basis of processing data from the Loznica meteorological station.

The maximum discharges in smaller catchments ($A < 1{,}000$ km^2) are the result of precipitation that last less than 24 hours. Therefore, it is necessary to reduce the maximum daily precipitation of a given probability of occurrence H (24 h, P) to the relevant rainfall H (T, P), i.e. to the amount of precipitation that leads to the occurrence of the maximum discharge. This is achieved with the help of the model shown below:

$$H_{(T,P)}[mm] = \frac{a \cdot T}{1440} \cdot \left(\frac{1440 \cdot A + 1}{A \cdot T + 1}\right)^B \cdot H_{(24h,P)}[mm] \, ,$$

where: $H_{(T,P)}$ is the relevant time of precipitation duration (T_k), probability of occurrence (P), $a \approx 1.0$, $A = 0.3$, $B = 0.79$ (value of coefficient B, relevant for the research area) from diagram, $T_k[min]$ is the relevant time of precipitation, $H_{(24h,P)}[mm]$ is the maximum daily precipitation with certain probability of occurrence.

The intensity of the relevant precipitation is obtained based on the relation:

$$I_{(T,P)}[mm\ min^{-1}] = \frac{a}{1440} \cdot \left(\frac{1440 \cdot A + 1}{A \cdot T + 1}\right)^B \cdot H_{(24h,P)}[mm] \, ,$$

where: $I_{(T,P)}$ is the intensity of the relevant precipitation (T_k), probability of occurrence (P).

Runoff curve number

The runoff curve number CN allows the determination of the effective rainfall (runoff), i.e., the proportion of "losses" in relation to the total precipitation.

According to the SCS procedure, soils are classified into four hydrologic classes based on potential runoff conditions. The four hydrologic soil classes are referred to as A, B, C, and D, with Class A having the lowest runoff potential and Class D having the highest runoff potential. The criteria for classifying soils into hydrologic classes include the minimum amount of infiltration, the depth to the impermeable layer, groundwater level, etc. In practice, it is usually determined on the basis of the pedological composition of the soil.

Depending on the hydrological class of the soil (A, B, C, D), which is determined on the basis of the minimum amount of infiltration for one hour, land use and hydrological conditions (weak, medium, good) on certain land, the corresponding value of the runoff curve number CN is determined. The hydrological classes of certain soil types in the study area were determined based on the classification of soil types in Serbia according to the hydrological classes of the SCS method.

The unique value of the runoff curve number CN_{sr} valid for the whole basin is calculated according to the expression:

$$CN_{sr} = \frac{a_1 \cdot CN_1 + a_2 \cdot CN_2 + \cdots + a_n \cdot CN_n}{\sum_{i=1}^{n} a_i} \, .$$

The runoff curve number CN is first determined by defining all combinations of soil hydrologic class and land use throughout the watershed, and then weighting is used to determine the mean value for the watershed. CN values for the various conditions can be found in the literature.

The value of CN number determined in this way refers to the average past runoff conditions. In order to also take into account the less favourable conditions that usually prevail during extreme runoff events (when the infiltration-retention capacity of the basin is reduced to a minimum, e.g., due to water saturation of the soil), in practice the CN number is calculated for the so-called above-average runoff conditions.

The effective (rain) precipitation P_e

The SCS method for separating effective and total precipitation was developed in the 1950s in the Hydrology Department of the SCS (Soil Conservation Service, 1972) in the United States. The method focuses on converting total precipitation R_{br} (gross) to effective precipitation R_e (net), i.e., determining the portion of precipitation that constitutes direct runoff.

The effective rain P_e can be determined for any duration using the following equation:

$$P_e[mm] = \frac{(P_{br} - 0.2 \cdot d)^2}{P + 0.8 \cdot d},$$

where: $d[mm]$ is the soil moisture deficit:

$$d[mm] = 25.4 \cdot \left(\frac{1000}{CN} - 10\right),$$

where: CN is the runoff curve number.

Table 2.18: Calculation for research area

Total (gross) precipitation P_{br}	*The effective (net) precipitation P_e*, probability P = 0.2 to 10%

Source: Authors

The synthetic unit hydrograph

The unit hydrograph is defined as the hydrograph of direct runoff due to one unit of effective rainfall uniformly distributed over the catchment area and having a constant intensity during the effective duration. The synthetic unit hydrograph is created based on the calculated values:

- $t_p[h]$ – the lag time:

$$t_p[\mathrm{h}] = 0.751 \cdot \frac{(L \cdot L_C)^{0.336}}{\sqrt{I_u}}$$

- $T_k[h]$ - the effective precipitation duration:

$$T_k[h] = 2(T_C)^{1/2} + t_p,$$

- $T_p[h]$ – the time to peak the hydrograph rise duration:

$$T_p[h] = \frac{T_k}{2} + t_p\ ,$$

- $T_r[h]$ – the time of recession:

$$T_r[h] = k \cdot T_p,$$

- k - the shape hydrograph coefficient:

$$k = T_p / T_k \, .$$

The time base of the hydrograph T_b is calculated as the sum of the rise and fall durations of the hydrograph:

$$T_b = T_r + T_p \, .$$

Based on the defined time base of the synthetic unit hydrograph T_b, the peak (maximum) ordinate of the synthetic unit hydrograph q_{max} is calculated:

$$q_{max}[m^3/s/mm] = \frac{0.56 \cdot A \cdot 1.0}{T_b} \, .$$

Relevant high water $Q_{max}(\%)$

By using the combined procedure, the maximum discharge of a certain probability of occurrence $Q_{\max}(\%)$ is obtained as:

$$Q_{max}(\%) \; [m^3/s] = q_{max} \cdot P_e(\%) \, .$$

Through the calculation procedure, the maximum discharge was obtained for the return periods of T = 100, 50, 20, and 10 years (probability of occurrence P = 1 %, 2 %, 5 % and 10 %) was determined for above-average moisture conditions for the profile of future barrier sites.

Above-average moisture conditions occur when the soil is highly or completely saturated, meaning that infiltration and retention capacity is reduced to a minimum. Such conditions occur when the soil receives large amounts of precipitation in the period before extreme rainfall occurs or when snowmelt coincides with the occurrence of heavy precipitation.

2.3.6 Collection of hydrological data

Several watercourses form on the steep slopes of the Gučevo Mountains, which, due to their characteristics, are typical torrential watercourses that frequently flood the village of Trbušnica and the Banja Koviljača, as well as the Loznica-Bajina Bašta regional road and numerous infrastructure facilities.

As a preventive measure, in addition to the key role of erosion control works in this area and in the function of protection against torrential floods, constant monitoring of precipitation and river discharge in these torrential streams is extremely important. In this sense, it is proposed to install two automatic gauging stations on the most important torrential rivers, namely

- on the Trbušnica River, and
- in the Simića potok River Basin, on its main branch - Gučevski potok.

In the river basins of the Trbušnica and Gučevski potok, it is necessary to install an automated system for measuring and distributing data at regular intervals and in case of emergency (heavy rain or torrential rain). The automated system consists of a precipitation station in the river basin and gauges and ultrasonic sensors in the riverbed of two torrents. At regular intervals, all collected measurement data is sent every 15 minutes, which is used for regular analyses. All measured water level data are stored in the sensor's memory every minute.

Extraordinary sending of data is triggered by the occurrence of higher intensity precipitation and the occurrence of a higher water level in the riverbed, all in accordance with the predefined criteria.

Any torrential wave can be predicted and monitored within 1, 2, 3 and 6 hours. The set criteria give a certain level of alarm depending on how much precipitation has fallen in a certain area or how high the water level is in the bed of a certain torrent.

The advantage of the modern automatic gauges and associated software integrated into the system is that more agencies receive an alert regardless of where they are located and have a realistic basis for timely response and organisation of defense against torrential floods.

Measuring range, desired resolution, measuring procedure, reporting dynamics

For the selected Trbušnica and Gučevski potok river basins, one gauging station (with a defined micro-site) is sufficient to collect hydrological data, which is:

- It will allow observation and reporting during the whole year (24 × 7) to ensure the registration of the water level of the torrent with the help of the water level sensor node (with the associated manual water level measuring rod and the provision of lighting, with the installation of markers and control markers) with an accuracy of 1.0 cm. The sensor is placed above the water (the sensor must not be in contact with water);
- Sensor node (SN) for measuring the water level - the simplest solution is a battery supply via solar cells; the battery must be replaced every few years. It is desirable that the device SN also support a normal 220-volt power supply. For this type of device, the possibility of sending information about the battery status (e.g. falling below 50%, 25% and 10%) is important;
- A possible solution based on the use of simple MCU (micro-controller unit) platforms and sensor modules, up to commercially available solutions with an integrated WSN (wireless sensor node) and sensor module. There is a wide range of integrated solutions and dedicated sensor modules (up to 5 m);
- The measuring stations (sensor nodes) must support two working models and measurement methods: regular and periodic or emergency (urgent) reporting; and
- Under the regular conditions, the reporting period is every 15 minutes; and
- Under the emergency conditions, the reporting period is every 5 minutes;
- Fixed values for certain alarm levels, and
- Automatic sending of reports after detection of increased probability of flooding.

2.4 Hydrological analysis of maximum flows to the profile of proposed hydrological stations

The hydrological calculation was made for the purposes of assessing the hydrological - hydraulic condition of the large waters of the Trbušnica River and the Gučevski Potok in the area of the projected/anticipated hydrological station (sensor for the flood early warning system) in the valley of Banja Koviljača.

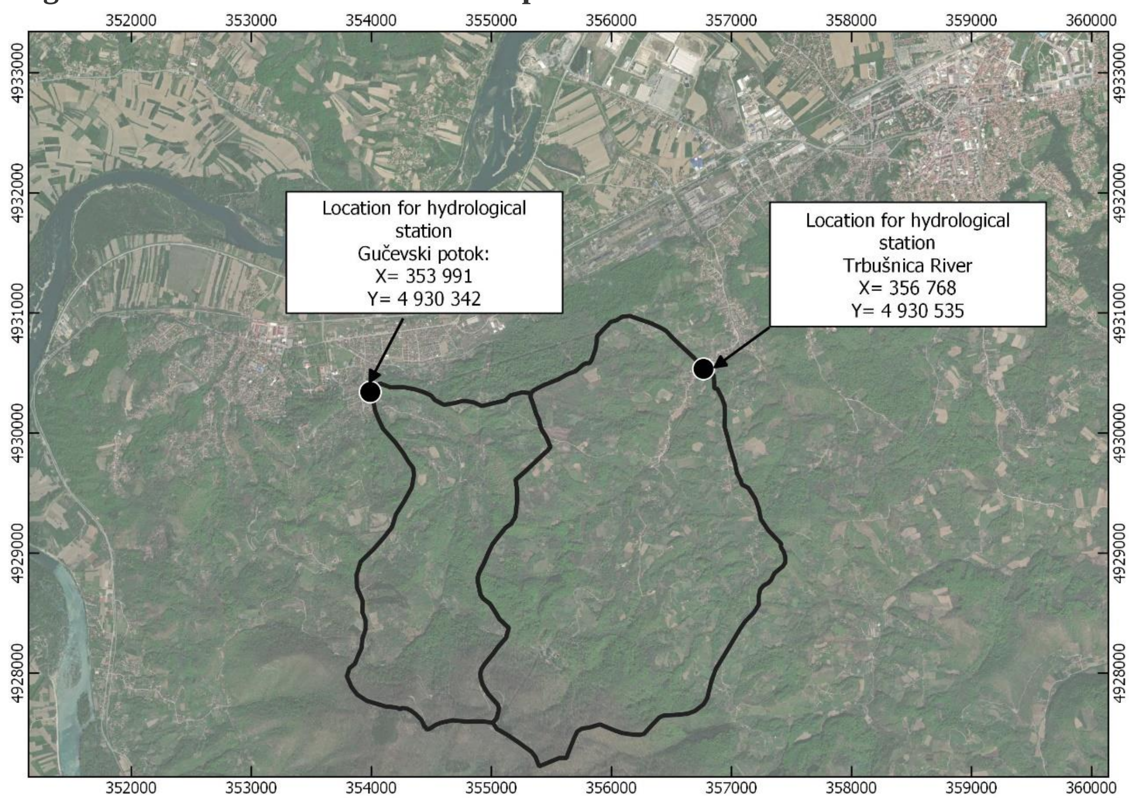
The task of hydrological analysis of large waters is to define the characteristics of large waters in selected profiles. For the purposes of this hydrological analysis, the maximum flows of large water were calculated for occurrence probabilities of 1%, 2%, 5% and 10%, that is, for return periods of 100, 50, 20 and 10 years.

It should be noted that no hydrological observations and measurements have been carried out on this watercourse so far, and methodologies that are used in practice for hydrologically unstudied watersheds have been used.

2.4.1. Hydrological Computational profiles

The hydrological analysis was carried out for the profiles on the Trbušnica River and Gučevski Potok in the settlement of Banja Koviljača, in the area of the designed/anticipated hydrological station (sensor for the needs of the flood early warning system). The position of the profile with coordinates and the associated catchment areas is shown in Figure 2.27.

Figure 2.27: Position of the observed profiles with the associated catchment areas



Source: Authors, based on available Satellite data (ESRI)

2.4.2. Morphological characteristics of the basins

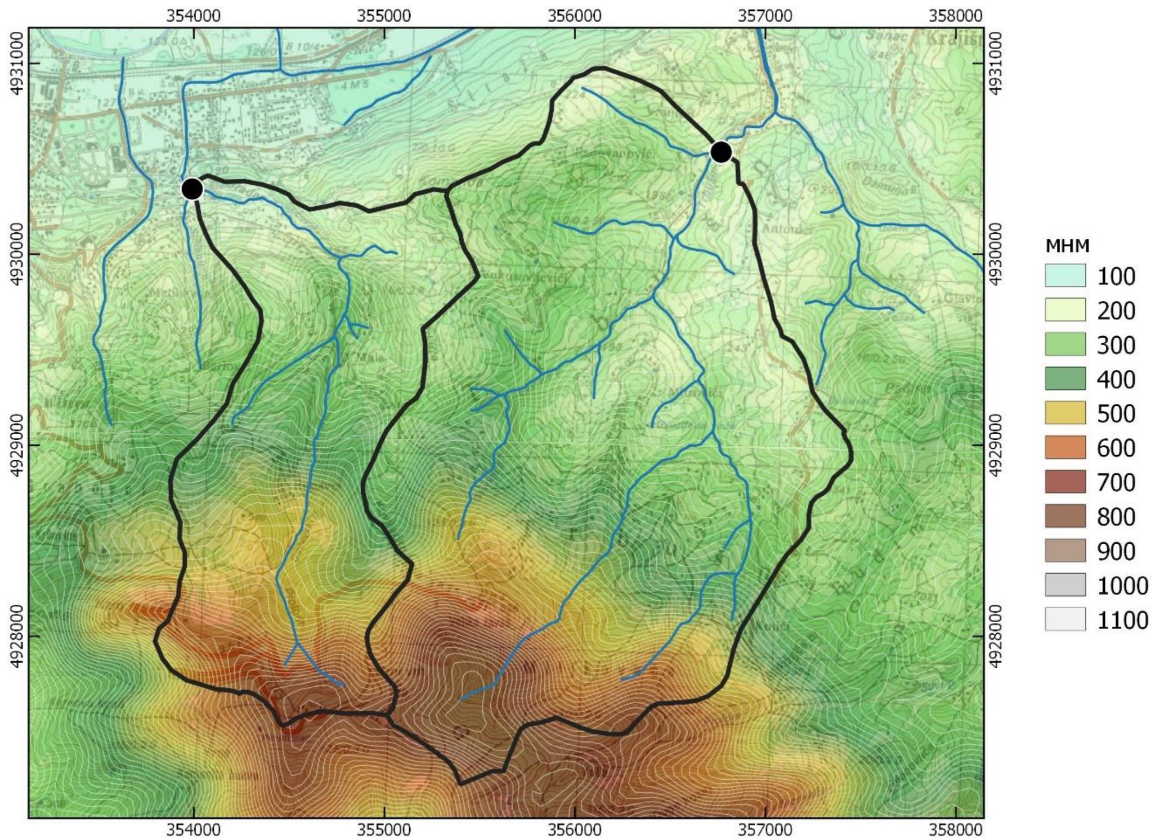
Table 2.19 shows the basic hydrographic characteristics of the catchment areas, which were determined on the basis of a topographic map of scale 1:25,000 and digital terrain model, while Figure 2.28 shows the situation of the catchments up to the profile.

Table 2.19: Morphological characteristics of the river basins

River	Profile	A km^2	L km	I_{ur} %	I_{sr} %	H_{min} mnm	H_{sr} mnm	H_{max} mnm
Trbušnica	hydrological station (sensor)	6.07	5.74	7.3	10.1	195	375	775
Gučevski potok	hydrological station (sensor)	2.90	5.16	9.9	10.8	135	392	696

where: A - area of the river basin, L - maximum length of the stream, Iur - balanced drop of the stream, Hsr, Hmax, Hmin - mean, maximum and minimum height of the river basin.

Figure 2.28: The view of the catchment area up to the profile



Source: Authors, based on available Topographic data (Military-geographic Institute)

The longitudinal profile of the longest stream of the observed Trbušnica river basin, with the plotted mean drop of the stream Isr and the leveled drop of the stream Iur, is shown in Figure 2.29. The longitudinal profile of the longest stream of the observed Gučevski Potok basin is shown in Figure 2.30.

Figure 2.29: Longitudinal profile of the longest stream – Trbušnica river

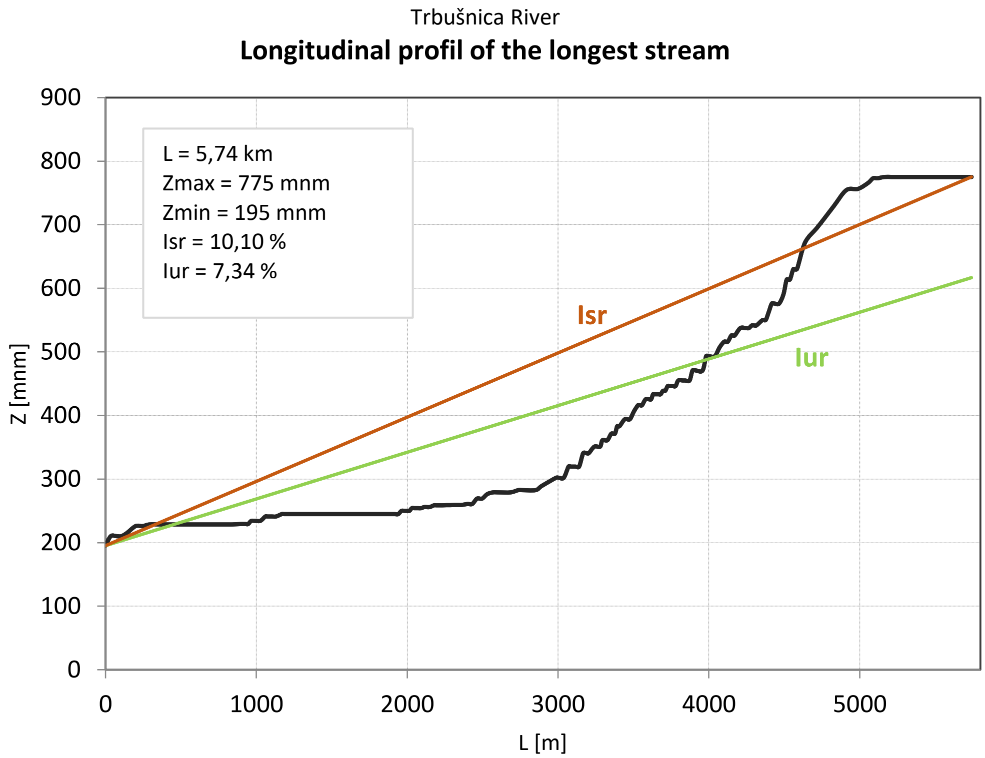
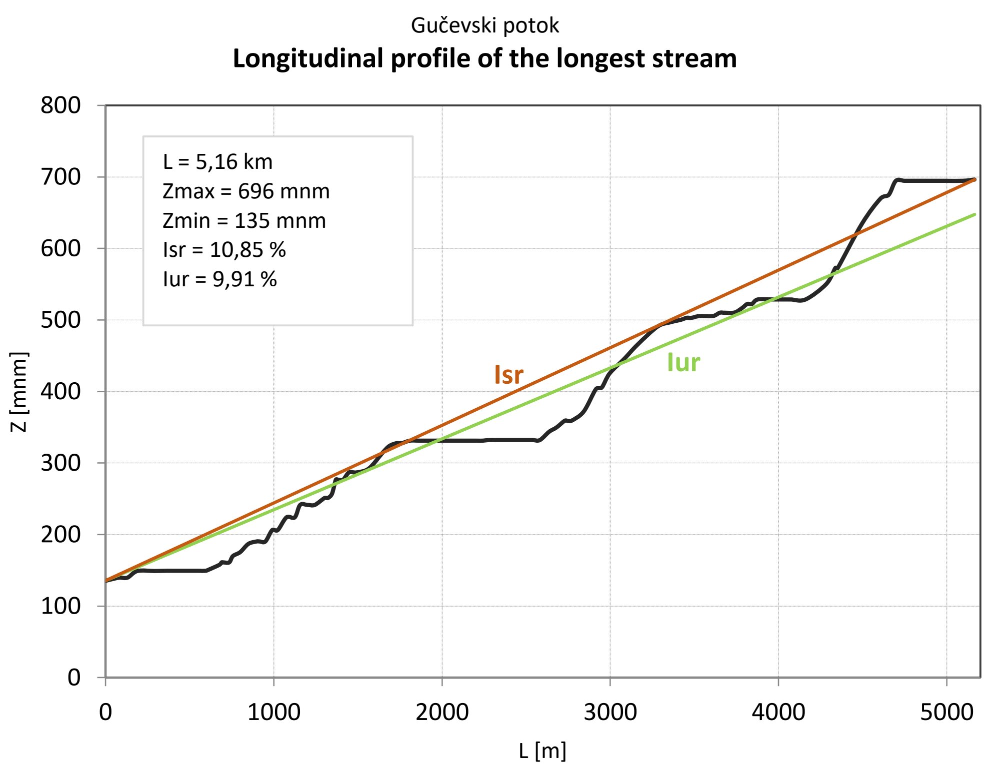


Figure 2.30: Longitudinal profile of the longest stream – Gučevski potok



Source: Authors, based on available data

2.4.3. Land use

The Land use was analyzed from the available sources. Corine Land Cover (2018) and land cover obtained from the Republic Geodetic Agency are used.

According to Corine Land Cover, the area of the Trbušnica river basin is dominated by mixed forests with predominantly agricultural areas that have a larger proportion of natural vegetation. Broad-leaved forests are also represented, while coniferous forests are represented in a smaller percentage.

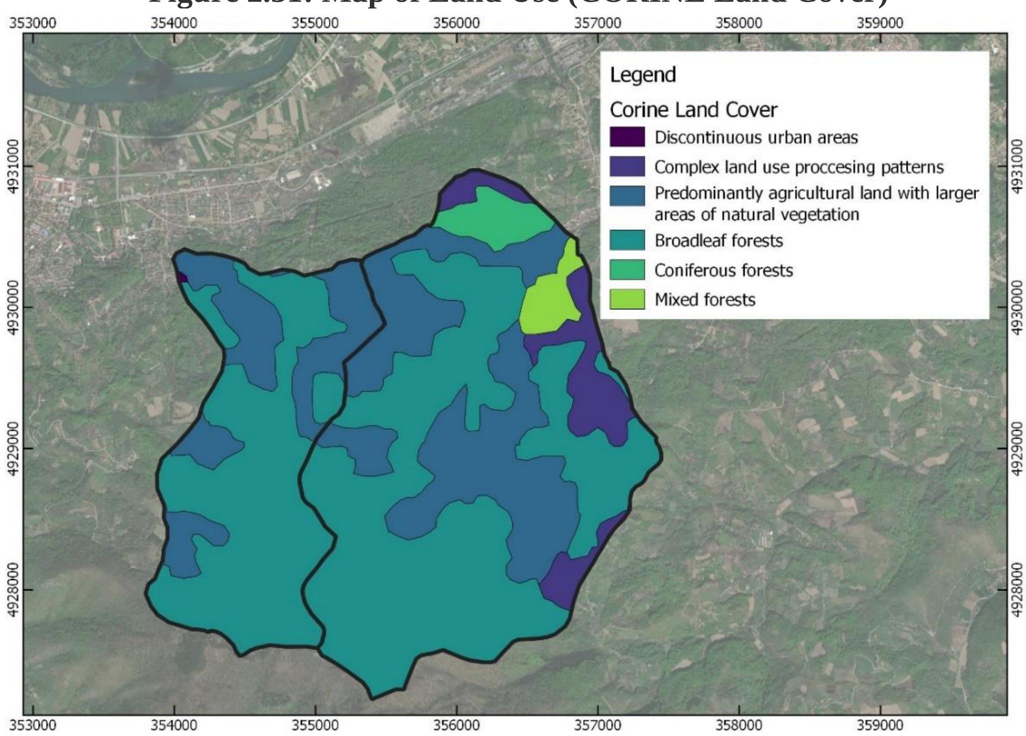
On the surface of the watershed up to the profile on the Gučevski potok, there are predominantly agricultural areas and broad-leaved forests. Urban areas are also represented in the lower part of the basin.

The representation of different ways of land use in the catchment area is shown in table 2.20. Figure 2.31 shows the representation of different types of land cover (CORINE Land Cover).

Table 2.20: Land use in catchment areas

Land Use	Profile Trbušnica		Profile Gučevski potok	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Complex land use processing patterns	0.92	15.09	0.00	0.00
Predominantly agricultural land with larger areas of natural vegetation	1.74	28.60	1.20	41.27
Discontinuous urban areas	0.00	0.00	0.37	12.69
Broadleaf forests	0.83	13.70	1.33	46.04
Coniferous forests	0.26	4.24	0.00	0.00
Mixed forests	2.33	38.37	0.00	0.00
TOTAL	6.07	100.00	2.90	100.0

Figure 2.31: Map of Land Use (CORINE Land Cover)



Source: Authors, based on CORINE Land Cover data

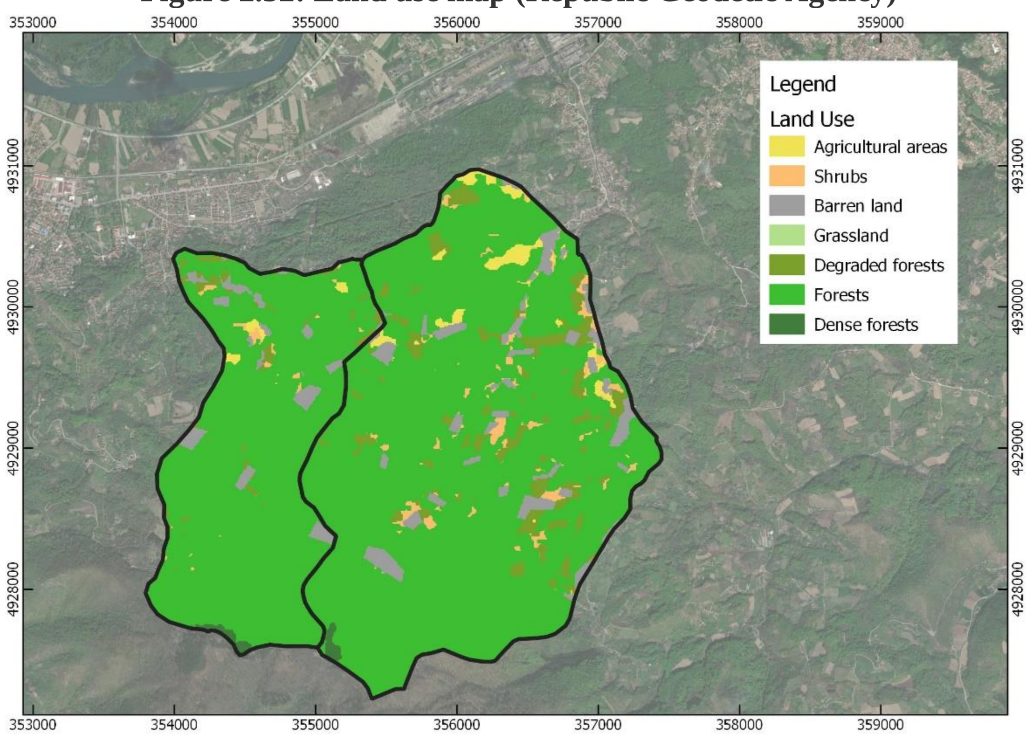
According to the land cover of the Republic Geodetic Agency, the surface of the Trbušnica river basin is dominated by forests with a large percentage of representation. Other categories are represented in a smaller percentage.

On the surface of the watershed up to the profile on the Gučevski potok, forests also dominate.The representation of different ways of land use in the catchment area is shown in Table 2.21. Figure 2.32 shows the representation of different types of land cover.

Table 2.21. Land use in catchment areas

Land Use	Profile Trbušnica		Profile Gučevski potok	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Agricultural areas	0.15	2.51	0.03	0.96
Shrubs	0.20	3.34	0.04	1.31
Bare soils	0.35	5.82	0.16	5.56
Grassy areas	0.00	0.01	0.00	0.03
Degraded forests	0.44	7.23	0.10	3.36
Forests	4.91	80.83	2.55	88.04
Dense forests	0.02	0.26	0.02	0.74
TOTAL	6.07	100.00	2.90	100.0

Figure 2.32: Land use map (Republic Geodetic Agency)



Source: Authors, based on available Satellite data and data RGA (Republic Geodetic Agency, Serbia)

As the bases used differ significantly in the representation of land use, for further calculation the base of the Republic Geodetic Agency will be used, which is more precise (resolution 10m), while the Corine Land Cover base is recommended for larger watersheds, since it has a larger scale (R1:100,000).

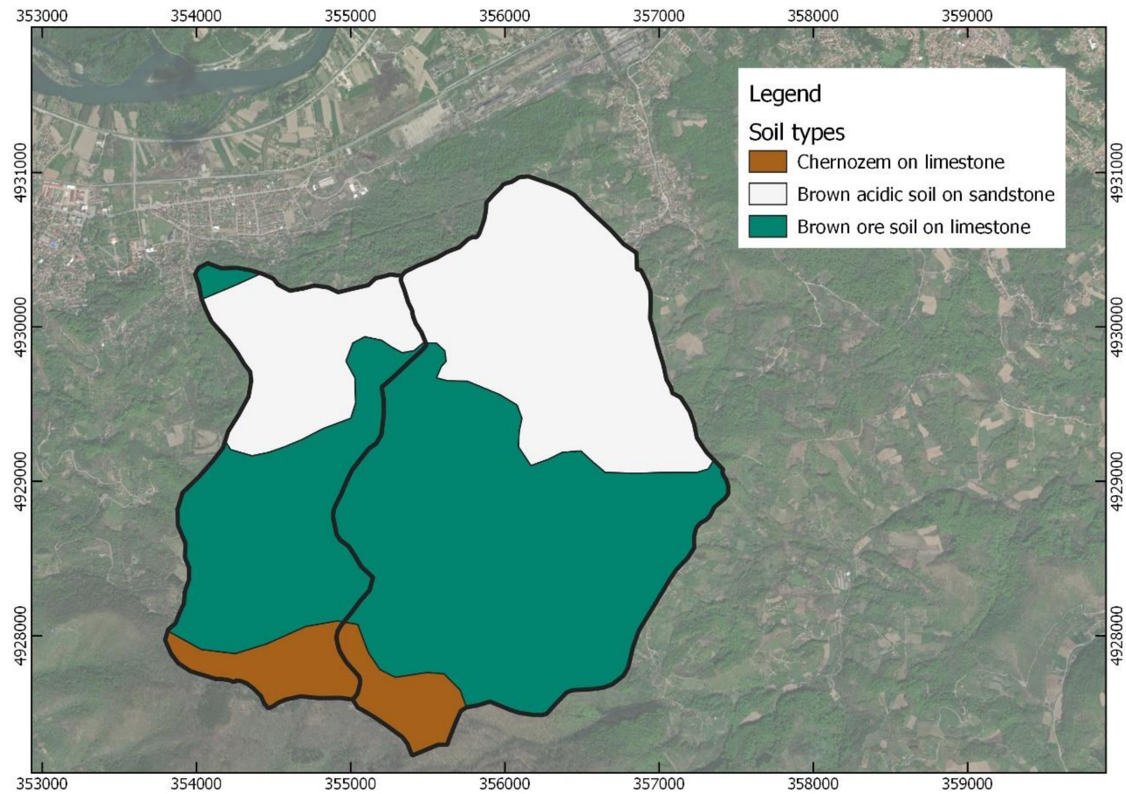
2.4.4. Representation of soil types

For the purposes of analyzing the pedological composition of the studied area, the 1:50,000 scale Pedological Map of the Republic of Serbia (Soil Institute, Belgrade, 1966 and 1967) was used. Figure 2.33 shows the pedological map of the watershed, and Table 2.22 shows the representation of different soil types.

Table 2.22. Representation of soil types in the catchment area

Soil types	Profile Trbušnica		Profile Gučevski potok	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Chernozem on limestone	0.31	5.11	0.37	12.66
Brown acidic soil on sandstone	2.22	36.62	0.96	33.03
Brown ore soil on limestone	3.54	58.27	1.57	54.31
TOTAL	6.07	100.00	2.90	100.0

Figure 2.33: Pedological Map



Source: Authors, based on available Satellite data (ESRI)

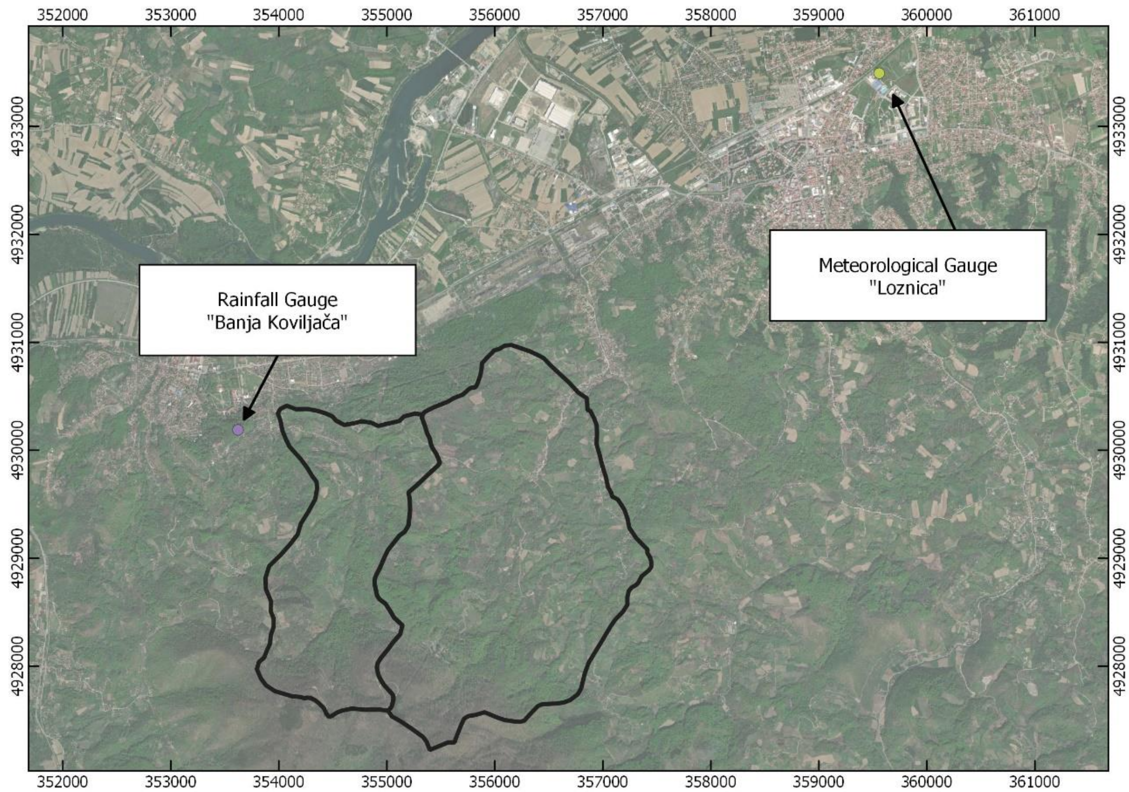
2.4.5. Hydrological analysis of large waters

For the purposes of calculating the relevant large waters in the given profiles, a precipitation-runoff model based on the theory of the synthetic unit hydrograph was applied to determine the peak ordinate of the unit runoff, as well as on the SCS method for determining effective precipitation.

Analysis of heavy rains

Precipitation, as an input parameter in the precipitation-runoff model, was used in the form of dependence "maximum height of rain – duration – probability of occurrence" (H-T-P curves) for rains of high intensity and short duration. For the purposes of this hydrological analysis, data from the main meteorological gauge "Loznica" was used, the location of which can be seen in Figure 2.34.

Figure 2.34: Location of the precipitation and meteorological gauge



Source: Authors, based on available Satellite data (ESRI)

There is not a single gauge in the catchment area for which the hydrological calculation is carried out, except for the rainfall gauge "Banja Koviljača", which is in the immediate vicinity of the Gučevski potok basin, as well as the main meteorological gauge "Loznica", whose data was used for the hydrological calculation. The ordinates of the probability distribution of maximum rain heights for different durations of rain with different occurrence probabilities (H-T-P curve) for the main meteorological gauge were taken from the literature "Intensities of heavy rains in Serbia" (Prohaska et al., Institute for Water Management Jaroslav Černi, 2014).

SCS method for effective rain

The US soil conservation service (Soil Conservation Service - SCS, today the National Resource Conservation Service - NRCS) developed a method for calculating the rain loss function. The basic setting of the SCS method for rain losses is that the height of effective rain Pe is always less than or equal to the total height of rain P, and that the water absorbed into the soil after the start of runoff Ia is always less than or equal to the maximum soil capacity S.

The amount of water absorbed by the soil before runoff begins is called the initial loss Ia, so the maximum "potential" effective rainfall is equal to (P - Ia). The assumption of the SCS method is that the ratios of actual and potential effective rain on the one hand, and actual and potential losses on the other, are equal:

$$\frac{P_e}{P - I_a} = \frac{I}{S}$$

in which case:

$$P = P_e + I_a + I$$

It follows from the previous two formulas:

$$P_e = \frac{(P - I_a)^2}{(P - I_a + S)}$$

By studying a large number of experimental watersheds, SCS found a relationship between initial and maximum soil capacity:

$$I_a = 0.2S$$

By entering this formula, it follows:

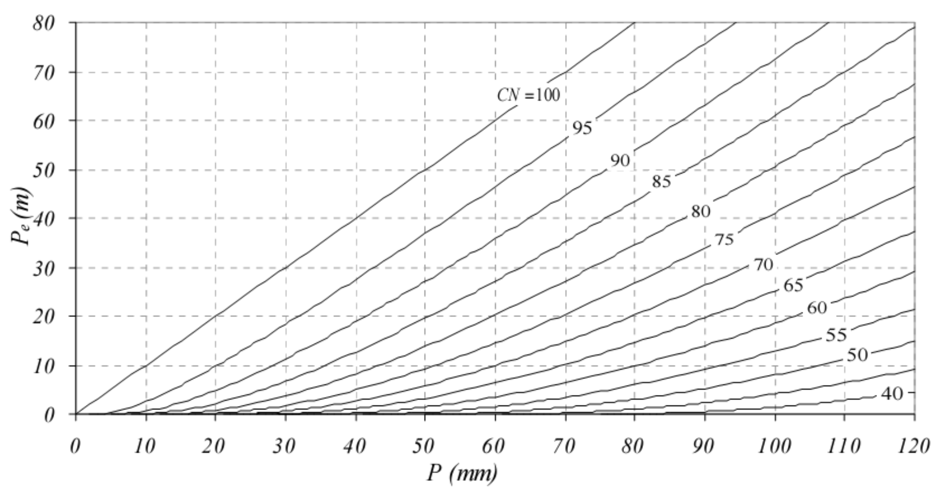
$$P_e = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Instead of land capacity S, the so-called runoff curve number CN as a parameter in the above equation. The number CN is dimensionless and its values range between 1 and 100, and its relation to S is given by:

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

where S is given in millimeters. For impervious and water surfaces, CN takes the value 100, while for natural surfaces, CN < 100. The relationship between P, Pe and CN is represented by the SCS diagram, shown in Figure 2.35. This diagram is valid for normal runoff conditions.

Figure 2.35. Diagram of the ratio of total and effective rain according to the SCS method



Source: Authors

The determination of the hyeogram of effective rain is done here indirectly, via the summary line of rain. For each time interval, the ordinate of the summary line of the effective rain Pe(t) is obtained according to the given equation based on the ordinate of the summary line of the fallen rain P(t) or via the diagram in Figure 2.35 for the given CN. It should be taken into account that the total amount of rain must be greater than the initial losses, because no more rain can be lost than has fallen. So:

$$P_e = \begin{cases} \dfrac{\left(P(t) - 0.2S\right)^2}{\left(P(t) + 0.8S)\right)}, & P > 0.2S \\ 0 \ , & P \leq 0.2S \end{cases}$$

With the summary line of effective rain determined in this way, a histogram of effective rain can be constructed.

SCS method - determination of CN number

The value of the runoff curve CN is based on the hydrological class of the soil, the type of land use, the method of cultivation and the previous runoff conditions.

According to the SCS, soils are divided into four hydrological classes depending on potential runoff conditions. The four hydrological soil classes are designated as A, B, C and D, where class A has the lowest runoff potential and class D the highest. Criteria for classifying land into hydrological classes include the minimum amount of infiltration, depth to the impervious layer, groundwater level, etc. In practice, it is most often determined on the basis of the pedological composition of the soil.

Table 2.23 shows the division of all represented soils in the basin (according to Table 2.22) into hydrological soil classes.

Table 2.23: Classification of represented soil types into hydrological soil classes (HSG)

Soil type	Hydrological soil class
Crnica on limestone	B
Brown acidic soil on sandstone	B
Brown ore soil on limestone	B

Source: Authors, based on available data

The number of the runoff curve CN is determined first by defining all combinations of the hydrological class of land and the way of use in the entire catchment area, and then by weighting, the mean value for the catchment is obtained. CN number values for different conditions can be found in the literature, e.g. NRCS National Engineering Handbook (2009).

The value of the CNII number obtained in this way refers to the average previous runoff conditions. In order to include the less favorable conditions that usually prevail during extreme events of high water (when the infiltration-retention capacity of the watershed is reduced to a minimum due to, for example, soil saturation with water), in practice the CN number is calculated for the so-called above-average outflow conditions (CNIII).

The adopted runoff curve number values CN for above-average runoff conditions are CNIII in Table 2.24.

Table 2.24. Result of CN number calculation

River	Profile	CN_{II}	CN_{III}
Trbušnica	hydrological gauge (sensor)	60	78
Gučevski potok	hydrological gauge (sensor)	60	78

Source: Authors, based on available data

Synthetic unit hydrograph method

The unit hydrograph is defined as the hydrograph of direct runoff due to unit effective rain that is evenly distributed over the surface of the basin and is of constant intensity during the effective duration.

In unstudied watersheds, synthetic unit hydrographs are used, the construction of which is based on the transposition of data from other watersheds through regional connections between watershed characteristics and hydrograph characteristics.

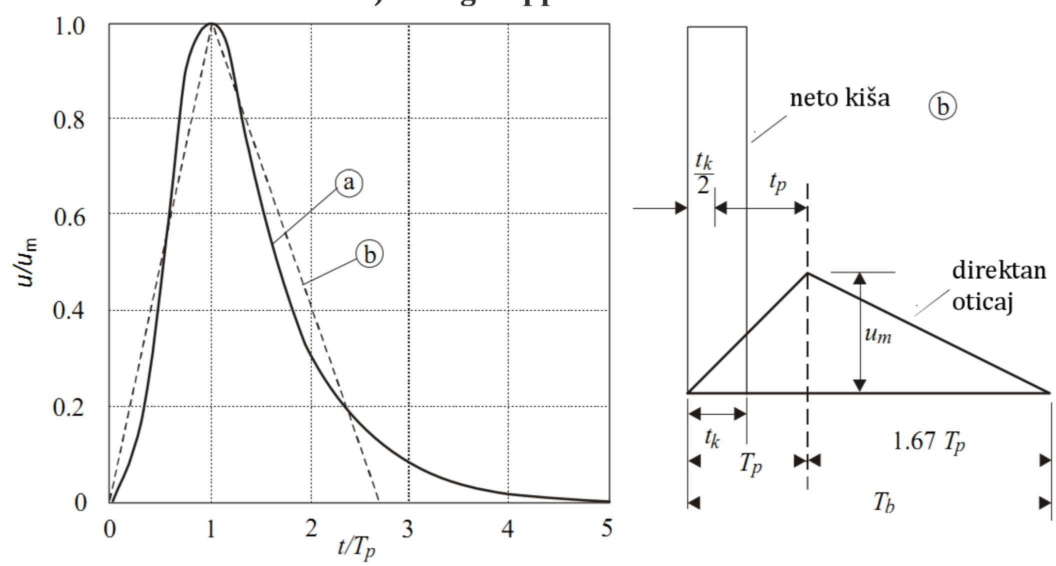
With the SCS dimensionless unit hydrograph (Figure 2.36), time is expressed in relation to the time of rise of the hydrograph Tp, and the ordinate in relation to the maximum ordinate of the unit hydrograph um. In order to apply such a hydrograph, it is necessary to know the rise time Tp, while the maximum ordinate um is determined from the condition that the area under the future unit hydrograph is equal to the runoff volume.

The hydrograph rise time Tp can be expressed using the catchment delay time tp:

$$T_p = t_p + \frac{t_k}{2}$$

where tk is the rain duration. The delay time tp is most often determined either through the physical characteristics of the watershed or by estimating the concentration time of the watershed.

Figure 2.36. Synthetic unit hydrogram according to SCS: a) curvilinear unit hydrogram and b) triangle approximation



Source: Authors, based on available data

In practice, the modification of the synthetic hydrograph proposed by Brajković and Jovanović (Jovanović, 1989) is often used. According to this modification, the time of the descending branch of the hydrograph Tr, as well as the base of the hydrograph Tb, are not fixed but amount to:

$$T_r = rT_p \quad и \quad T_b = (1 + r)T_p$$

where r is a constant for a given watershed and depends on the size of the watershed and the purpose of the areas in the watershed.

The delay time of the watershed tp, which determines the rise time of the hydrograph Tp, is determined from the regional dependence:

$$t_p = at_k + t_0$$

where all times are expressed in hours. It is considered that the parameter a depends on the area of the basin, and the parameter t0 on the physical characteristics of the basin, such as in the following empirical dependence:

$$t_0 = 1.06\left(\frac{L}{I_{ur}}\right)^{0.47}$$

where L is the maximum length of the stream (in km) and Iur is the balanced drop of the stream (in percent).

The maximum flow ordinate (expressed in m3/s) is calculated as:

$$Q_{max} = \frac{2 \cdot A \cdot P_e}{T_b \cdot 60} \cdot 1000$$

where: A - basin area (km2), Pe - effective precipitation (mm) and Tb - hydrograph base, i.e. time from the beginning to the end of the triangular hydrograph (min). The base of the hydrograph is the sum of the time of the rise of the hydrograph Tp and the time of the fall of the hydrograph Tr.

Rain duration tk is adopted as the duration of rain which, based on the authoritative HTP curve, gives the highest (most unfavorable) flows.

2.4.6. Results

Through the calculation procedure, the maximum flows were obtained for the occurrence probabilities p=1%, p=2%, p=5% and p=10%, that is, for return periods of 100, 50, 20 and 10 years.

Table 2.25: Calculated high water flows

River	Profile	Q_{max} (m^3/s)			
		1%	2%	5%	10%
Trbušnica	hydrological gauge (sensor)	19.1	16.5	12.2	10.5
Gučevski potok	hydrological gauge (sensor)	10.3	8.9	6.6	5.7

where: p - probability of occurrence and Qmax - peak ordinate of the flood wave hydrograph.

Source: Authors, based on available data

Figure 2.37: Computational hydrograms of large water waves on the Trbušnica profile

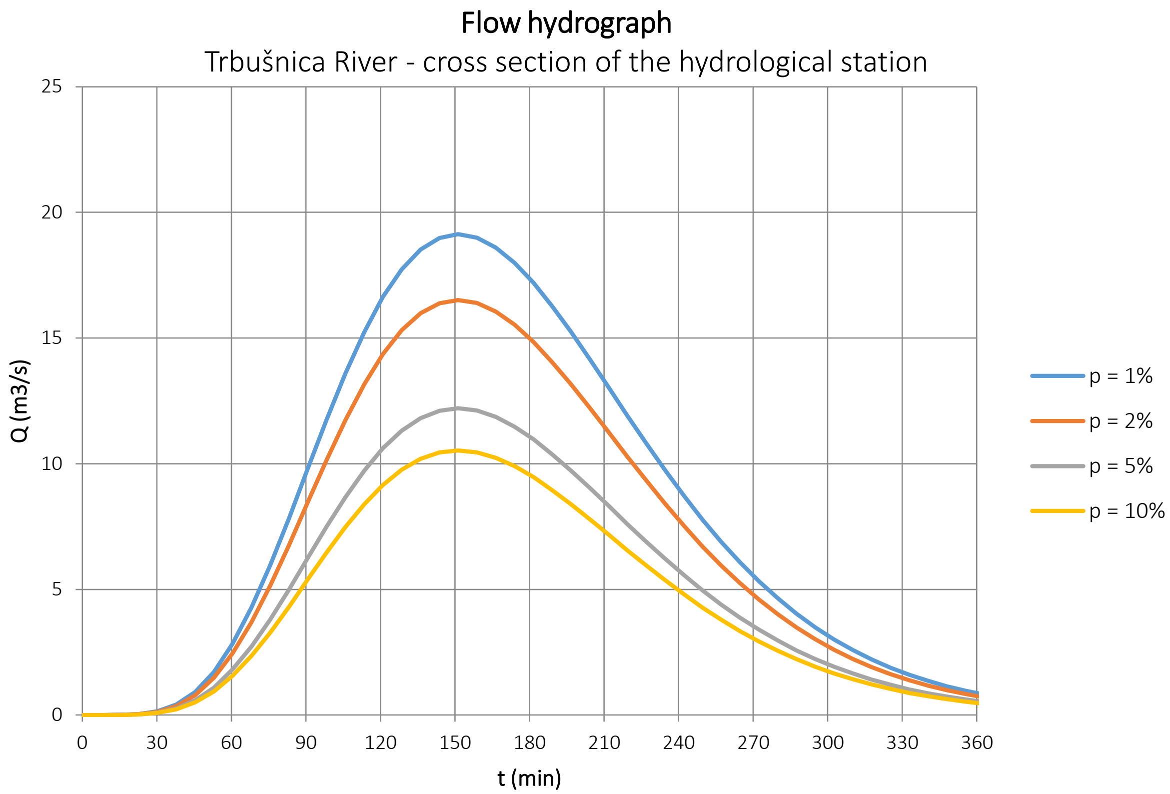
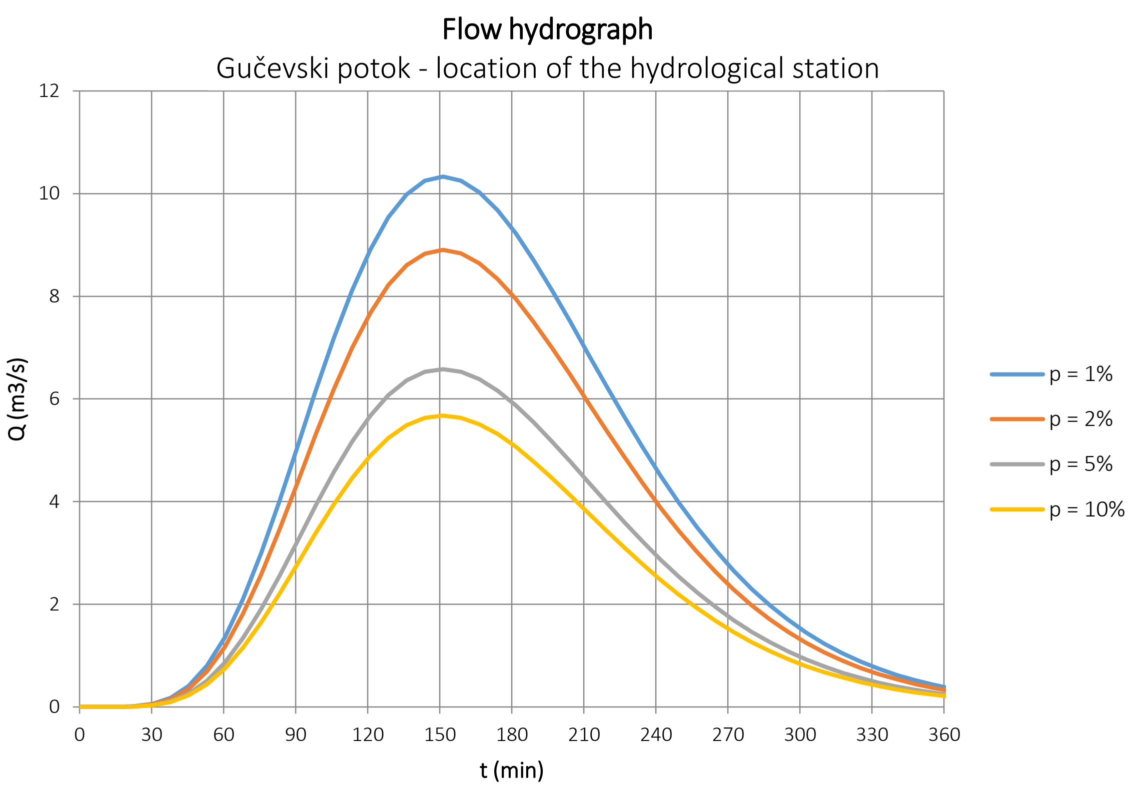


Figure 2.38: Computational hydrograms of large water waves on the Gučevski Potok profile



Source: Authors, based on available data

2.4.7 Control of calculated values

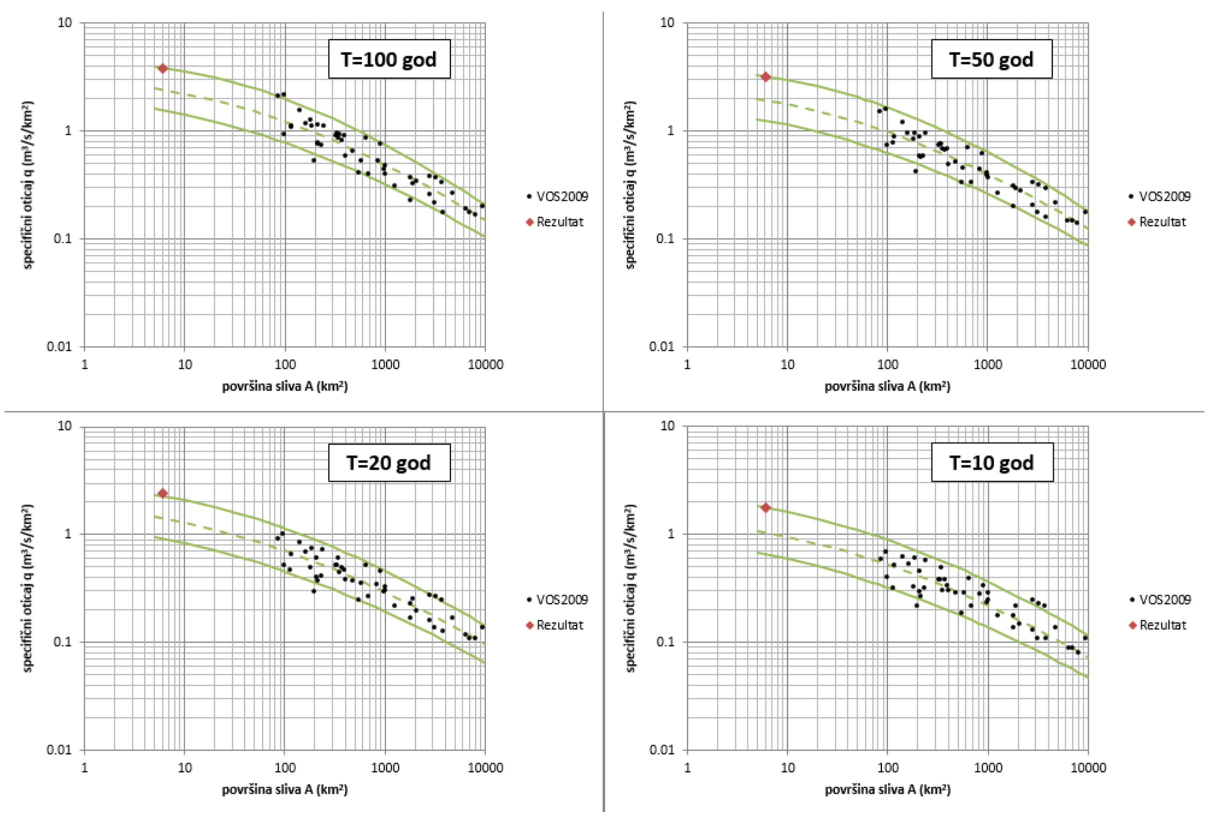
The control of the calculated values was carried out by applying the envelope of the specific outflow of large waters for the territory of Serbia. Values of the specific outflow of large waters, ie. the flow module of large waters or the module of the maximum annual flow, were taken from the Hydrological Bases of the Water Management Foundation of the Republic of Serbia (2009), for a total of 44 hydrological stations with a catchment area of less than 5000 km2, for all considered return periods (T=10, 20, 50 and 100 years). The envelopes of the given fields of points (dependence of the specific flow of large water on the surface of the basin) were adopted by applying the Krieger curve, which has the form:

$$q = aA^{(bA^{c}-1)}$$

where: A - basin area in km2, a,b,c - regional parameters. Regional parameters a, b and c are adopted according to the dependence given by Janković and Malošević (Waterworks, 1989).

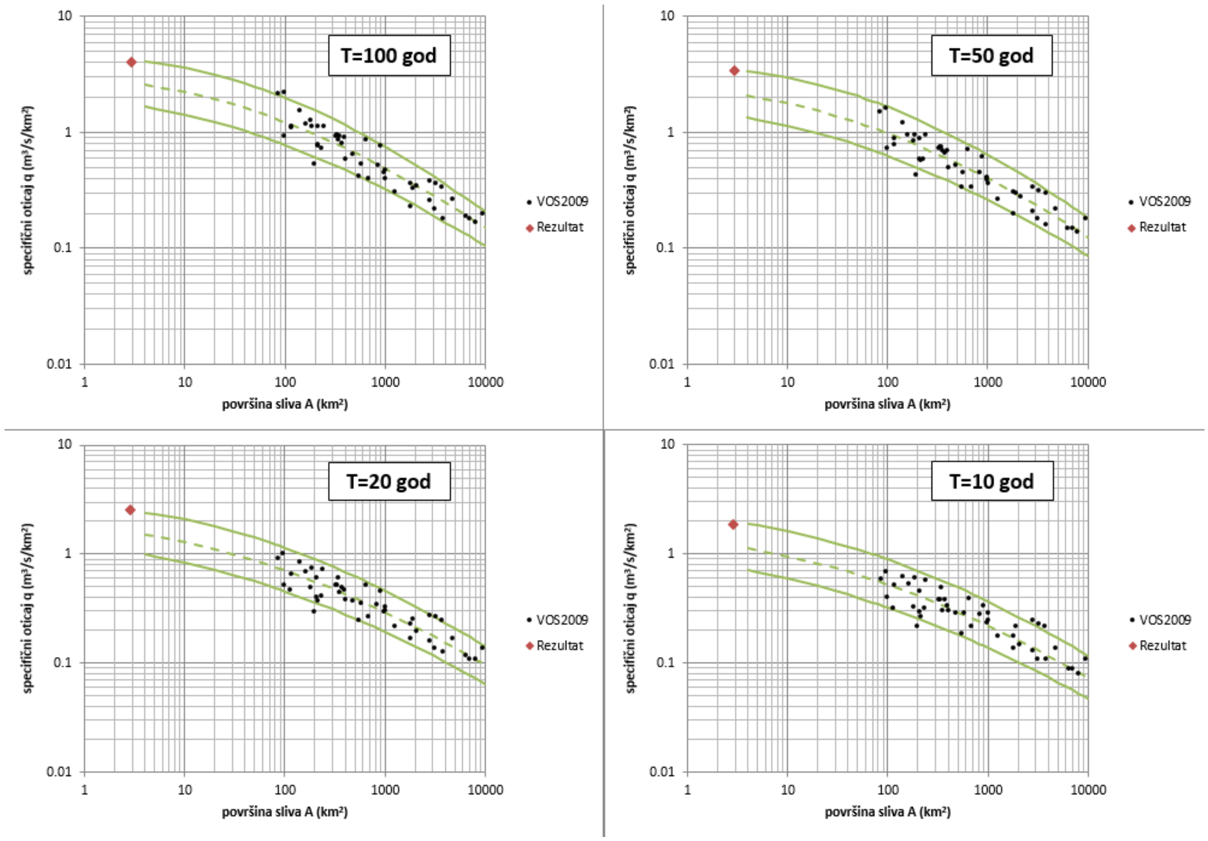
Figures 2.39 and 2.40 show the values of specific outflows from hydrological stations throughout Serbia with the corresponding envelopes and the values of the calculated values for the observed watersheds.

Figure 2.39: Specific runoff of large waters of watersheds in Serbia and the result of flows obtained in the Trbušnica watershed



Source: Authors, based on available data

Figure 2.40: Specific runoff of large waters of watersheds in Serbia and the result of flows obtained in the Gučevski potok watershed



Source: Authors, based on available data

2.5. Flood hazard maps

Flood risk maps for different probabilities of occurrence in the wider studied area, were made on several occasions in the previous 10 years.

For the Drina area in the stretch from Banja Koviljača to Loznica, flood zones were created through the following projects:

- Flood event expertise (2014),
- Study of Flood Prone Areas (SoFPAS 2, 2020),
- Drina River Basin Management Project in the Western Balkans (2021).

For the narrower research area, the Trbušnica River and Gučevski Potok basins, no flood zone analysis was done in the previous period.

Flood event expertise (2014)

The project "Expertise of the flood event (2014)" was carried out for the reconstruction of certain flood events, in a certain area that was affected by the flood in May 2014. The expertise was carried out by the Institute for Water Management "Jaroslav Černi", and the customer was PWMC "Srbijavode". The aim of the expertise was to analyze the flood event in a certain area.

The maps were made as a reconstruction of the flood event in a 1D model.

Study od Flood Prone Areas (2020)

Study of Flood Prone Areas in Serbia (SoFPAS 2) - The project of creating flood hazard and risk maps in Serbia was carried out with the aim of drawing up a flood risk management plan based on the obtained maps and harmonizing it with the EU Directive on floods in Serbia (COWI A/S 2019). Maps were made for 74 significant flood areas, among which is the "Drina from the mouth to the Zvornik dam", a significant flood area that is of interest to the studied area.

Maps were made for different probabilities of occurrence, for 3 scenarios: Q50, Q100 and Q1000.

Drina River Basin Management Project in the Western Balkans (2021)

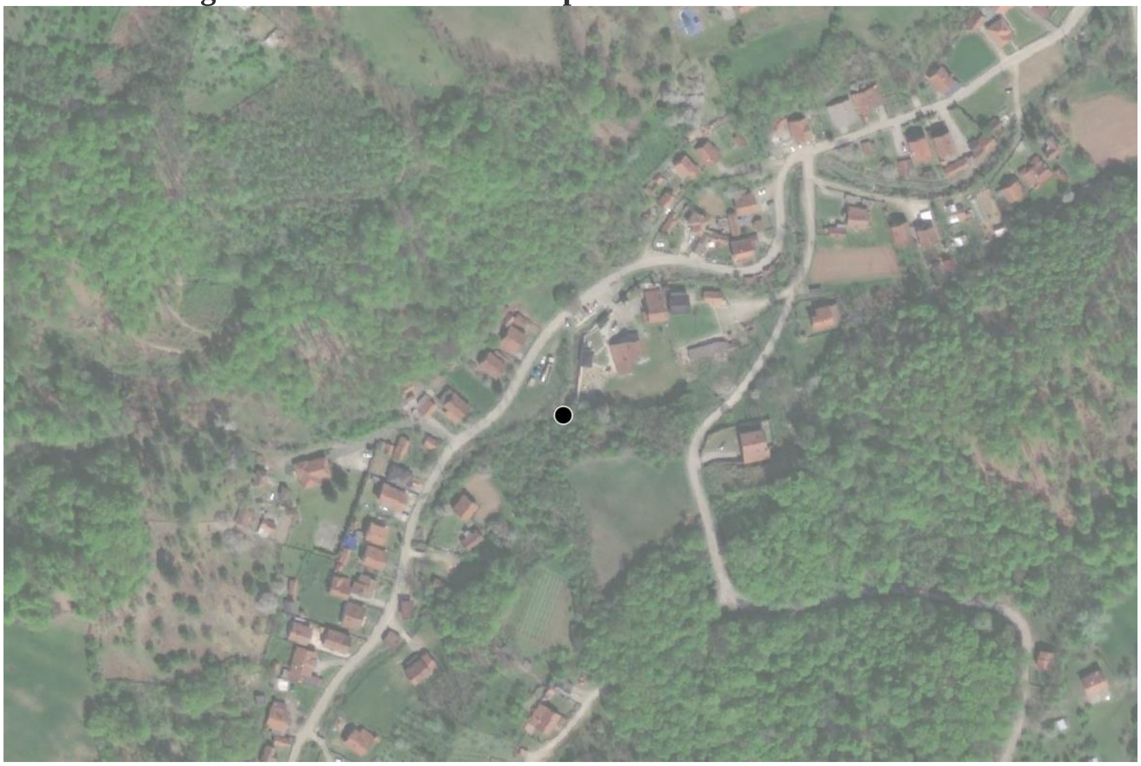
Western Balkans Drina River Basin Management Project (WBDRBMP) - Drina River Basin Water Resources Study (DRB) and hydrological and hydraulic modeling of the Drina River Basin with reservoir management was conducted from 2020 to 2021.

In addition to other objectives, the project aimed to analyze flood zones for the Drina course and certain tributaries for the following scenarios: Q20, Q100, Q500 and Q1000.

2.5.1. Calculation of flood hazard maps in the study area

The calculation of hazard maps is a hydraulic analysis, that is, the calculation of the flood zone for certain scenarios. The task of the hydraulic analysis is to, for the calculated authoritative flows, look at the effects of the large waters of the Trbušnica River and the Gučevski Potok on the sites where the hydrological stations are planned, as well as on the stretch of the section downstream from the profile of the planned hydrological stations, up to the mouth of the Drina River.

Figure 2.41: The view of the profile on the river Trbušnica



Source: Authors, based on available Satellite data (ESRI)

Figure 2.42: The view of the profile on the Gučevski Potok

Source: Authors, based on available Satellite data (ESRI)

Bases for hydraulic calculation

For the purposes of this hydraulic analysis, transverse profiles in the watercourse bed were not recorded, and there is no digital model of the terrain with a more detailed resolution, so for these reasons, available data on the terrain was used, which results in a less accurate flood zone. A global terrain elevation model was used for the considered area with a resolution of 10x10 m.

The routes of the riverbed that most closely follow the middle of the main riverbed have been adopted. The beginning of the route is defined by the profile where the hydrological station is planned, and the end of the route is the mouth of the watercourses in the Drina.

2.5.2 Calculation method

The selected Projection in which the backgrounds and results are displayed is UTM 34N (EPSG: 32634). The hydraulic calculation was modeled in the program HEC-RAS 6.3 (US Army Corps of Engineers), in the module for two-dimensional flow. The reason why 2D modeling was chosen is that it better represents the speed of the flow, which directly affects the erosion by the river flow in the area through which the water flows.

The following bases were used for hydraulic modeling:

- Digital terrain model,
- Land Use Map, on the basis of which Manning's resistance coefficients can be determined depending on the purpose of the land.
- Scope of 2D modeling (Perimeter). In this case, it is the part of the basin downstream from the planned measuring point. Within this scope, a computational network is formed.
- The flow line of the considered watercourse, which is entered as a Breakline, which thickens the computational grid in the area of the watercourse. The flow line was determined using an orthophoto of the river flow.
- Boundary conditions:
  - An upstream external boundary condition entered as a hydrograph (flow change over time). Hydrological analysis up to the profile is necessary to set this boundary condition,
  - A downstream external boundary condition entered as a levelogram (level change or constant level over time), flow curve or normal depth. In this case, the normal depth was adopted as the downstream boundary condition,
  - Internal boundary conditions such as flows at hydrological stations or levels in reservoirs.

Hydraulic modeling of the Trbušnica River

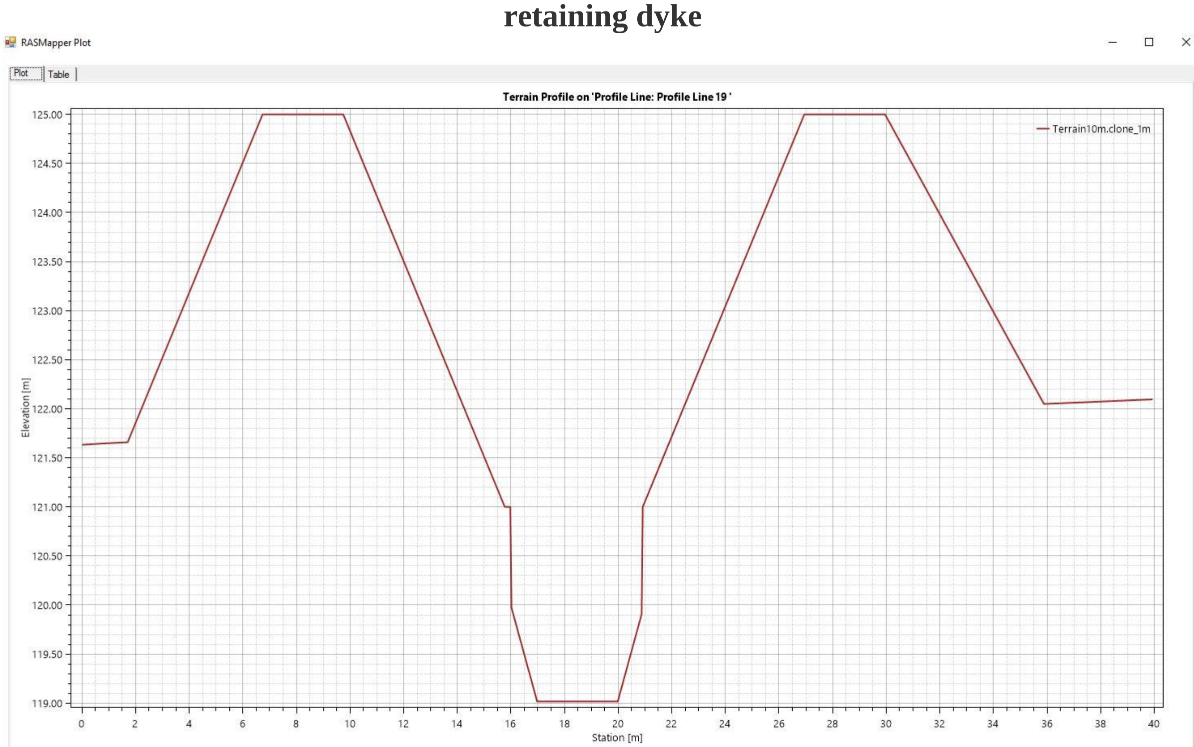
- To cover the 2D modeling, a part of the watershed downstream from the measurement site was taken.
- The upstream boundary conditions were obtained by Hydrological analysis for the occurrence probabilities Q (1%, 2%, 5% and 10%) from Table 2.25.
- Normal depth is taken as the downstream boundary condition.
- A digital terrain model with a resolution of 10x10 m was used.
- To cover the considered area, the land use map of the Republic Geodetic Agency was used.
- The existing water structure (levee) was sketched based on the available information:

- The downstream part of Trbušnica with a regulated riverbed and two-sided retaining embankments is roughly approximated (Figure 2.44), using the analysis of satellite images (Figure 2.43) and available descriptions of water structure.

Figure 2.43: Tentative estimate of dike rate width using Google Satellite in RAS Mapper

Source: Authors, based on available Satellite data (ESRI)

Figure 2.44: Approximate cross-section of the downstream part of Trbušnica with two-sided retaining dyke

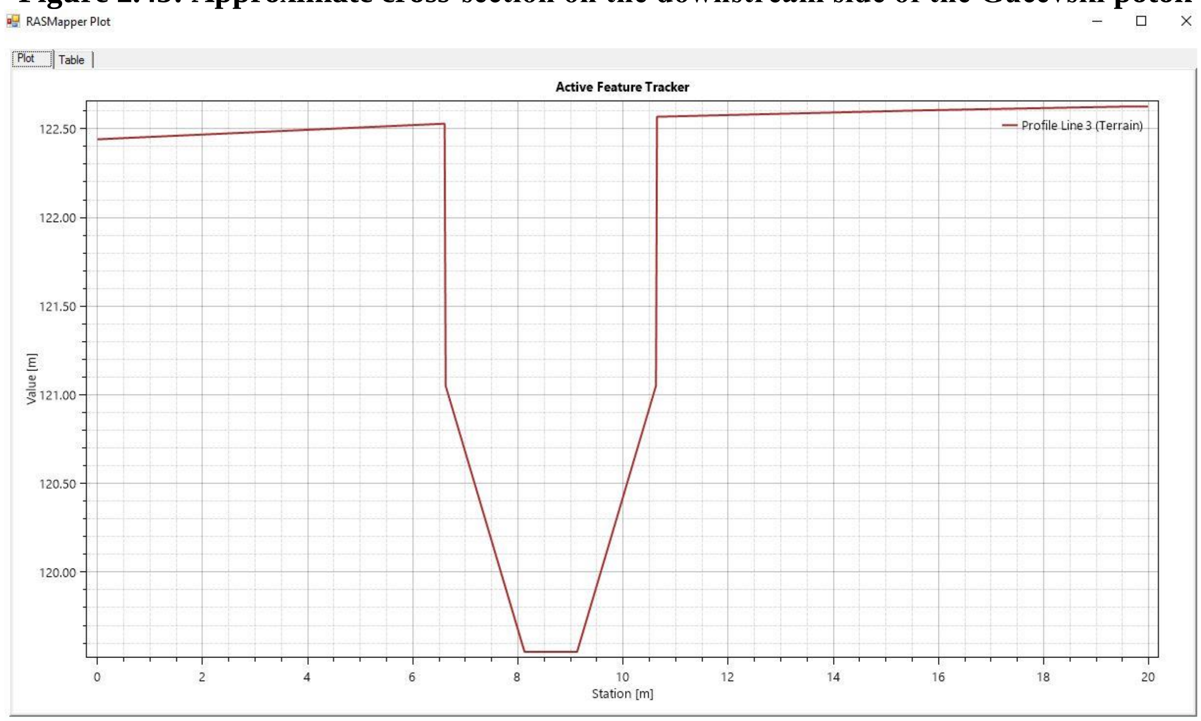


Source: Authors, based on available data

Hydraulic modeling of Gučevski potok

- To cover the 2D modeling, a part of the watershed downstream from the measurement site was taken.
- Upstream boundary conditions were obtained by hydrological analysis for the probability of occurrence Q (1%, 2%, 5% and 10%) from table 2.25.
- Normal depth is taken as the downstream boundary condition.
- A digital terrain model with a resolution of 10x10 m was used.
- To cover the considered area, the land use map of the Republic Geodetic Agency was used.
- Since there is no data on the geometry of the riverbed, based on satellite images, a riverbed was assumed, which was imprinted in the digital model of the terrain (Figure 2.45).

Figure 2.45: Approximate cross-section on the downstream side of the Gučevski potok

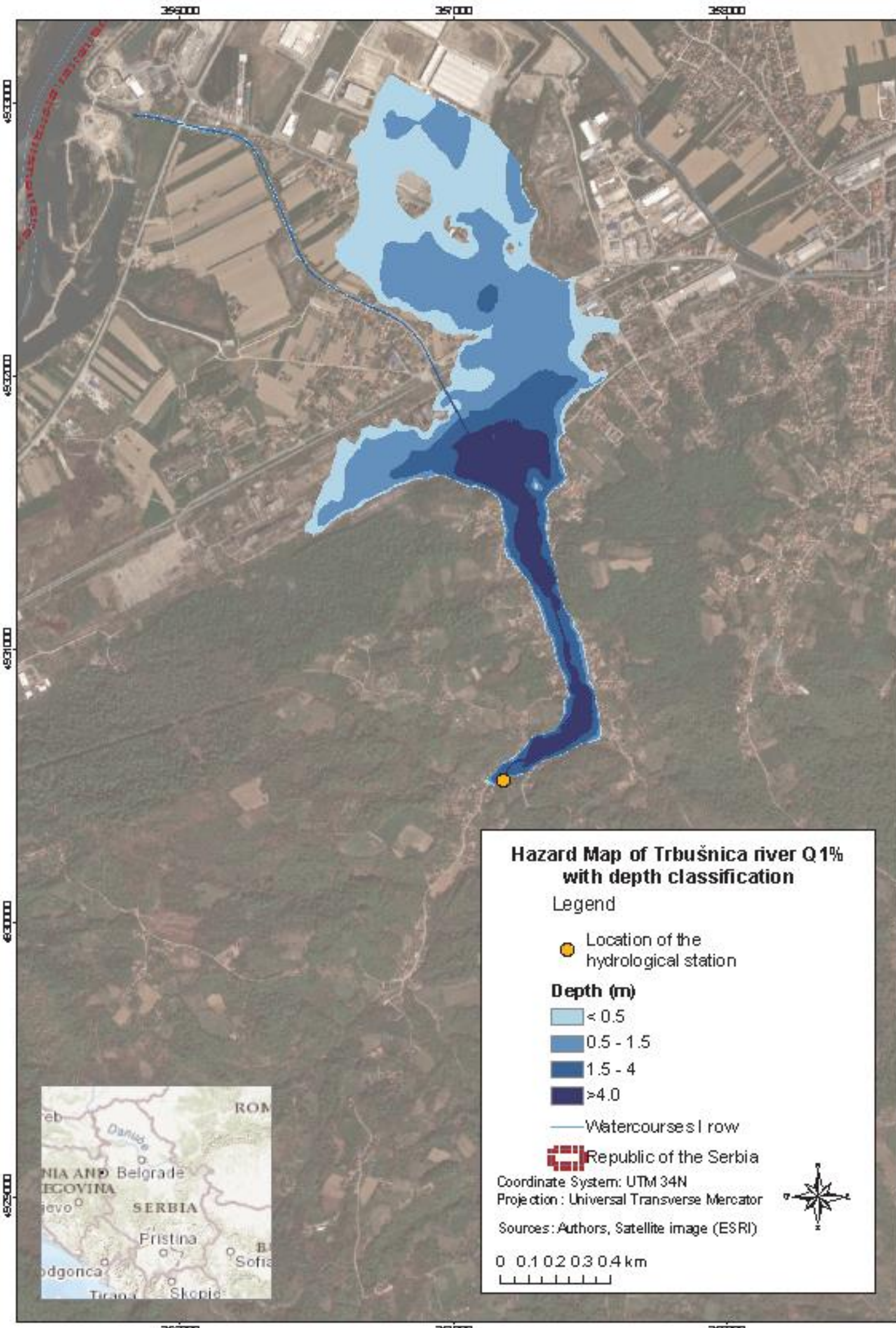


Source: Authors, based on available data

2.5.3 Results of hydraulic calculation

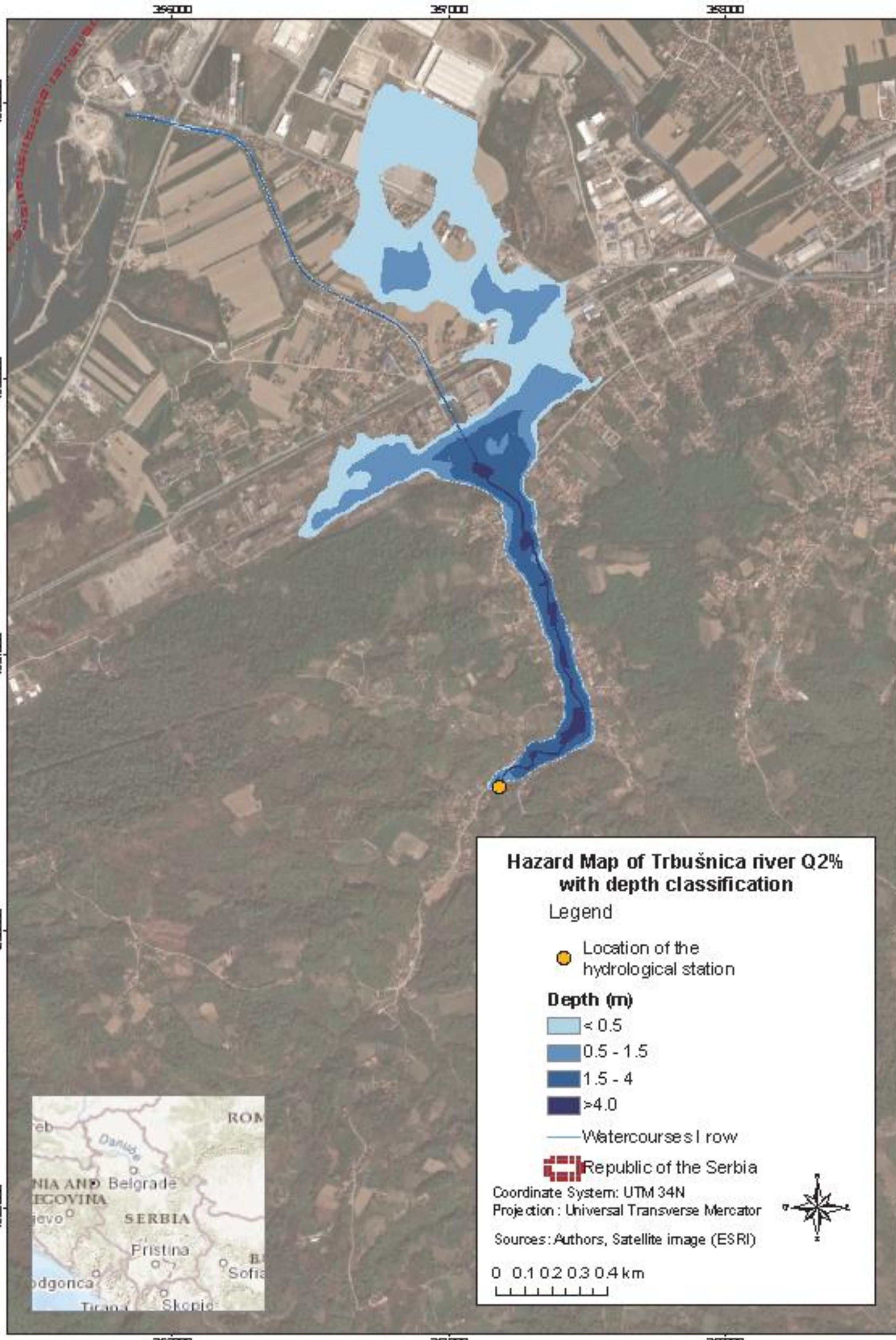
Simulations were run for unsteady 2D flow and results were obtained for four scenarios (Q1%, Q2%, Q5% and Q10%). For these scenarios, the maximum calculation depths and maximum calculation speeds can be found in the Figures 2.46 – 2.53.

Figure 2.46: Hazard map of Trbušnica river Q1% with depth classification



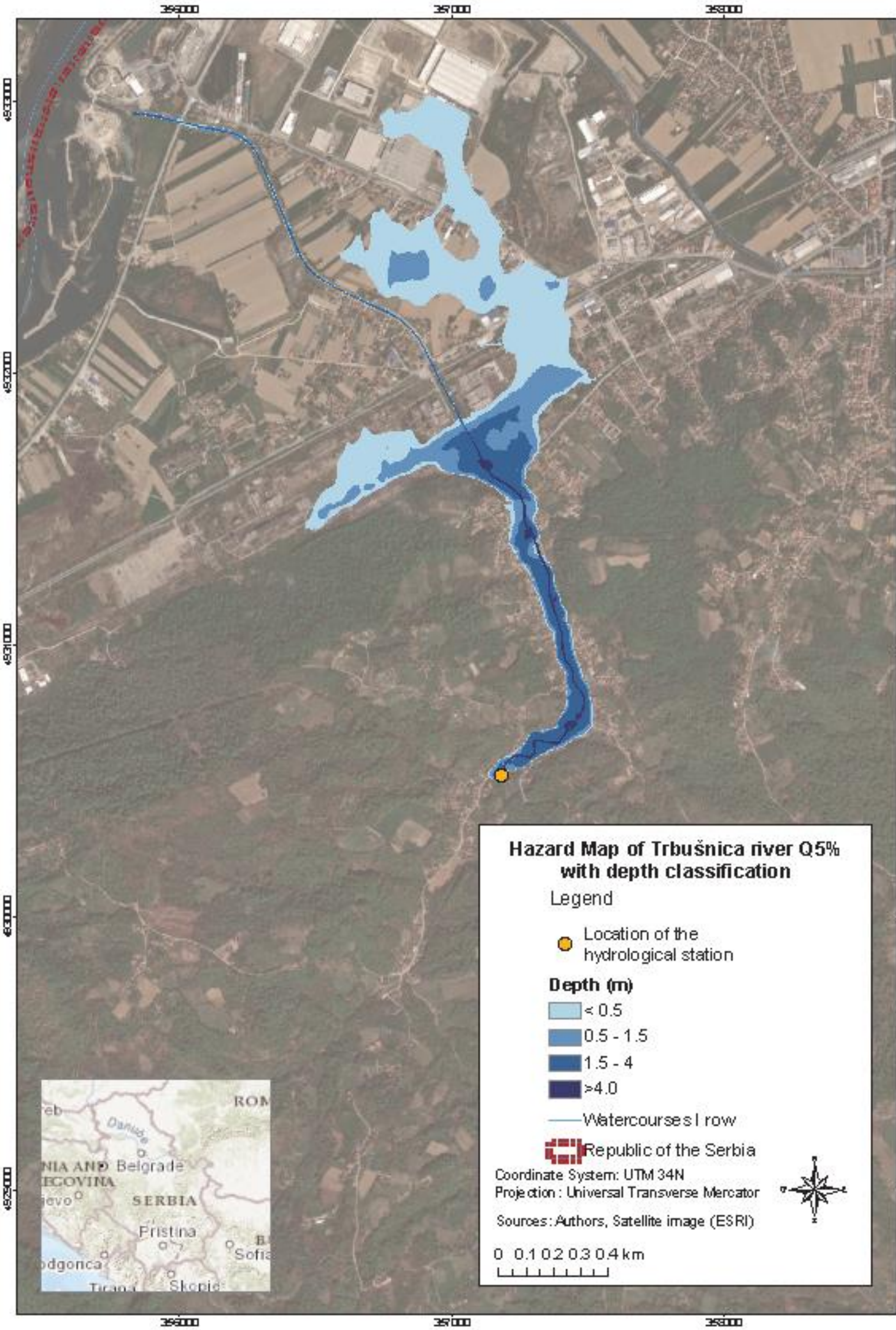
Source: Authors, based on available data

Figure 2.47: Hazard map of Trbušnica river Q2% with depth classification



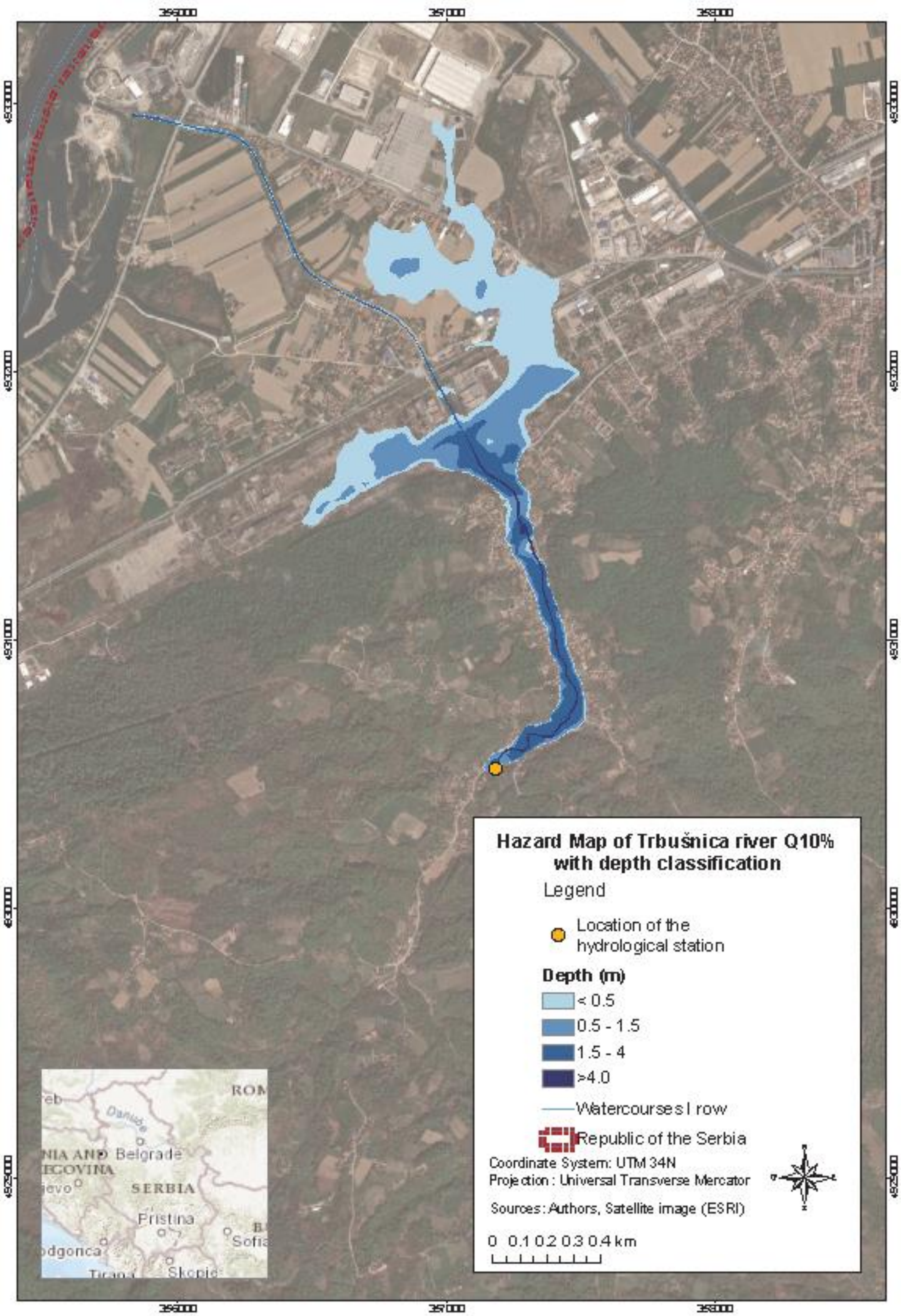
Source: Authors, based on available data

Figure 2.48: Hazard map of Trbušnica river Q5% with depth classification



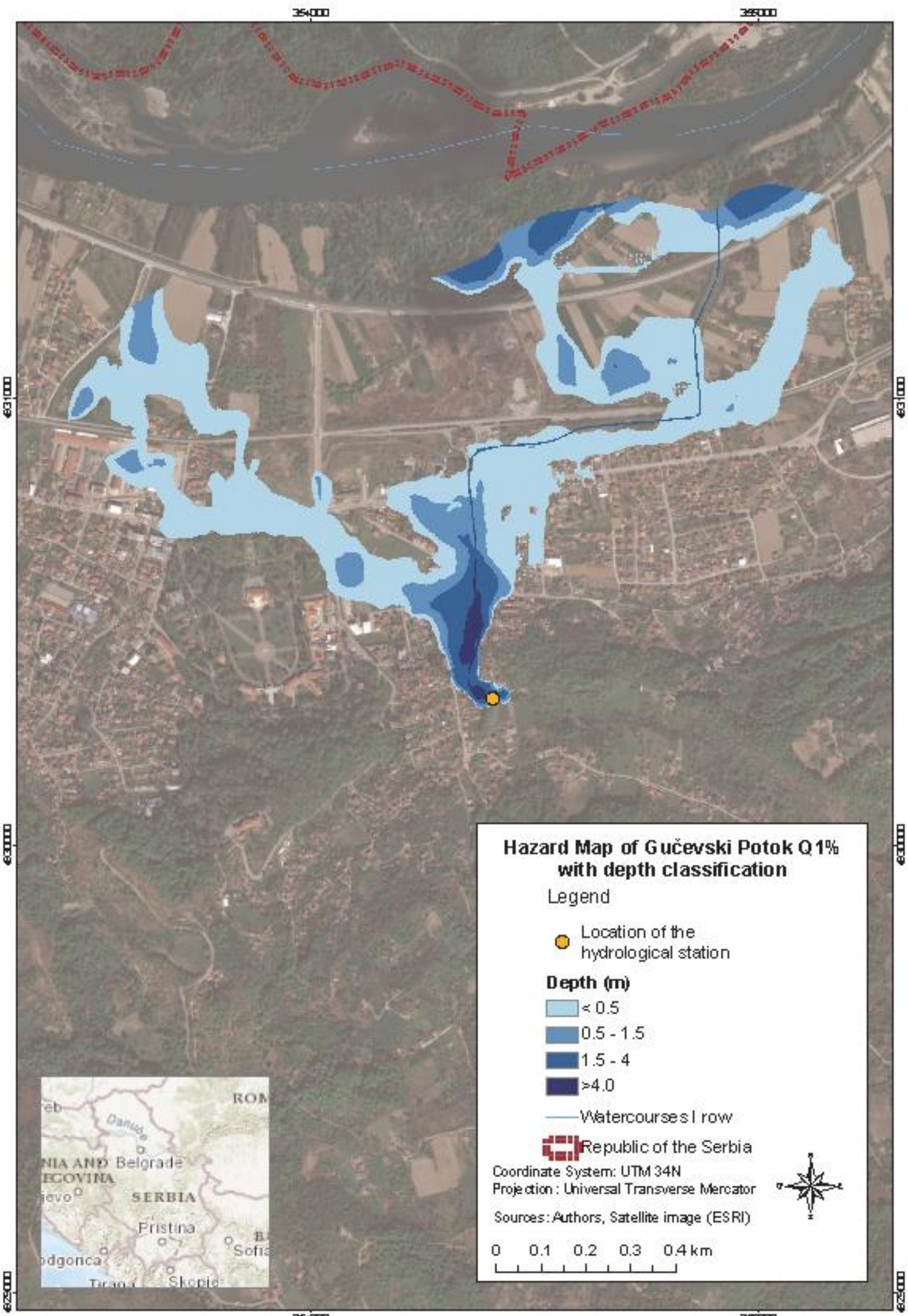
Source: Authors, based on available data

Figure 2.49: Hazard map of Trbušnica river Q10% with depth classification



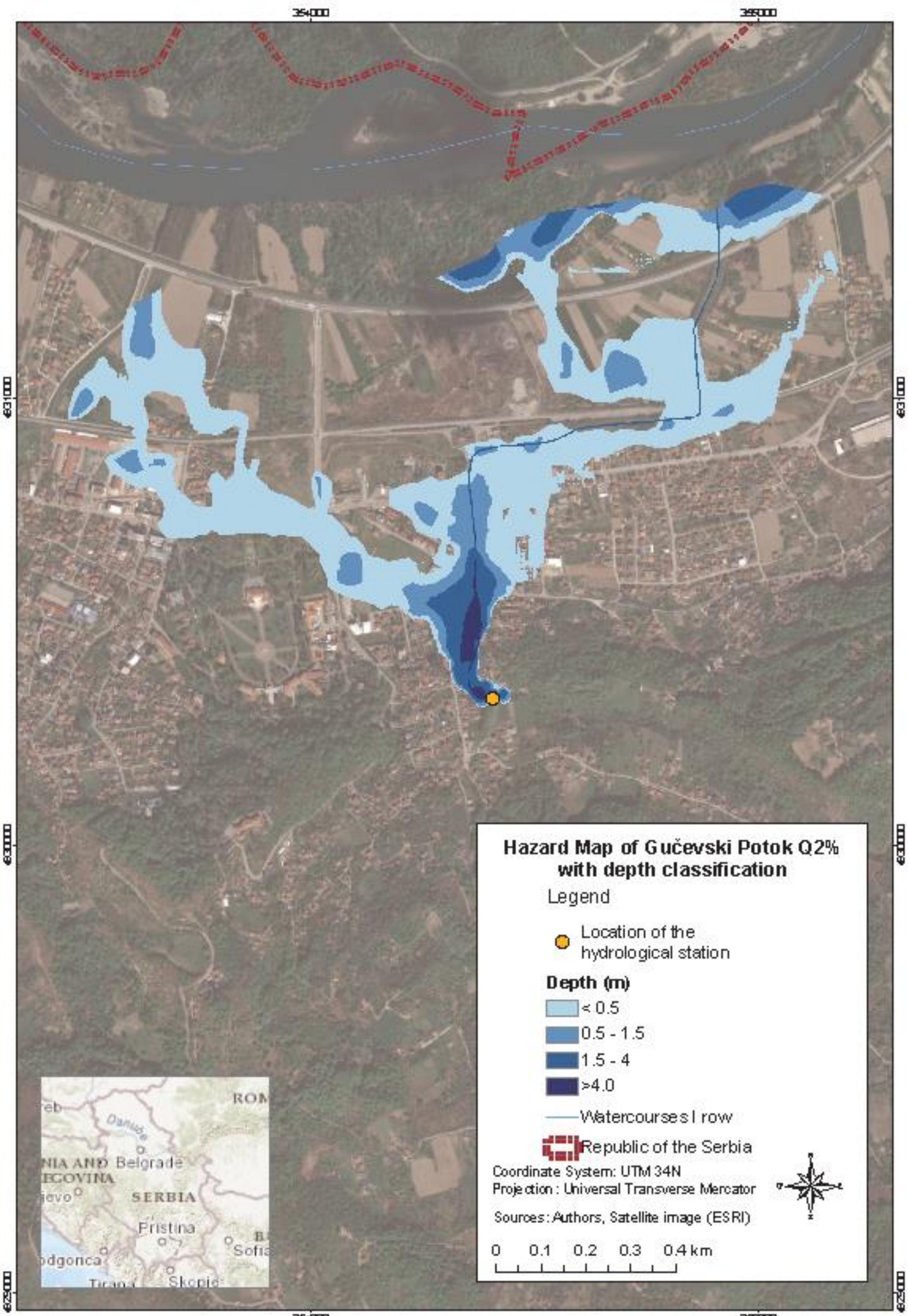
Source: Authors, based on available data

Figure 2.50: Hazard map of Gučevski potok Q1% with depth classification



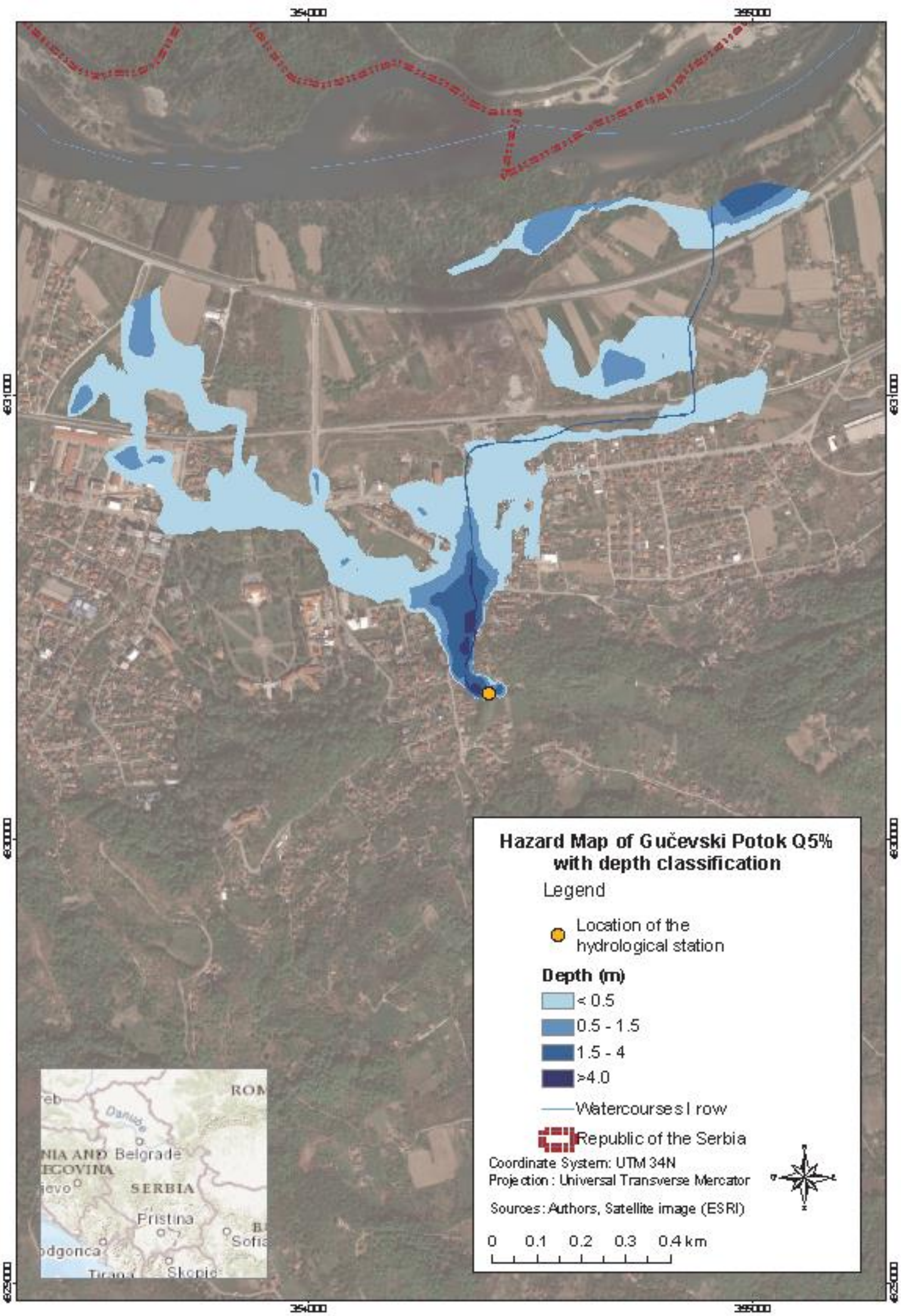
Source: Authors, based on available data

Figure 2.51: Hazard map of Gučevski potok Q2% with depth classification



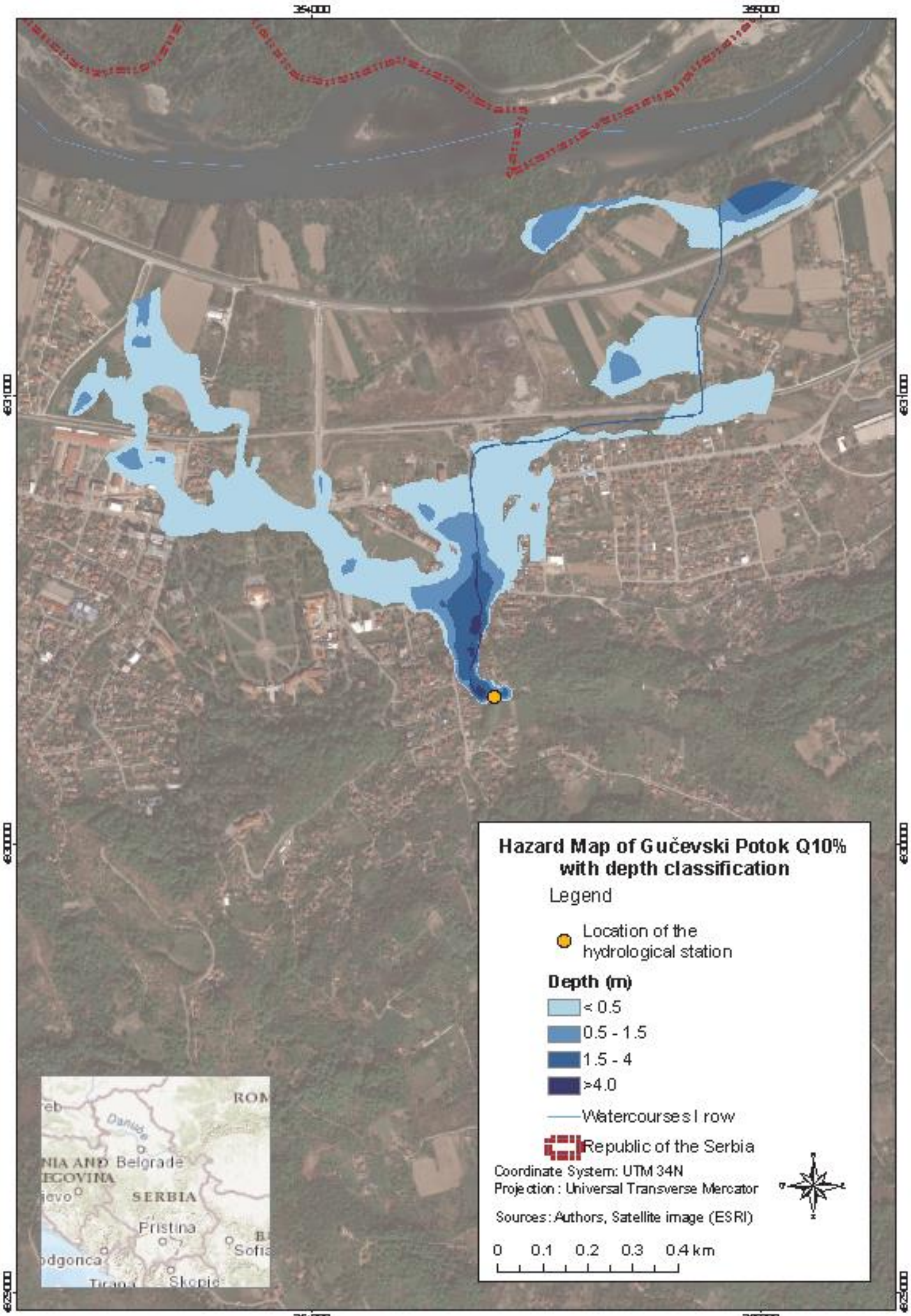
Source: Authors, based on available data

Figure 2.52: Hazard map of Gučevski potok Q5% with depth classification



Source: Authors, based on available data

Figure 2.53: Hazard map of Gučevski potok Q10% with depth classification



Source: Authors, based on available data

2.5.4 Conclusion of hydraulic analysis

After the hydrological - hydraulic analysis of the Trbušnica River and the Gučevski Potok in the area of the designed/anticipated hydrological stations, it was concluded that the calculated and displayed flood zone does not best reflect the situation on the ground in terms of flood risk and that a more precise flood zone is necessary to determine and a more detailed digital terrain model.

In addition to the digital model of the terrain, which can be obtained by various methods of recording and data processing (LiDAR, photogrammetry, etc.), it is also necessary to record transverse profiles of all protected buildings, as well as bridges and river crossings, i.e. all characteristic profiles on the watercourse. Only after the integration of such a digital model of the terrain and recorded protective objects, bridges, crossings, can we consider the flood zone reliable.

2.6. Flood risk analysis in the observed area

Within natural disasters, floods are the most common form of threat to the territory of the city of Loznica, accompanied by landslides, so the risks and damages are great. In the last 18 years, the territory of the city of Loznica was repeatedly affected by torrential floods loaded with a large amount of sediment, which caused the need to take a series of measures to protect people and property and eliminate the consequences, and there was a very close risk of catastrophic damage. The estimated damage from floods in 2001 was 192 million dinars, in 2005 and 2006 it was 250 million dinars, and in 2010 it was 178 million dinars and in 2014 it was 1,527,350,007.00 dinars, while indirect damages significantly higher (data from the Operational Plan for Flood Defense for Tier II Waters for the City of Loznica).

Floods in the territory of the city of Loznica occur as a result of heavy rainfall that leads to the uncontrolled spilling of a large amount of water, mainly torrential watercourses or sudden warming of snow, and often combined. Since the riverbeds are mostly unorganized, winding, overgrown with vegetation, a large number of natural and artificial obstacles within the riverbed with insufficient openings of bridges and culverts, flooding and damage to property and other protected values are very frequent.

The table 2.26 and Figures 2.54 – 2.61 show potentially threatened objects by floods with a certain probability of occurrence. Data on buildings were used from the database of the Republic Geodetic Agency of Serbia.

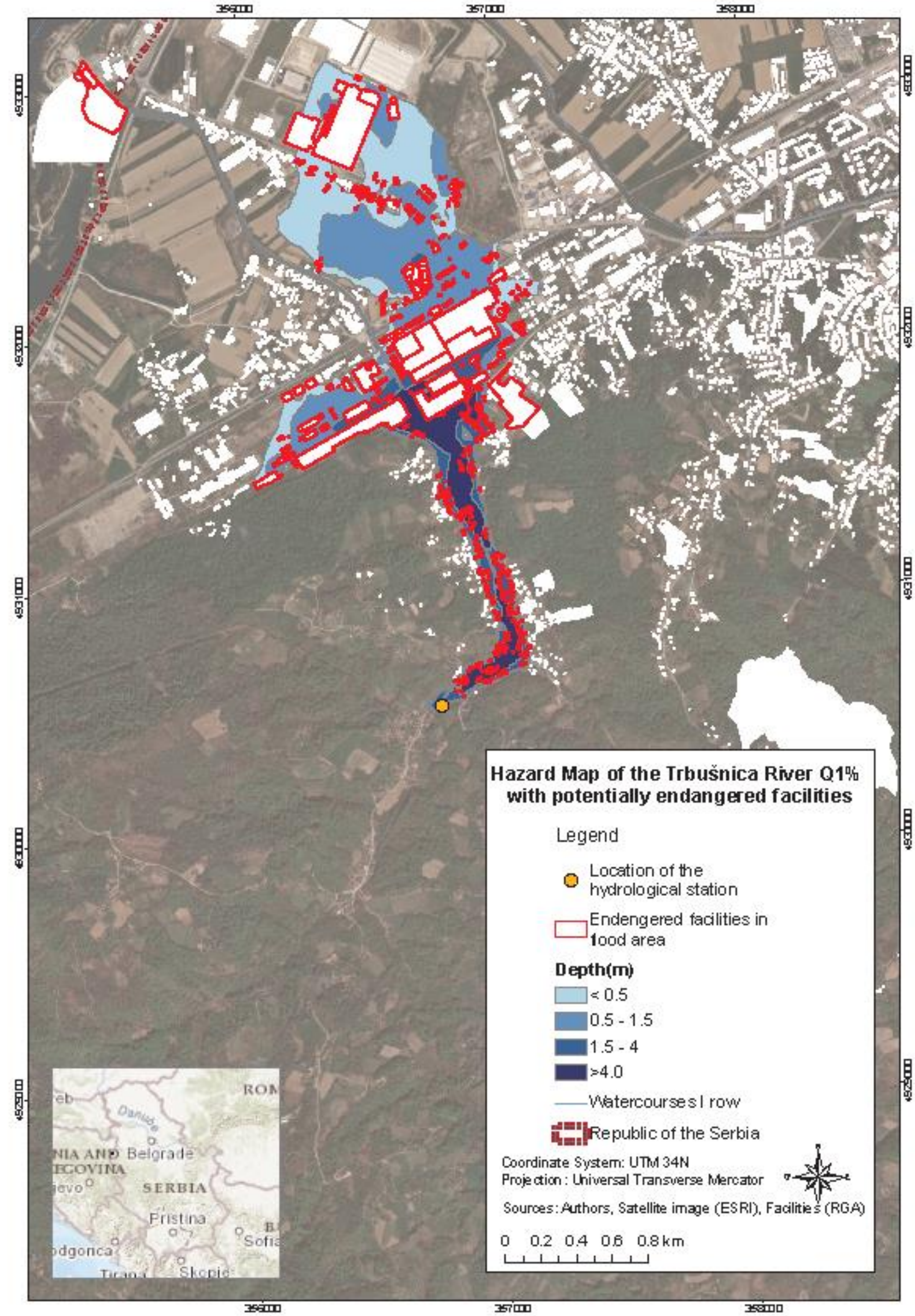
Taking into account the mentioned shortcomings (missing foundations) when determining the flood zone for different probabilities of occurrence, the risk analysis in the observed area carries with it potential errors. It is suggested that a detailed risk analysis be carried out after obtaining all the necessary foundations for hydraulic modeling of the large waters of the Trbušnica River and Gučevski Potok. Also, obtaining geospatial data of all risks in the analyzed area would contribute to a better risk analysis and indicate areas with higher and lower risk of flooding.

Table 2.26: Presentation of the number of endangered cadastral plots, buildings and areas in the territory of the city of Loznica

River	Flows (Q%)	Depth (m)	Endangered area (ha)	Number of endangered objects			Number of endangered cadastral plots		
				Banja Koviljača	Loznica	Trbušnica	Banja Koviljača	Loznica	Trbušnica
Trbušnica	Q1	< 0,5	36	0	194	1	0	335	14
		0,5-1,5	40	0	184	1	0	277	13
		1,5-4	16	0	180	2	0	179	12
		> 4	14	0	124	0	0	113	6
	Q2	< 0,5	42	0	182	0	0	303	12
		0,5-1,5	19	0	115	2	0	183	12
		1,5-4	13	0	137	1	0	131	6
		> 4	3	0	21	0	0	44	5
	Q5	< 0,5	36	0	162	1	0	267	13
		0,5-1,5	13	0	99	2	0	156	12
		1,5-4	11	0	116	1	0	111	9
		> 4	2	0	3	0	0	24	5
	Q10	< 0,5	28	0	137	0	0	241	13
		0,5-1,5	13	0	113	2	0	136	12
		1,5-4	9	0	100	1	0	103	7
		> 4	1	0	1	0	0	18	5
Gučevski potok	Q1	< 0,5	32	281	0	0	519	0	0
		0,5-1,5	7	106	0	0	190	0	0
		1,5-4	4	74	0	0	124	0	0
		> 4	1	24	0	0	48	0	0
	Q2	< 0,5	30	277	0	0	506	0	0
		0,5-1,5	7	113	0	0	195	0	0
		1,5-4	4	72	0	0	115	0	0
		> 4	1	23	0	0	47	0	0
	Q5	< 0,5	26	262	0		433	0	0
		0,5-1,5	5	78	0	0	142	0	0
		1,5-4	3	62	0	0	110	0	0
		> 4	1	13	0	0	37	0	0
	Q10	< 0,5	24	258	0	0	420	0	0
		0,5-1,5	4	91	0	0	149	0	0
		1,5-4	3	58	0	0	102	0	0
		> 4	1	10	0	0	36	0	0

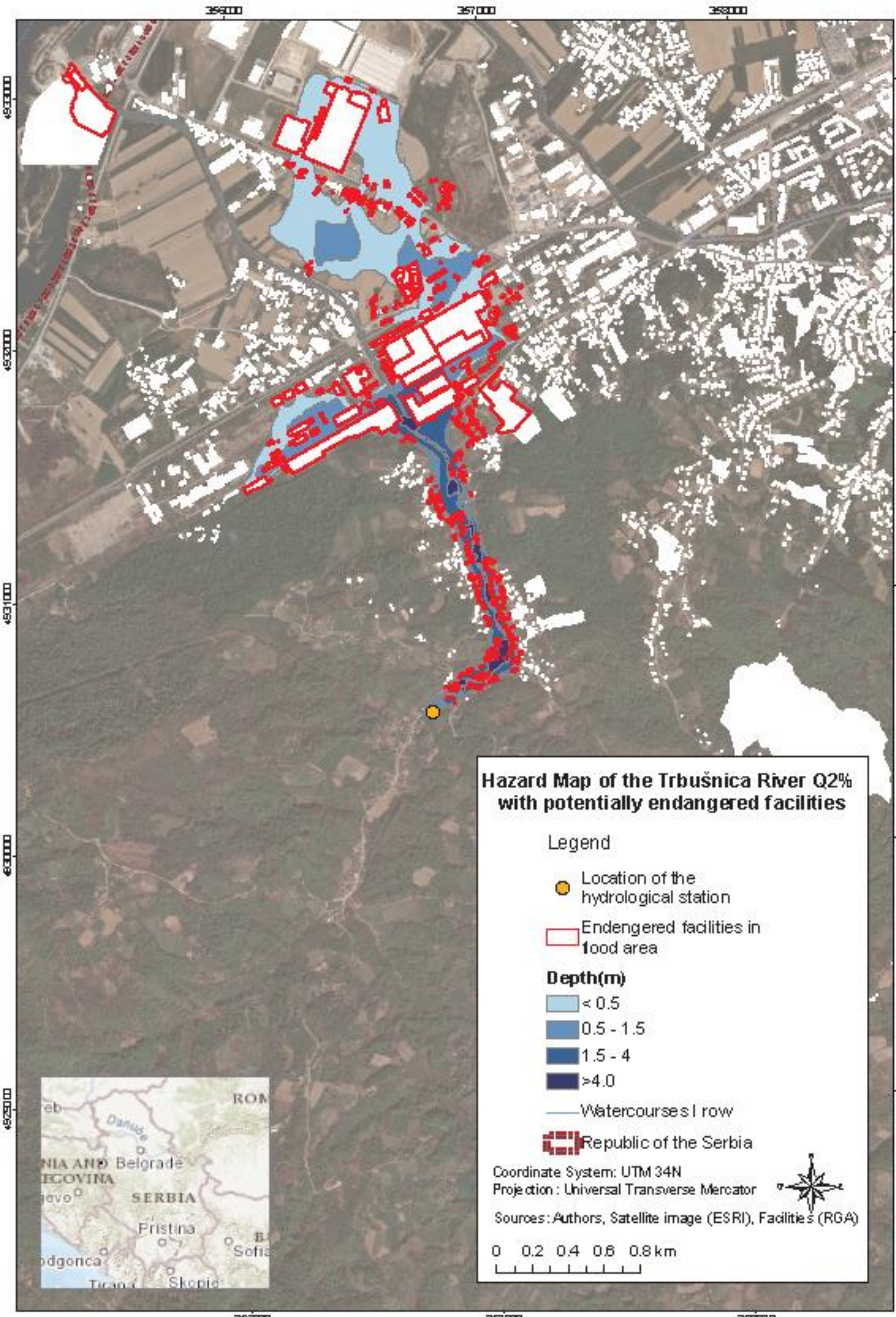
Source: Authors, based on the Republic Geodetic Agency Serbia data

Figure 2.54: Hazard map of Trbušnica river Q1% with potentially endangered facilities



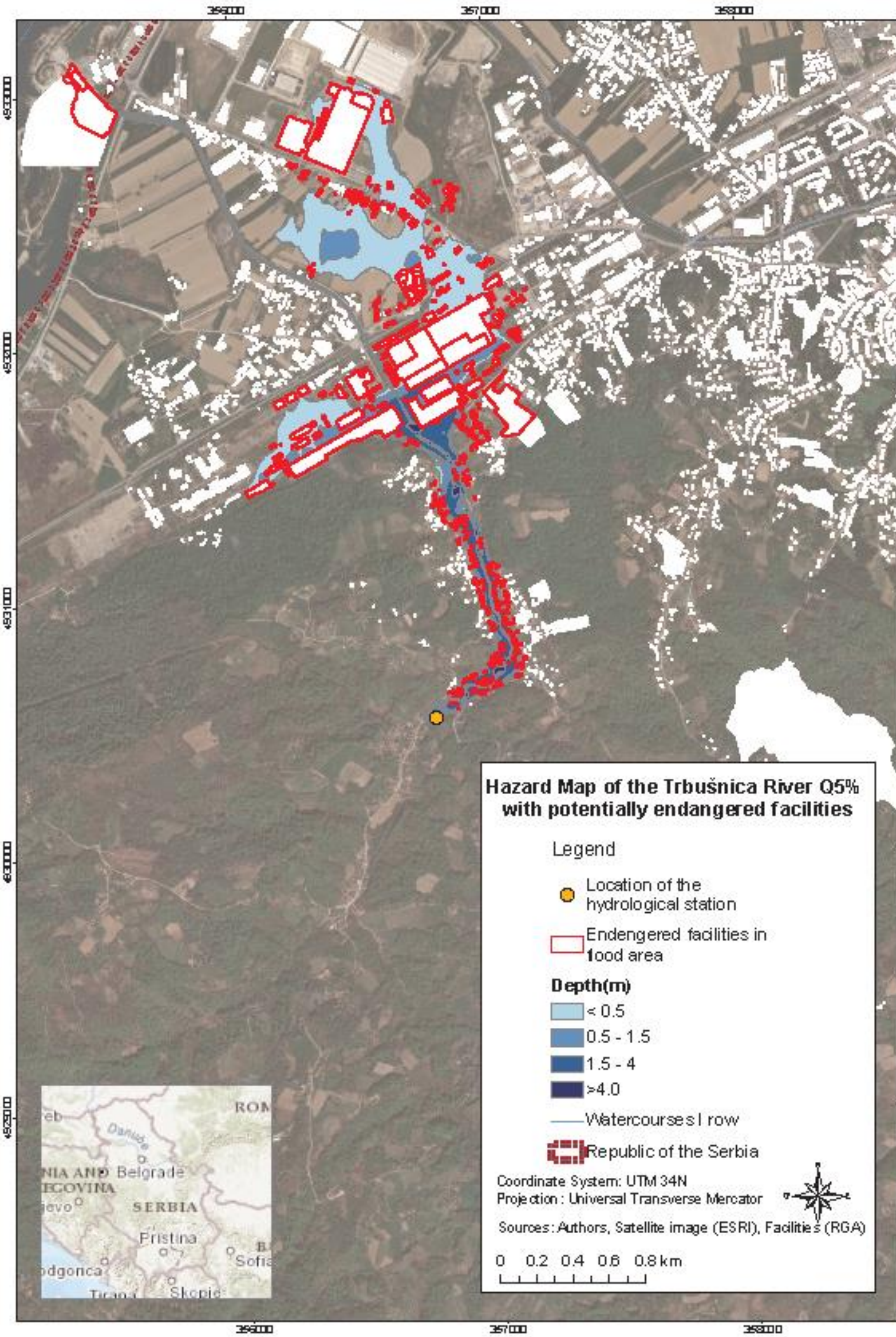
Source: Authors, based on available data

Figure 2.55: Hazard map of Trbušnica river Q2% with potentially endangered facilities



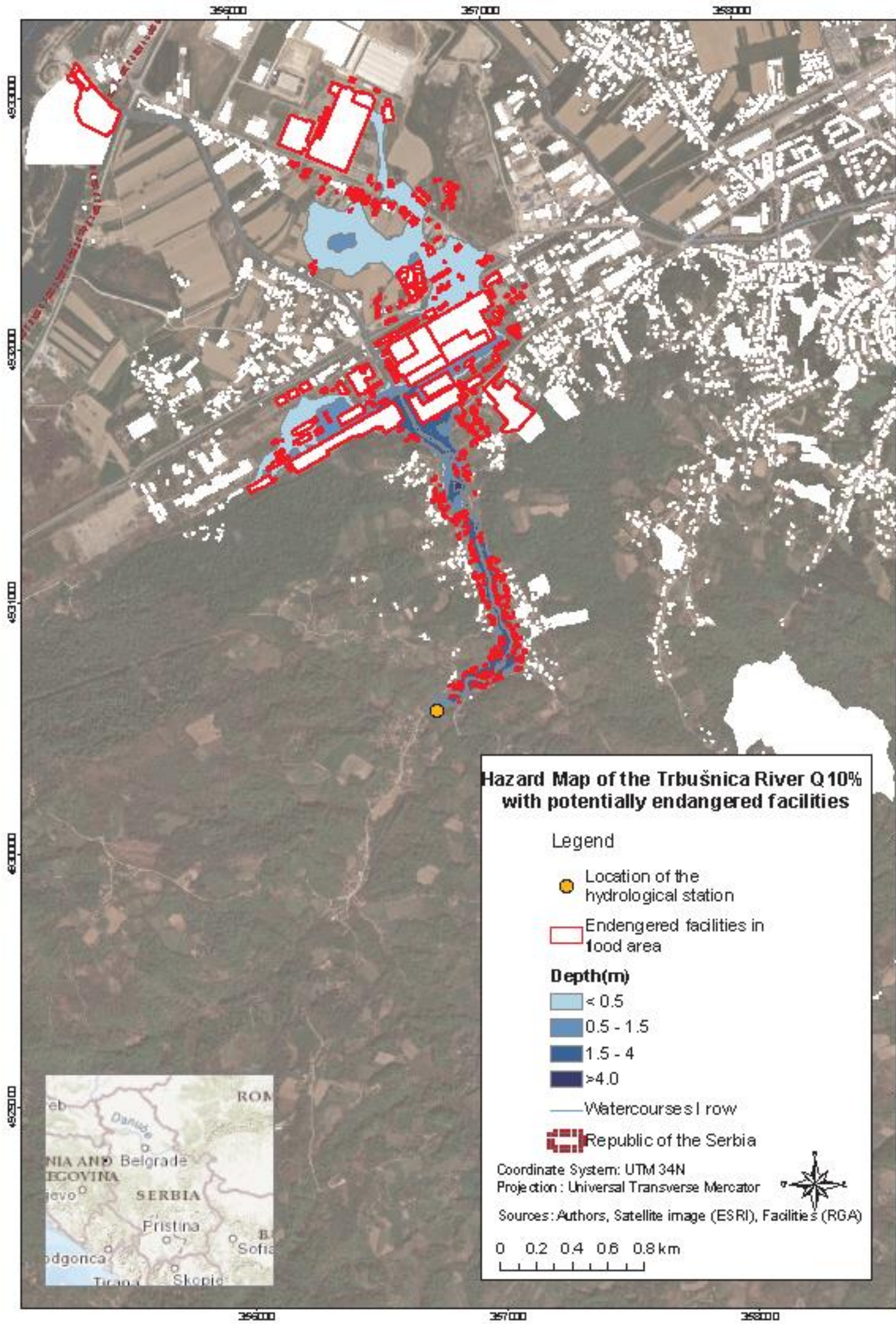
Source: Authors, based on available data

Figure 2.56: Hazard map of Trbušnica river Q5% with potentially endangered facilities



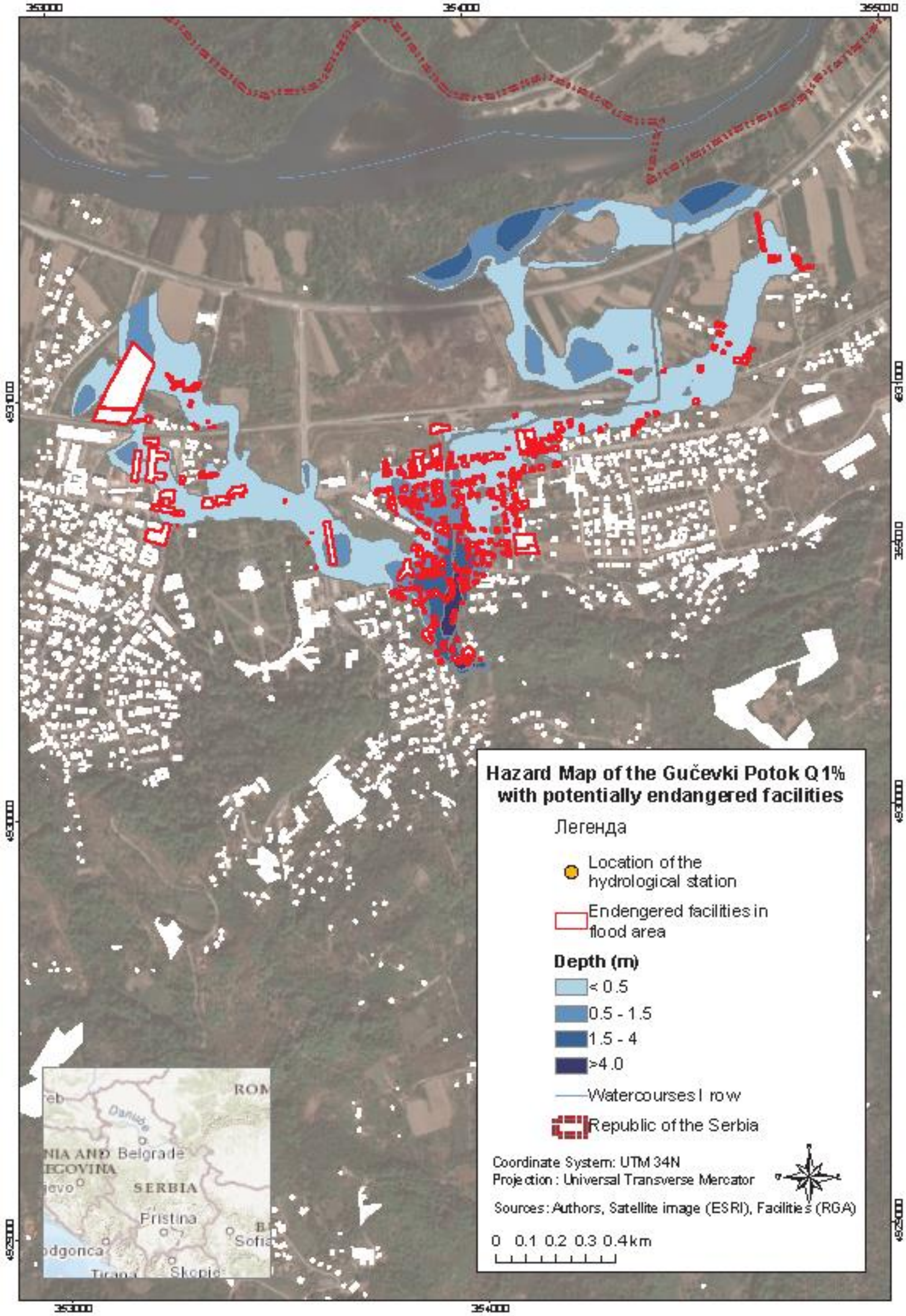
Source: Authors, based on available data

Figure 2.57: Hazard map of Trbušnica river Q10% with potentially endangered facilities



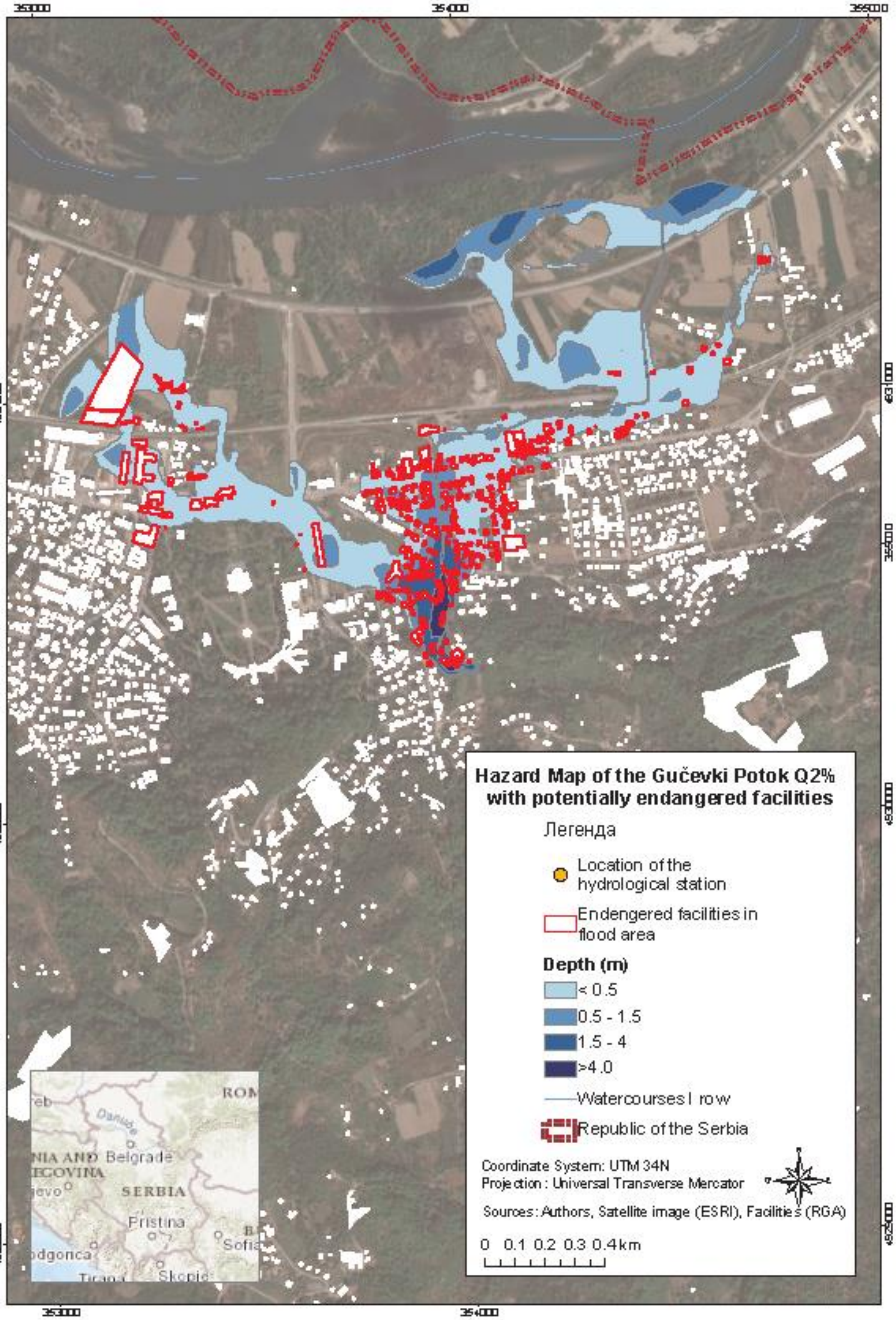
Source: Authors, based on available data

Figure 2.58: Hazard map of Gučevski potok Q1% with potentially endangered facilities



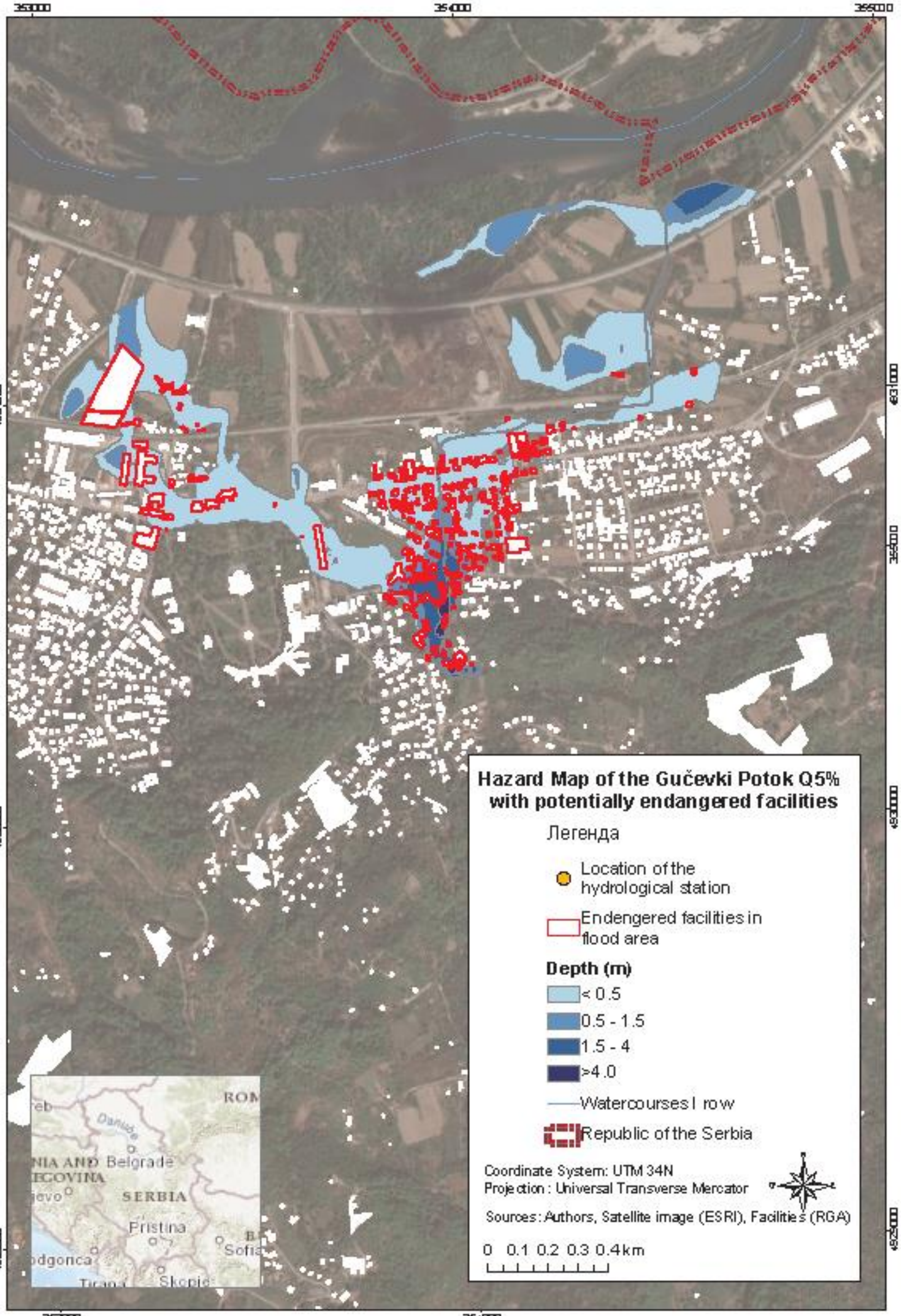
Source: Authors, based on available data

Figure 2.59: Hazard map of Gučevski potok Q2% with potentially endangered facilities



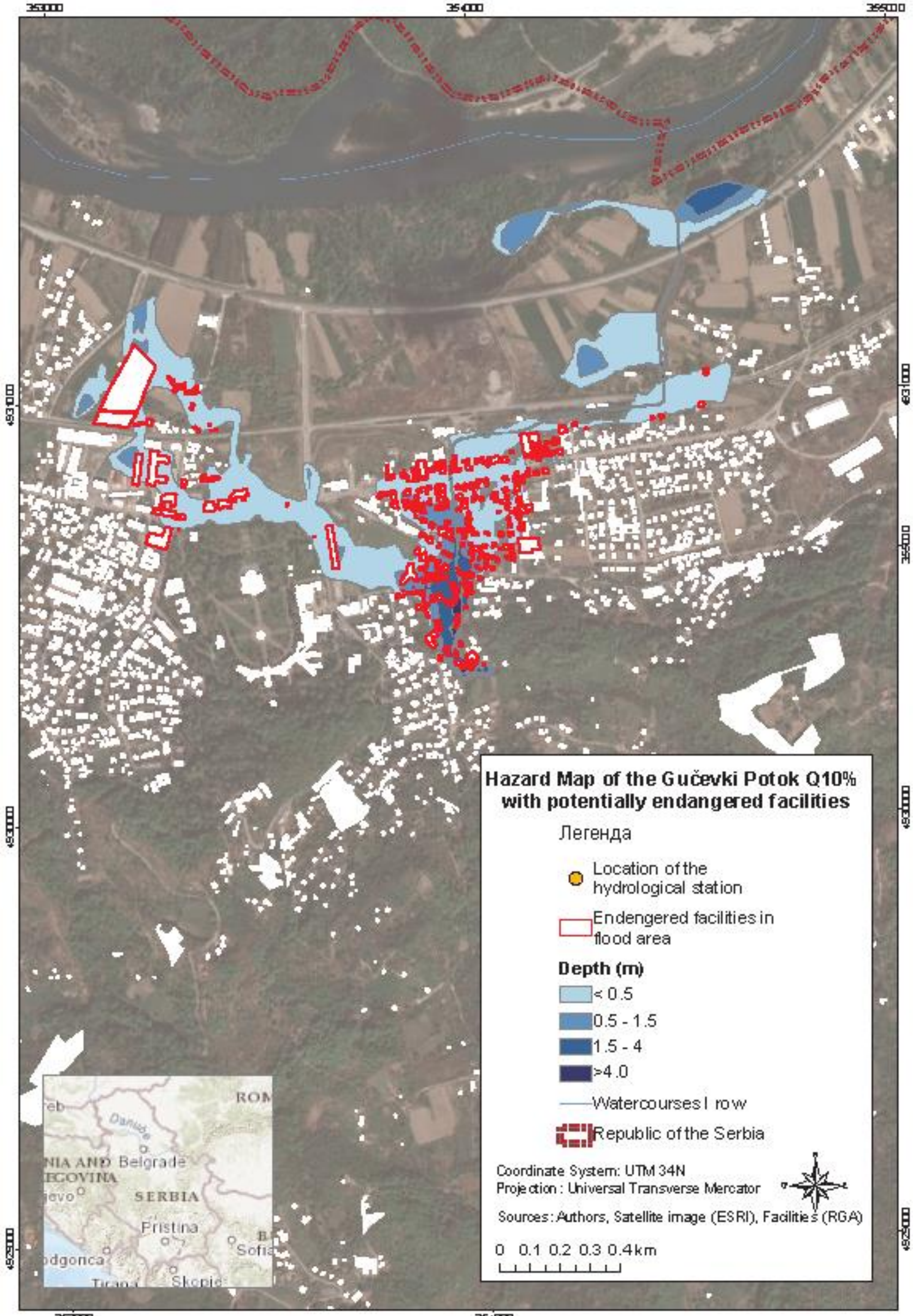
Source: Authors, based on available data

Figure 2.60: Hazard map of Gučevski potok Q5% with potentially endangered facilities



Source: Authors, based on available data

Figure 2.61: Hazard map of Gučevski potok Q10% with potentially endangered facilities



Source: Authors, based on available data

3. TECHNICAL SPECIFICATIONS FOR DATA ACQUISITION AND MEASURING DEVICES FOR THE EARLY WARNING SYSTEM IN DRINA RIVER BASIN

Abstract: In this chapter the technical requirements for Data Acquisition and Measuring Devices for the Early Warning System in Drina River Basin are given in line with the defined scope of work, as well as in line with the information and additional requirements defined in scope of the Project, i.e. given in the other chapters of this Final Report.

According to the defined initial requirements and goals regarding the needed data acquisition and measuring devices, which are presented in clear technical manner, the thoroughly analysis of these requirements is performed, and the main Guidelines for the Development of Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin is provided (in subsections 3.1 - 3.4). In this respect, two different types of measuring station devices were observed: the measuring station for gathering of the water level in the river bed data, and the measuring station for gathering of the meteorological and climate data, with the main difference between these being the required set of physical parameters that must be measured. In order to properly position and observed these measuring station devices, the general concept of the Early Warning System in Drina River Basin from communication point of view is presented (in subsection 3.1), in which the measuring stations are connected to the Internet, and thus to central application server (software), by the means of wireless access network, employing an embedded wireless communication interface module in order to establish the wireless connectivity through the wireless or wired access gateway. Therefore, the basic functionalities for these measuring stations on information and communications technology level are defined. Also, based on these, the essential requirements for these measuring stations devices (as the integrated hardware-software platforms) that should be installed at specified micro-locations are identified, such as requirements related to the suitable communication interfaces that enable reliable interfacing of modules within the platform, adequate wireless interface module for network connectivity, the local processing unit and memory capacity, local software application, detection of emergency (alarm) state, and the adequate electric power supply source, as well as the additional requirements which should be supported in relation to the operational, functional and economical aspects of the observed Early Warning System in Drina River, such as low-cost and low operational expenditures (OPEX) design, the flexibility of design that allows re-configuration and modifications during the development phase and the onsite operation. Accordingly, a demand that development and implementation of measuring stations should be based on commercially available EU (European Union) certified hardware components is set, which support all the operational, functional and economical aspects of the observed Early Warning System in Drina River Basin.

After these more general requirements are summarized, based on the comprehensive analysis of available technologies, as well as the commercially available solutions and hardware components that can support these requirements, the set of general technical specifications for the development of the observed measuring stations are defined (in subsection 3.2). Hence, after the more general specifications, detailed technical specifications related to the environmental requirements (including the enclosure, i.e. casing) for both type of measuring stations are defined (in subsection 3.2.2), as well as those for the electric power supply unit (in subsection 3.2.3), which are defined under a general assessment that the power supply for the measuring station for gathering of the water level in the river bed data should be realized with a battery power supply, while power supply for the measuring station for gathering of meteorological and climate data should in general be realized as the autonomous battery powered supply with the solar panel. Afterwards, the basic requirements (in form of technical specifications) related to the sensor devices needed for the operation of required measuring stations are given (in subsection 3.2.4), in line with the inputs stated in Methodological Guidelines for

Establishment of Early Warning System in River Drina Basin (in section 2), as well as based on comprehensive overview of commercially available sensor devices (with some typical sensor devices given in Appendix 1). Specifically, it is concluded that the ultrasonic-based water level sensor devices should be used for the measuring station for gathering of the water level in the river bed data, the set of sensor devices for the measuring station for gathering of the meteorological and climate data is identified, and the general technical specifications related to these sensor devices are specified accordingly.

Further, in order to facilitate upcoming design, development and implementation of the observed measuring station devices, the basic requirements (in form of technical specifications) related to the operation, measurement, data logging and reporting modes of the observed measuring stations are defined (in subsection 3.2.5). Thus, two operational modes for the measuring station device that must be supported are identified (i.e. active operation mode and power saving operation mode) and thoroughly specified. Also, two reporting modes that must be supported are identified (i.e. regular reporting mode and emergency reporting mode) and specified, including the required options that allow transition between these modes. Moreover, the general technical specifications related to the default operation, measurement, data logging and reporting modes, separately for the set of sensor devices for both type of measuring stations, are specified and presented.

After that, the basic requirements related to the types and formats of transmitted messages are defined (in form of technical specifications). Thus, the general specification of the uplink message format for both type of observed measuring station devices are given (in subsection 3.2.6). Based on these, the required storage capacity for the acquired measurement data at the central application server on the daily and on the monthly basis per one measuring station (separately for both type) is calculated, as well as the required local storage capacity, which should be provided in measuring stations, for (optional) data logging of the acquired measurement data on the daily and weekly basis.

Finally, the issue of measuring station devices network connectivity is thoroughly analyzed (in subsection 3.2.7), and the basic requirements for the wireless/wired communication technology able to provide reliable, secure and available network connectivity are provided in details (in the form of technical specifications), with the LoRaWAN (Long-Range Wide Area Networks) technology found to be the most suitable options. Also, some additional basic requirements related to the installation, maintenance and setting of measuring stations devices are specified (in subsection 3.2.8).

The general guidelines on the possible approaches to design, development and implementation of the observed measuring stations are also defined (in subsection 3.3). The general implementation block (design) schemes for development of the required measuring station devices are presented and elaborated. In scope of this, several options are presented: the general implementation (design) block scheme for the design and development through the integration by using separate modules (control module, sensor devices, communication devices, power supply module, etc.), marked as “design from the scratch”, a general implementation (design) block scheme for the design and development through the integration by using integrated wireless sensor nodes (with or without internal power supply) and sensor devices, and a general implementation (design) block scheme for the design through the acquirement and adjustment of existing and commercially available measuring station solutions. Also, in all three cases the solution with the power supply based on battery unit (internal or external), or the solutions with the autonomous battery powered supply with the solar panel (or other external power source) are described and observed. As a result, the general recommendation for the design, development and implementation of the observed measurement stations is given, and general comparison of these possible measuring station devices design and implementation options is presented in tabular form taking into the account factors related to the design and development process, the level of possible risks of unsuccessful or inadequate design and development, factors that influence the final solution cost, and production cost of the designed and developed measuring station devices when the design and development cost are excluded. Also, to facilitate future design and development process, the general operation flowchart for the realization of the measurement, reporting and reception cycle during the typical active operating mode are given for the both type of required measuring stations. Also, the general guidelines and requirements on the measuring station location selection, installation, and measuring station maintenance are stressed.

In the end, these technical specifications are concluded (in subsection 3.4) with a definition of basic requirements related to the required certification process as the part of design and development process of here observed measuring stations (i.e. Data Acquisition and Measuring Devices) as the electric and electronic devices. Beside thus, as separate appendices (i.e. Appendix 1 and Appendix 2), the overview of some typical commercially available sensors devices, wireless sensor devices and measuring stations that satisfy basic requirements for the observed measuring stations is provided, as well as the overview of some typical integrated wireless sensor node devices that may be used for the development of the observed measuring stations. The scope of these appendices is to present some of the typical commercially available sensor devices and wireless sensor devices for the required measurements (i.e. water level, precipitation, soil humidity and air temperature), and the complete measuring stations, that cover all demanded measurements (i.e. the described solutions are selected based on previously defined measurements requirements and technical specifications).

3.1 The overview of the initial requirements for Data Acquisition and Measuring Devices

The initial requirements and functionalities, as defined in section 2 (i.e. Methodological Guidelines for Establishment of Early Warning System in Drina River Basin), which must be supported by the Data Acquisition and Measuring Devices, and consequently covered and mandatory supported by these technical specifications, are:

- Two different types of sensor nodes (i.e. Data Acquisition and Measuring Devices) are required for the establishment of Early Warning System in Drina River Basin, that is:
    - The measuring station for the gathering of meteorological and climate data, which comprises the measurement equipment capable of measuring the amount of liquid precipitation over a period of time (i.e. rain gauge or pluviometer station), soil moisture and air temperature. The measurements are expected to be performed as 24/7/365 process (i.e. constantly, throughout the entire day, and on every day of the year - 24 hours a day, 7 days a week, 365 days a year), with all the measured date being sent periodically to the central software application of the Early Warning System (i.e. to Data Acquisition, Distribution and Early Warning Software) with the regular reporting period not longer than 60 minutes and the emergency (urgent) reporting period of 15 minutes or 60 minutes depending on the measured parameter. The required measurement resolution for meteorological and climate parameters are defined as:
        - The measurements of the liquid precipitation over a period of time (i.e. rain gauge or pluviometer station) should be performed every 15 minutes, with the resolution of 0.5 mm, and with the regular reporting period of 60 minutes and emergency reporting period of 15 minutes (if not defined otherwise in the Final project report),
        - The measurements of the soil moisture should be performed every 15 minutes, with the resolution of 5%, and with the regular reporting period of 60 minutes and emergency reporting period of 60 minutes, and
        - The measurement of the air temperature should be performed every 15 minutes, with the resolution of 0.1°C, and with the regular reporting period of 60 minutes and emergency reporting period of 60 minutes.

    Notice: The choice of location for the installment and other operational requirements of this measuring station are defined in section 2. The possibility to change reporting period through the use of remote control of the measurement station is defined as optional, while possibility to generate the automatic reporting (i.e. transition to emergency reporting mode) based on the measured data (i.e. when the measured data pass the predefined thresholds) is here defined as the mandatory one. The choice if some of measured data, specifically the air temperature and the soil moisture, should be reported constantly (i.e. the current temporal values) in the form of periodical hourly reports (as defined in this document), or instead, only the daily reports should be sent containing the minimum, maximum and average values, should be determined in design and development phase.

The measuring station for the gathering of the water level in a river bed data. Measurements are expected to be performed as 24/7/365 process (i.e. constantly, throughout the entire day, and on every day of the year - 24 hours a day, 7 days a week, 365 days a year), with all the measured data being sent periodically to central software application of the Early Warning System (i.e. to the Data Acquisition, Distribution and Early Warning Software) with 5 minute measurement period, and with the regular reporting period of 15 minutes and the emergency (urgent) reporting period of 5 minutes. The required measurement resolution for the water level in the river bed measurements is defined as 1 mm, while the requested measurement accuracy is 1 cm. **Notice:** The choice of location for the installment and other operational requirements of this measuring station are defined in section 2. The possibility to change reporting period through the use of remote control of the measurement station is defined as optional, while possibility to generate the automatic reporting (i.e. transition to emergency reporting mode) based on the measured data (i.e. when the measured data pass the predefined thresholds) is here defined as the mandatory one.

- The Early Warning System in Drina River Basin should also enable to download required meteorological and climatic data from the existing meteorological stations in the area of interest (the fixed stations of the Republic Hydro meteorological Service of Serbia). **Notice:** This feature should be provided by the central software application of the observed Early Warning System (i.e. Data Acquisition, Distribution and Early Warning Software);
- The data and message formats used for the purpose of data gathering and distribution in the observed information and communications technology (ICT) system should be compatible with the Data Acquisition, Distribution and Early Warning Software;
- The choice of micro-locations for the instalment of the observed measuring stations is very important for the successful operation of the Early Warning System in River Drina Basin, and should be done according to the criteria defined in subsection 2.3.1, for the measuring stations for the gathering of meteorological and climate data, and the criteria defined in subsection 2.3.5 for the measuring stations for the gathering of the water level in the river bed data;
- For the specific target area, the selected micro-location in Drina River Basin (i.e. the river basins of Trbušnica and Gučevski potok), the relatively small number of measuring stations (i.e. Data Acquisition and Measuring Devices) is required. Thus, a relatively small number of measuring stations could also be expected for other micro-locations in the targeted River Drina Basin, thus resulting with up to several hundred measuring stations for the entire River Drina Basin. For the specific micro-location the following measuring stations are required:
    - The one measuring station for the gathering of meteorological and climate data, which should be located in the vicinity of World War I monument at the Gučevo Mountain summit); and
    - The two measuring stations for the gathering of the water level in the river bed data, the one for the river Trbušnica and the one for the Gučevski potok, with the specific locations defined in section 2;
- The measurement stations should be realized as the outdoor installed electronic devices, capable of working under the harsh outdoor environmental condition; and

- In order to lower the capital expenditures (CAPEX) and operational expenditures (OPEX) for the Early Warning System for the Drina River Basin as a whole, the main storage, measured data processing and alarming capabilities of this system should be realized on the system level, as the functionalities of the central software application of Early Warning System (i.e. the Data Acquisition, Distribution and Early Warning Software) and not at the measuring stations (i.e. Data Acquisition and Measuring Devices). Therefore, the measuring stations are expected only to periodically perform the required measurements and send reports (in the regular manner or in emergency manner) on the measured parameters towards the central software application of the Early Warning System, with the minimum local storage and processing capacity needed. **Notice:** The additional refinement (in comparison to the one defined in these technical specifications) of the measuring stations reporting model, can be done during the design and development phase (when the specific hardware and software options would be known), in order to ensure further energy savings of the measurements stations (i.e. the higher level of energy efficiency), to reduce the required capacities of the wireless communication links, as well as to reduce CAPEX and OPEX, without the loss in the measurement and reporting performance at the system level.

3.2 The main Guidelines for the Development of Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin

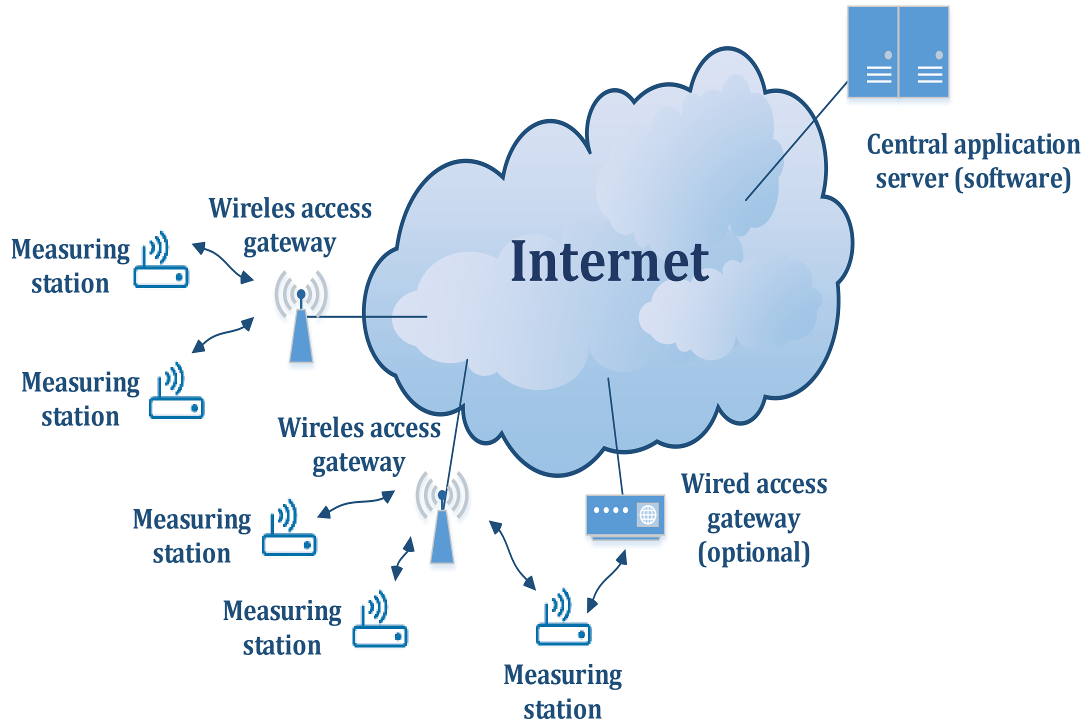
According to the previously given initial requirements for required Data Acquisition and Measuring Devices (i.e. measuring station devices or sensor nodes), it is necessary to develop two different types of measuring station devices (i.e. the appropriate Data Acquisition and Measuring Devices):

- the measuring station for gathering of the water level in the river bed data (RBWL-MS), and
- the measuring station for gathering of the meteorological and climate data (MCD-MS).

The main difference between these two types of measuring stations is the required set of physical parameters that must be measured. This may results with a slightly different technical specification related to the energy consumption, the hardware and software complexity, the supported modes of operation and reporting, etc. In fact, the RBWL-MS device must enable the reliable and automatic remote monitoring (i.e. data acquisition and measuring) of single physical parameter, the water level in the river bed, which can be realized by using a single sensor device. On the other hand, the more complex MCD-MS device must enable the reliable and automatic remote monitoring and measuring of several physical parameters (i.e. precipitation, soil moisture and air temperature), which demands employment of the several sensor devices. Therefore, in the following technical specifications these two different types of measuring stations are treated separately, except in a case when some general requirements are considered that are common for the both types of these measuring stations.

We here considered a general concept of the Early Warning System in Drina River Basin from the communication point of view, in which here observed measuring stations (i.e. Data Acquisition and Measuring Devices) represent the end points, i.e. IoT (Internet of Things) sensor node devices, of this system, while the central application server (on which the central application software of the system operates) presents the central point of the system, which can be implemented as the separate application server with the Internet access, the application on data center platform, or as the cloud-based solution, as in Figure 3.1. In this concept, the observed measuring stations are connected to the Internet, and thus to the central application server (software), by the means of wireless access network, employing an embedded wireless communication interface module in order to establish the wireless connectivity through the wireless access gateway (i.e. GSM/GPRS, UMTS/3G, LTE/4G, NB-IoT/4G, 5G, LoRaWAN, WLAN, etc.), or in some specific case by using the wired access interface, as an additional optional solution, to connect to the wired access gateway (i.e. cable connection to Ethernet/IP router).

Figure 3.1: The general concept of the Early Warning System in Drina River Basin from the communication point of view



Source: Authors

Based on this general concept, there exist multiple available technology solutions able to provide suitable network connectivity of the considered measurement stations with the central application server of the observed system, and also able to fulfill the specific requirements for the both type of measuring stations. However, for all these solutions it is necessary to provide support of basic functionalities for these measuring stations on ICT (Information and Communications Technology) level, such as:

- the end-to-end network connectivity of all the measuring station devices (sensor node devices) in the system must support IP (Internet Protocol) based access of the central application server (software application), with the following requirements: the reliable and timely transmission of all measured data and sensor device status information (e.g. remaining battery supply capacity) towards the central application server (with specified reporting period, reporting modes, latency and reliability), the adequate support for the remote control, configuration (re-configuration) and management of all the measuring station devices in the system, and
- the support for the regular operation of sensor functionality (i.e. the required data acquisition and measurement), which includes: the local (onsite) and/or remote control of one or more sensor devices connected to measuring station, support for temporary local storage, the local processing and analysis (i.e. the measurement data averaging, the detection of alarm/emergency state as the crossing of some predefined threshold values) for the specified reporting periods as required by the specific measurement procedures (depending on the type of the particular sensor device) and/or the reporting modes (i.e. the regular periodic reporting mode and the emergency reporting mode triggered by the locally generated alarm or the remote downlink commands sent to the measuring stations by the central application software).

The general technical solution for development of the required measuring stations, as presented in this document, define the adequate technical specifications for the observed measurement stations (as the integrated hardware-software platform) that should be installed at the specified micro-locations, and which must enable:

- The seamless local connection (interfacing) of the all sensor device units within the given measurement station and further towards the central application server (by the supported wired or wireless communication interface module),
- The suitable configuration of the operational parameters (i.e. default pre-deployment and onsite configuration of sensor devices, reporting parameters, local processing, storage and/or alarm detection parameters) and the communication settings for the development of measuring station devices,
- The support for remote re-configuration for the considered measuring stations (if needed), and
- The support for the local storage, processing and analysis of all the measured data, including the local detection of the emergency (alarm) state based on the predefined threshold values.

In this respect, there are several essential requirements that must be supported:

- Sensor devices must support suitable communication interface (i.e. common RS-485 or RS-232 interfaces) for the connection within the measurement station device, while the measurement station device as a whole must enable local access, i.e. via NFC (Near Filed Communication), Bluetooth or USB (Universal Serial Bus) interfaces, for the onsite and the pre-deployment configuration purposes;
- Measurement station devices must provide adequate wireless interface module (i.e. GSM/GPRS, 4G/NB-IoT, LoRaWAN), and optionally can provide additional wired Ethernet connectivity, for the support of required network connectivity;
- Measurement station devices must provide local controller (processing) unit as well as the local software application which is responsible for the proper operation of the measuring station as a whole, including: sensory functionality in line with the predefined measurement procedure for the each measured physical parameter, implementation of timely reporting on measurement data and other status data towards the central application server (software) by using provided communication interface module in line with the predefined reporting modes, the support of local processing, storage and analysis of measurement data, and the realization of the remote control and (if used) re-configuration by the central application software,
- Measurement station device must provide sufficient local memory capacity (internal ROM/RAM memory and/or optional external memory, i.e. MicroSD cards) for the purpose of the local storage of measurement and analysis data, with the required capacity defined depending on the set of measurements provided by specific device;
- Measurement station device should support (if so defined) detection of emergency (alarm) state occurrence based on the predefined threshold values, and optionally can support device status alarm (i.e. security alarm, battery supply depletion alarm);
- Measurement station device must provide adequate electric power supply source (with specified parameters and the suitable capacity for the envisioned device operational lifetime), i.e. battery supply unit or an autonomous power supply based on solar power source. Optionally, the direct power supply from the electric power distribution grid may be provided if there is the access to the power grid on the specific location of the measuring station (i.e. on installation site).

Additional requirements that should be supported related to the operational, functional and economical aspects of the observed Early Warning System in Drina River Basin are:

- The developed and implemented measuring station devices must present the low-cost solutions (in comparison with the already available solutions on the market);
- The developed and implemented measuring station devices operation should be the automatic, remote-controlled and highly energy efficient in order to result with the lowest operational expenditures (OPEX) possible, and to allow the long-term operation without the frequent onsite maintenance (i.e. repairs or battery replacement);
- The design of developed measuring stations should be flexible enough to allow re-configuration and modifications related to the issues that arise during the system testing and operational deployment (i.e. due to the issues unforeseen in development and implementation phase), as well as to enable the long-term operation disregarding technological, operational and other changes introduced to the central application server (software); and
- The design, development and implementation of measuring stations should be based on the commercially available EU (European Union) certified hardware components (i.e. that possess EU declaration of conformity), provided with the corresponding firmware (which should be predominantly the low-cost solutions), which satisfy all basic technical requirements, and that can be acquired with the minimum 2 year warranty.

3.2.1 The general technical requirements for development of measuring stations

The measurement stations should be realized as the outdoor installed electronic devices capable of operating under the harsh outdoor environmental conditions, and without the additional (special) casing equipped with the additional support of HVAC (heating, ventilation, and air conditioning) regulating equipment.

Taking into the account so far defined locations for measuring station placement for the selected micro-location in Drina River Basin (as given in the previous section), as well as the expected locations for both types of measuring station in the broader Drina River Basin area (which should be determined by using the same methodology as defined in other project reports), the measuring stations are expected to be installed in rural environment and mostly far away from the settlements and populated areas, with the low probability of viable access to the electrical power distribution grid and the wired or the short-range wireless communication infrastructure (i.e. access network infrastructure). Thus, the operation of developed measuring stations must be supported without the local connection to the electrical power grid and the communication access networks, such as Internet access via optical or copper cables, WLAN (Wireless Local Area Networks) or WPAN (Wireless Personal Area Networks). This also conditions that measuring stations must be completely automatic, remotely controlled devices, i.e. the self-sustained devices without the continuous human control and supervision on the site, with the low requirements related to their onsite maintenance and operating support. That is, only rare visitation of sites for the purpose of battery replacement, installation checks, emergency data download and re-configuration of the operating measuring devices can be planned or expected. Furthermore, the measuring station, in general, must support autonomous operation in terms of the electric power supply and network connectivity, which should be realized by using long-range low-power wireless communication technologies, such as LPWAN (Low Power Wide Area Networks).

3.2.2 The basic environmental requirements (general technical specifications)

The previously discussed conditions for the employment and installation of the observed measuring stations in the rural environment and the uncontrolled weather and climate conditions, causes very strict requirements related to the operational environment and the casing (i.e. enclosure) of these measuring stations as a whole, and for all the separate parts (i.e. the separately enclosed wireless communication interface modules and/or micro-controller unit modules, the separately enclosed sensor devices, cable interfaces, etc.).

Taking into the account expected working conditions and installation environment, the enclosure of the measuring station devices (as integrated solutions and/or separately enclosed modules), must enable proper intrusion protection so that:

- Total dust tight is realized (i.e. full protection against dust and other particulates, including a vacuum seal, tested against continuous airflow);
- High level of moisture protection (i.e. the protection against low-pressure jets of directed water from any angle, with the limited ingress permitted with no harmful effects, or the protection against direct high pressure jets), and
- The casing must also provide resilience to the Ultra-Violet (UV) radiation.

The general technical specifications on the environmental requirements are given in Table 3.1, and these are same for both type of measuring stations (RBWL-MS and MCD-MS devices). These technical specifications are valid for the integrated devices (i.e. the measuring station devices implemented in the single enclosure), and also for all the separately enclosed modules and cable interfaces of the measuring station installation.

Table 3.1: The general technical specifications related to the environmental requirements for both type of measuring stations

Operating temperature	-30°C to +60°C
Operating humidity	0 -100 %
Ingress protection	IP66 (minimum IP65)
Enclosure	UV resistant (Anti-UV) polycarbonate plastic
Mounting	DIN rail, wall, pole
Additional	Seamless access to input/output interfaces CE marking certification must be supported

Source: Authors, based on available data

3.2.3 The basic requirements for electric power supply (general technical specifications)

Considering previously defined general requirements and the expected installation in predominantly remote and rural environment, the several feasible power supply options for measurement stations can be considered:

- The regular 220 V AC power supply from the electric power distribution grid can be observed. Yet, its availability highly depends on the specific installation location (measurement point). Then again, the general assumption is that in most of the expected measurement points this kind of power supply will not be available. Thus, this power supply option can be considered only as the optional one. Taking into the account the comprehensive overview of the commercially available measurement station solutions (with some of them given in Appendix 1), this optional solution is suitable only for the measurement station intended for gathering of meteorological and climate data (MCD-MS), characterized with the higher power consumption;
- The more general option is the battery power supply. There are existing battery powered wireless sensor devices (see Appendix 1) based on LoRaWAN and NB-IoT LPWAN technologies that are designed to work without the external power supply (i.e. from the electric power grid or autonomous power supply with the solar panel), with the expected life time spanning to the several years. There are also available (see Appendix 2) battery powered general integrated wireless sensor nodes that enable porting of one or more sensor devices. These devices are designed as highly

energy efficient and can be used for the development and implementations of both observed measuring stations (this will be considered in more detail in Section 3.3). Therefore, in the case of specific design of measurement station devices, with the highly energy efficient communication and operation (with the low duty cycle, i.e. duty cycle below 1% as defined for LoRaWAN devices), the battery powered supply can be absolutely viable solution. This solution is considered as the most favorable if the device cost, the required maintenance and complexity are observed, and can be highly recommended for the design, development and implementation of RBWL-MS devices, since it is characterized with lower power consumption. Nevertheless this solution may not be viable for the higher power consuming MCD-MS devices;

- The power supply based on the autonomous battery powered supply with the solar panel. This solution can be considered recommendable (due to the higher cost and complexity) only if the battery power supply option is not viable, i.e. in a case of the measurement stations for gathering of meteorological and climate data (MCD-MS devices), characterized with the higher power consumption. There are specific commercially available modules with the lower power supply capacity suitable for here observed application scenarios. These modules consist of solar power, power management unit and battery unit. Also, a specific solution of this kind may be developed and designed according to the requirements for the observed measuring station devices;
- Finally, if IP/Ethernet connectivity is available on the measurement location (i.e for MCD-MS evices), the PoE (Power over Ethernet) option can be considered. However, this option can be assumed as very unlikely to be available. In case this option is perused, the recommendation is to consider only development and implementation specific measurement devices for this type of locations. In fact, the more general support of this network connectivity and power supply option, as widely available optional feature, would result in the much higher cost and device complexity (due to the processor, memory and other hardware requirements related to the support of the IP/Ethernet protocol stack). This kind of power supply can be suitable only in the case of the measurement station intended for gathering of meteorological and climate data (MCD-MS) which is characterized with the higher power consumption.

In order to allow remote monitoring of currently available power supply capacity (i.e. the remaining battery capacity level for battery power supply or rechargeable battery in case of autonomous battery powered supply with the solar panel) the measurement and reporting on this should be enabled (as defined in Section 3.3).

Considering a previously described options, as well as the reported power consumption of the commercially available measuring stations (RBWL-MS and MCD-MS devices) as in Appendix 1, the following recommendation are here defined:

- The power supply for the measuring station for gathering of the water level in the river bed data (RBWL-MS devices) should be realized with the battery power supply, and aligned with the basic requirements defined in Table 3.2;
- The power supply for the measuring station for gathering of meteorological and climate data (MCD-MS devices) should be realized as autonomous battery powered supply with the solar panel (that also support regular 220 V AC power supply from electric power distribution grid), aligned with the basic requirements defined in Table 3.3.

  Notice: However, the development of an optional measuring device type with the Ethernet connectivity and PoE power supply can also be considered for MCD-MS devices. Nevertheless, this option should not be considered as the additional one for the regular measuring station devices of this type due to relatively high increase in cost and complexity.

Table 3.2: The general technical specifications related to the electric power supply requirements for the RBWL-MS device

Power supply option	Battery power supply
Required battery lifetime	Built-in replaceable battery should work for the minimum 5 years and the expected 10 years period without replacement in case of the regular 15 minutes reporting interval
Power supply	In general: DC 12 V/50 mA DC (should be defined according to the sensor device used)
Battery type (recommended)	Li-SOCI2
Measurement and reporting of battery capacity level	Should be supported via MCU (Micro-Controller Unit) board, and reported regularly with the other measurement data
Additional	CE marking certification must be supported

Source: Authors, based on available data

Table 3.3: The general technical specifications related to the electric power supply requirements for the MCD-MS device

Power supply option	Autonomous battery powered supply with the solar panel
Required autonomous power supply lifetime	At least 5 years without the replacement of the rechargeable battery unit
Power supply	In general: 6 – 12/15 V DC charging battery with AC adapter (should be defined according to the sensor devices used)
Solar panel	2 – 15 W, 0.3 - 1 A (should be defined according to the power consumption)
Battery capacity level measurement and reporting	Should be supported via MCU (Micro-Controller Unit) board, and reported regularly with the other measurement data
Additional	CE marking certification must be supported
Notice: *PoE power supply option can be observed instead of here considered one, but not as an additional option, but as the option for specifically designed MCD-MS devices.*	

Source: Authors, based on available data

3.2.4 The basic requirements for the sensor devices (general technical specifications)

In this subsection the basic requirements related to the sensor devices needed for the operation of required measuring stations will be defined. These are given in line with the initial requirements defined in Section 2 (and given in subsection 3.1), as well as based on overview of commercially available sensor devices (with some typical sensor devices given in Appendix 1).

The sensor devices for the development of the RBWL-MS devices

In case of the RBWL-MS device the only sensor device required is the one for measurement of the water level in the river bed, with the required measurement resolution value of 1 mm, and 1 cm accuracy. There are several technological solutions suitable for this sensor device, such as:

- The low-cost lidar-based distance sensor for the monitoring of river water level, with the measurement accuracy inversely proportional to the measured distance, i.e. with the typical accuracy around 1 cm for the measurement distances below 10 m, and under the operating temperatures in the range of 10°C to 30°C;
- The low-cost pressure gauges with the temperature correction, characterized with 1 cm accuracy. However, these devices are sensitive to the windy conditions and water waves, have issues related to the measurements in shallow water bad, and are prone to damage under the above observed conditions;

- The low-cost sensor devices designed by using digital cameras with the water measuring poles and adequate image processing (with the introduction of infrared sensors in the case of night conditions). These solutions, including those with the machine learning employed for measuring results refinement, have relatively low measuring accuracy;
- The low-cost sensor devices based on specific GNSS (Global Navigation Satellite System) interferometric measurements, which are not enough tested yet, and are basically planned for the installation on the bridges and relatively high above the water level;
- The radar-based sensor devices, which have the superior accuracy and measuring characteristics, but also present high-cost solutions, and thus are unacceptable for the here observed application scenario; and
- The low-cost ultrasonic-based sensor devices intended for distance measurements, which present simple solutions available in the form of the separate sensor devices or integrated, complete and configurable measuring stations (see Appendix 1). The measurement process is based on the transmission of ultrasonic waves, with subsequent measurement of components that are reflected back from the nearby objects (i.e. water surface). These sensor devices have relatively low-cost and are characterized with the measurement resolution of 1 mm and measurement accuracy defined as 1% of the full measurement scale. There are many commercially available solutions of this type that can be used to perform water level measurement with maximum measurement ranges between 5 m to 10 m.

Based on the above discussion, the sensor devices based on ultrasonic distance and/or level measurement technology are here considered to be optimal choice. According to overview of the commercially available solutions and the initial requirements defined for the Early Warning Systems in River Drina Basin (given in Section 3.1) the basic requirements for this type of sensor devices are specified in Table 3.4.

Table 3.4: The general technical specifications related to the water level sensor devices for the RBWL-MS devices

Measurement technology	Ultrasonic distance measurement
Measurement range	0.3 m – 5 m (optionally 0.3 m – 10 m range if needed)
Measurement resolution	1 mm
Measurement accuracy	±1% of the full scale (dependent on distance) or 1 cm
Response time	100 ms (maximum), 20 ms (recommended)
Communication interface	In general: RS-485 Modbus RTU (other interfaces can be supported)
Installation	Pole mounted. Baseline measurement must be done at the initial operation using water measuring rod.
Additional	CE marking certification must be supported

Source: Authors, based on available data

The sensor devices for development of the MCD-MS devices

In the case of the MCD-MS devices, the set of sensor devices is needed, that includes:

- The sensor device for the measurement of precipitation over a period of time (i.e. the rain gauge or the pluviometer station),
- The sensor device for the measurement of the soil moisture, and
- The sensor device for the measurement of the air temperature. **Notice:** The manufacturers of sensor device for the measurement of the air temperature mostly design and offer joint solution with measurement of the air temperature and the relative air humidity (as seen in Appendix 1). Therefore, the additional measurement of the relative air humidity is optionally viable if needed.

Based on the comprehensive overview of commercially available sensor solutions (partially given in Appendix 1), it is concluded that the lower-cost solutions mostly have common design and common characteristics, which correspond to required application conditions. Thus, based on the overview of the commercially available solutions and the initial requirements defined for Early Warning Systems in River Drina Basin (in subsection 3.1), the basic requirements for all these types of sensor devices are compiled in Table 3.5.

Table 3.5: The general technical specifications related to the water level sensor devices for the MCD-MS devices

RAIN GAUGE SENSOR DEVICE	
Collector Surface	Industry standard 200 cm^2
Measurement resolution	0.5 mm (minimum)
Measurement accuracy	±5%
Maximum Rain	12 mm/minute
Measurement sensitivity	1 tip per 0.2 mm or 1 tip per 0.5 mm
Evaluation	Digital
Response time	100 ms (maximum)
Communication interface	In general: RS-485 Modbus RTU (other interfaces can be supported)
Installation	Pole, fence or wall
Additional	CE marking certification must be supported
SOIL MOISTURE SENSOR DEVICE	
Measurement range for volumetric water content (VWC)	0 % - 50 % (optional 0 % - 100 %)
Temperature accuracy	±0.5℃
Measurement resolution	1%
Measurement accuracy	±5 % of reading (minimum)
Power supply	12 V – 24 V DC
Operating temperature range	-40 to 60°C
Response time	100 ms (maximum)
Communication interface	In general: RS-485 (other signals can be supported)
Installation	Fully embedded, with all probes inserted into the test medium (soil)
Additional	CE marking certification must be supported
AIR TEMPERATURE SENSOR DEVICE (WITH OPTIONAL RELATIVE AIR HUMIDITY SENSOR)	
Measurement range	Temperature: -40°C to +60°C Optional - Relative humidity: 0 % to 100 % RH
Measurement resolution	Temperature: 0.1°C Optional - Relative humidity: 1 %
Measurement accuracy	Temperature: ±0.5°C (0°C to +60°C) Optional - Relative humidity: ±4 %
Power supply	12 V DC (typical)
Response time	100 ms (maximum)
Communication interface	In general: RS-485 Modbus RTU or I²C (other interfaces can be supported)
Additional	CE marking certification must be supported

Source: Authors, based on available data

3.2.5 The basic requirements related to the operation, measurement, data logging and reporting modes for the observed measuring station devices (general technical specifications)

In order to provide the reliable, energy efficient and long-term measuring station operation, as well as the low-cost implementation, as demanded by the specified essential requirements, the different operation, measurement, data logging and reporting modes must be supported.

Two operational modes for the measuring station device must be supported:

- **Active operation mode**, in which device performs:
  - scheduled activation of all hardware resources (components) in scope of the transition from the power saving operation mode to the active operation mode,
  - measurement process realized by using all the connected sensor devices according to the configured measurement mode,
  - local processing, analysis and data logging of the acquired measurement data as defined by data logging mode (local data logging may be observed as optional feature – the decision related to the support of this feature should be made in the design and development phase depending on its importance on the system level and implementation cost of this feature),
  - reporting on the acquired measured data and status information, if so defined according to current reporting mode, which is realized by sending processed measurement data and status information to the central application server (i.e. sending of generated uplink report messages over embedded communication interface module),
  - listening for and the reception of the downlink command messages (if any) from the network access gateway (if sent by the central application server) by using the embedded communication interface module,
  - eventual updating (if required for the specific devices state conditions) of the reporting, measurement and data logging modes according to the acquired measurement data (i.e. by comparison of the acquired measurement data with the predefined threshold values) and/or according to the received downlink command messages, and
  - setting the real-time clock i.e. watchdog timer unit (WTU) for the next transition to the active operation mode followed by the scheduled transition to power saving (sleep) operation mode, realized as the deactivation of all unnecessary hardware resources (components).
- **Power saving (sleep) operation mode**, in which only the necessary hardware resources are powered while the other components are in the power saving state. The possible power saving level for each hardware resource (component) should be defined in the design, development and implementation phase, in order to achieve optimal operation and energy efficiency – this feature is highly reliable on the specific hardware options and can't be defined in general. During the power saving (sleep) operation mode, the provided real-time clock, i.e. watchdog timer unit, must remain active in order to generate trigger for the next transition to active operation mode.

The duration of total cycle, that consists of subsequent active operation mode and power saving (sleep) mode, is defined by the current measurement and reporting mode. The additional requirements regarding operation mode realization are:

- During the one total cycle, the duty cycle for the wireless communication interface module must be lower than 1%. This feature should be supported through the proper scheduling of the communication interface module activation;
- The uplink report message transmission should be acknowledged by the network access gateway (in general case). In the case of the unsuccessful transmission of the uplink report message additional 2 transmission attempts are allowed (if needed);

- The maximum duration of the active operation mode is 2 minutes (in case of the unsuccessful uplink transmission), and 1 minute for the regular successful uplink transmission in the first attempt; and
- If the chosen wireless technology support such operation, the reception of downlink command messages should be allowed only after a successful uplink report message transmission, with the specified maximum duration of the defined listening window (i.e. the period that starts after the transmission), e.g. around 2 seconds for LoRaWAN technology.

Two reporting modes for the measuring station device must be supported:

- **Regular reporting mode**, in which device less frequently sends periodic uplink report messages (i.e. when a reporting period of longer duration is adopted), and
- **Emergency reporting mode**, in which device more frequently sends periodic uplink report messages (i.e. when a reporting period of lower duration is adopted).

Notice: If several measurement periods are elapsed between the two subsequent uplink reporting messages being sent, the maximum value recorded between these two messages is sent.

The default reporting mode is set as the regular reporting mode, while the transition between the regular and emergency reporting modes can be triggered by:

- Local alarm activation (i.e. alarm detection) when the current reporting mode is regular reporting mode – if currently acquired and processed measurement data are found to have higher value than the predefined threshold values, the device is switched into the emergency reporting mode in the following active period (i.e. the next transition to the active operation mode). The measurement and data logging modes are updated accordingly;
- Local alarm deactivation (i.e. alarm shut down) when the current reporting mode is emergency reporting mode – if currently acquired and processed measurement data are found to have lower value than the predefined threshold values, the device is switched into the regular reporting mode in the following active period (i.e. the next transition to the active operation mode). The measurement and data logging modes are updated accordingly;
- The reception of downlink command message for transition to emergency/regular reporting mode (as an optional mechanism). If adopted, this transition mechanism has higher priority than the local alarm activation/deactivation mechanism. The measurement and data logging modes are updated accordingly.

Notice: During the development and implementation phase the final decision should be made if both or just one of the above defined mechanisms for the transition between the regular and emergency reporting modes should be supported. This decision should be made based on the specific hardware and software (HWS) resources and the cost of implementation.

In order to support local alarm activation/deactivation mechanism a measuring station device configuration must contain definition of threshold value/values for the specified measured physical parameter/parameters. For the observed application scenario (i.e. the Early Warning System in River Drina Basin), these threshold values are generally dependent on the measurement station location, and thus must be calculated according to the methodology specified the Section 2. The setting (i.e. configuration) and updating (i.e. re-configuration) of these threshold values should be done in the pre-deployment phase and/or by the onsite access (i.e. as the part of maintenance activity) during the device operation, respectfully.

Notice: An additional optional mechanism for the re-configuration of these threshold values may be introduced as the device remote control activity by using the specific downlink command messages. The eventual implementation of such mechanism should be defined during the following design, development and implementation phase, if so decided. The only drawback related to the introduction of this mechanism is the higher complexity of the central application software (that must provide monitoring and control of all the measuring station devices in the system), and a higher complexity and memory consumption of application software implemented on the measuring station devices.

The measurement mode is defined separately for the each connected sensor device (i.e. the measured physical parameter) and is dependent on the current reporting mode. The required support of the measurement mode for each sensor device includes:

- Definition of the measurement period for the given sensor device, which can be only defined as the integer participle of the regular and emergency reporting period. That is, if the measurement period is T_m the regular reporting period T_{rr} and emergency reporting period T_{er} must be defined as $T_{rr} = n \times T_m$ and $T_{er} = m \times T_m$ where n and m are integer values and $n > m$;
- The information (On/Off flag) if the specified sensor device should be active (i.e. perform required measurement process) the next time when the measuring station device is in the active operation mode; and
- Setting (*Multiple measurements*) if the measurement process for the specified sensor device should be done only once during the active operation period, or the multiple measurement (sampling) should be performed in order to acquire more accurate and precise measurement result through averaging of all measured values (with detection and discarding of outlier samples). This can be done by setting number of measurements N as an integer value ($N = 1$ for the single measurement). The required value N should be decided during the development and implementation phase, based on the chosen sensor device, achieved estimation (measurement) performance, time needed for the successive measurements and the optimization between a measurement performance and energy efficiency.

According to the current reporting mode, at the end of each active operation mode cycle the measurement mode is updated (except for the number of measurements N).

The data logging mode is defined separately for the each connected sensor device (i.e. the measured physical parameter) and is dependent on the current reporting mode. The required support of the data logging mode for each sensor device includes:

- Definition of the data logging period for the given sensor device, which can be only defined as the integer product (harmonic) of the measurement period. That is if the measurement period is T_m the data logging period T_{dl} must be defined as $T_{dl} = k \times T_m$ where k is an integer value;
- The information (On/Off flag) if the data logging should be performed for the specified sensor device the next time when the measuring station device is in the active operation mode; and
- Setting (*Data logging value*) if the data logging for the specified sensor device should store the average, minimum and/or maximum value of the observed parameter recorded during the period between the two consecutive data logging. Obviously, the temporary values of the measured parameter between the consecutive data logging instances should be temporary stored (these are not needed after the data logging is performed).

According to the current reporting mode, at the end of the each active operation mode the data logging mode is updated according to the device current configuration. **Notice:** The setting of the measurement mode and the data logging mode can also be remotely controlled, but this option is not mandatory and should not be pursued without the specific justification.

According to the overview of the commercially available sensor device solutions and the initial requirements defined for the Early Warning Systems in River Drina Basin (in subsection 3.1) the basic requirements for all types of sensor devices regarding the operation, measurement, data logging and reporting modes are defined in Table 3.6 and Table 3.7, for the MCD-MS devices and RBWL-MS devices, respectfully.

Table 3.6: The general technical specifications for the default operation, measurement, data logging and reporting modes related to the set of sensor devices for the MCD-MS devices

GENERAL SPECIFICATIONS FOR THE MEASURING STATION DEVICE			
Complete active operation mode/power saving operation mode cycle duration		Measurement period: 15 minutes (optionally 5 minutes for emergency mode)	
Sending uplink reporting message		Defined by the reporting period: Regular reporting – every fourth cycle Emergency reporting – every cycle	
Maximum number of subsequent reporting attempts (if unsuccessful)		3	
Maximum active period duration		1 minute for the successful reporting, maximum 2 minutes for the maximum 2 subsequent unsuccessful reporting	
Radio communication duty cycle (Tx/Rx)		1% (maximum)	
Download command messages reception		After successful uplink report message Listening period 5 seconds (max) Supported commands: Device On/Off, Regular/Emergency transition (optional)	
Reported measurement data and status info		The measured water rain fall (in mm), soil moisture (in %), temperature (in ℃) and remaining battery capacity (0-100%)	
SEPARATE SPECIFICATIONS FOR THE SENSOR DEVICES			
Reporting mode supported		Regular reporting	Emergency reporting
Rain gauge (precipitation) sensor device	Reporting period	60 minutes	15 minutes
	Supported reporting mode transition mechanism	Local alarm activation/deactivation Optional: Downlink command message	
	Measurement period	15 minutes	15 minutes (5 minutes optionally)
	Multiple measurements – *N*	Default value: 1 (to be specified during the development and implementation phase)	
	Data logging period	15 minutes	15 minutes
	Data logging value	maximum value	
Soil moisture sensor device	Reporting period	60 minutes	60 minutes
	Supported reporting mode transition mechanism	Local alarm activation/deactivation Optional: Downlink command message	
	Measurement period	15 minutes	15 minutes
	Multiple measurements – *N*	Default value: 1 (to be specified during the development and implementation phase)	
	Data logging period	60 minutes	60 minutes
	Data logging value	Maximum, minimum and average values	
Reporting mode supported		Regular reporting	Emergency reporting
Atmospheric temperature sensor device	Reporting period	60 minutes	60 minutes
	Supported reporting mode transition mechanism	Local alarm activation/deactivation Optional: Downlink command message	
	Measurement period	15 minutes	15 minutes
	Multiple measurements – *N*	Default value: 1 (to be specified during the development and implementation phase)	
	Data logging period	60 minutes	60 minutes
	Data logging value	Maximum, minimum and average values	
Notice: *The measurement period for the rain gauge sensor device may be defined as 5 minutes if needed (in emergency mode or for both modes). The measurement period may be defined as 60 minutes for soil moisture and air temperature sensor devices if needed to achieve better energy efficiency.*			

Source: Authors, based on available data

Table 3.7: The general technical specifications for the default operation, measurement, data logging and reporting modes related to the set of sensor devices for the RBWL-MS devices

GENERAL SPECIFICATIONS FOR THE MEASURING STATION DEVICE			
Complete active operation mode/power saving operation mode cycle duration		Measurement period: 5 minutes	
Sending uplink reporting message		Defined by the reporting period: Regular reporting – every third cycle Emergency reporting – every cycle	
Maximum number of subsequent reporting attempts (if unsuccessful)		3	
Maximum active period duration		1 minute for the successful reporting, maximum 2 minutes for the maximum 2 subsequent unsuccessful reporting	
Radio communication duty cycle (Tx/Rx)		1% (maximum)	
Download command messages reception		After successful uplink report message Listening period 5 seconds (max) Supported commands: Device On/Off, Regular/Emergency transition (optional)	
Reported measurement data and status info		Measured water level (300-5000 mm), and remaining battery capacity (0-100%)	
SEPARATE SPECIFICATIONS FOR THE SENSOR DEVICES			
Reporting mode supported		Regular reporting	Emergency reporting
Water level sensor device	Reporting period	15 minutes	5 minutes
	Supported reporting mode transition mechanism	Local alarm activation/deactivation Optional: Downlink command message	
	Measurement period	5 minutes	5 minutes
	Multiple measurements – *N*	10-20 (to be specified during the development and implementation phase)	
	Data logging period	15 minutes	5 minutes
	Data logging value	maximum value	

Source: Authors, based on available data

3.2.6 The basic requirements related to the types and format of transmitted messages (general technical specifications)

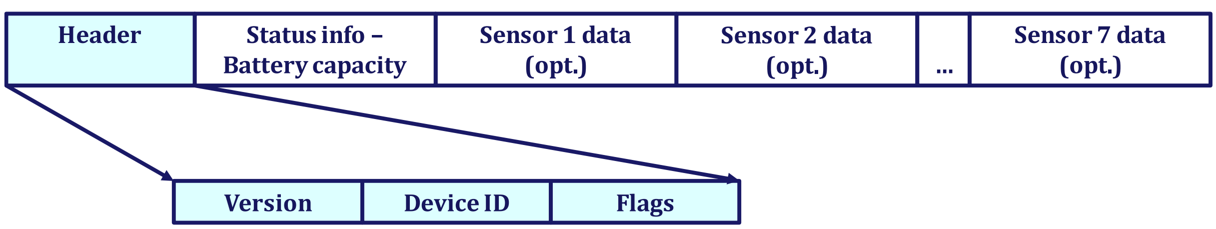
In order to support energy efficient operation with the low duty cycle (1% maximum) of the wireless communication interface, the so called push-up communication model is adopted. In the push-up communication model, the end devices (i.e. IoT sensor nodes, e.g. measuring station devices in the observed application scenario) automatically send the uplink report messages, which contain all the required measured data and the device status information, towards the central application server. In this specifications, the automatic transmission of these uplink report messages is triggered (initiated) periodically with defined reporting period, which is determined by the current reporting mode for the given measuring station device (i.e. actually 5 minute or 15 minute reporting period is deployed for the emergency and regular reporting mode of RBWL-MS device, and 15 minute or 60 minute reporting period is deployed for the emergency and regular reporting mode for RBWL-MS devices). The transition between the reporting modes, and thus change of the reporting period (i.e. reporting frequency) is realized locally (in the measuring station) by the comparison of the measured values and the predefined threshold values (for the purpose of alarm detection). Optionally, this transition can be supported through the remote control realized by the central application server that can send specific downlink command message.

Specified push-up communication model allows very simplified definition of the types and formats for the uplink and the downlink messages that are being transmitted between the measuring station devices, as the system's end points, and central application server, as the systems' central point. According to previous discussion and the previously defined requirements, the following uplink and downlink messages are required to be supported:

- Uplink report messages that contain all required measured data and the predefined device status information. These messages do not contain the timing information, which should be appended during transmission over the access network (i.e. by the wireless/wired access gateway or the other network device responsible for the forwarding of these messages to the central application server), or optionally by the central application server (based on the timing of the messages reception);
- Downlink command messages, which contain specific command identifier (ID) and the optional command parameters predefined for the specific command messages. This command messages are used to remotely control measuring station devices, i.e. to power on/off device or to change reporting period (i.e. the reporting mode as previously specified). The additional command messages may be specified as needed for the proper system operation;
- The other access network supported messages may be exchanged in order to allow measuring station device activation (i.e. *join* and *re-join* messages) in the observed wireless access network. These are defined differently depending on the selected communication technology and are not part of these specifications; and
- Optionally activated, uplink and downlink acknowledgment (ACK) messages for the purpose of acknowledgement of downlink and uplink messages reception.

The format of the uplink report messages for the both types of measuring station device can be commonly defined. These messages are relatively short with the application payload of 9 to 13 bytes.

Figure 3.2: The general format of the uplink reporting message



Source: Authors

The general format of these uplink report messages is specified as shown in Figure 3.2, with the following fields:

- Header, with the length of 5 bytes, consisting of:
  - The field Version (1 byte) reserved to specify the application protocol version,
  - The field Device ID (2 bytes) reserved to specify measuring station device ID (the given filed length enable addressing a maximum number of 65535 end point devices that can be considered as more than enough), and
  - The field Flag (2 bytes) reserved to indicate optional status information and if the respective sensor data are included (as being optional). The first byte containing 8 bits that can be used to indicate if the message contains status info, i.e. flag 15 the MSB (most significant bit), and up to 7 measurement data (if the flag is set to 1 the data is sent), i.e. flag 14 to flag 8, while the lower byte, i.e. flag 7 to flag 0 – LSB (least significant bit), can be used to indicate additional status info (i.e. regular/emergency reporting mode, certain operating issues, etc).
- Status info data (2 byte) is always sent (flag 15 = 1), and it is used to report on remaining battery capacity (in % or the battery voltage); and

- Sensor data 1 to 7 (2 bytes each) reserved for the reporting of up to 7 sensor devices (the reserve is included), of which only one (Sensor 1 data) is used for RBWL-MS devices and three (Sensor 1 data to Sensor 3 data) are used for MCD-MS devices.

Based on the above description the minimum uplink report message length is 7 bytes (Header and Status info), while the maximum length is 21 bytes. However, for the so far specified measuring station devices, the maximum length for RBWL-MS devices is just 9 bytes (when only Sensor 1 data is used), while the maximum length for MCD-MS devices is 13 bytes (when Sensor 1 data to Sensor 3 data are used). The example of uplink report message for the RBWL-MS and MCD-MS devices are given in the Table 3.8 and Table 3.9, respectfully.

Table 3.8: The general specification of the uplink message format for the RBWL-MS devices

Field	Parameter name	Type	Conversion	Unit
Header	Version	uint8		
	Device ID	uint16		
	Flags (15-0)	uint16		
Status info	Battery voltage	uint16	x/1000	V
Sensor 1 data	Measured distance/level	uint16	x	mm

Source: Authors

Table 3.9: The general specification of the uplink message format for the MCD-MS devices

Field	Parameter name	Type	Conversion	Unit
Header	Version	uint8		
	Device ID	uint16		
	Flags (15-0)	uint16		
Status info	Battery voltage	uint16	x/1000	V
Sensor 1 data	Measured precipitation data	uint16	x	mm
Sensor 2 data	Measured soil moisture data	uint16	x	%
Sensor 3 data	Measured air temperature data	uint16	(10x-400)/10	℃

Source: Authors

The periodic reporting requires sending of very short messages, and thus requires relatively low energy consumption for the purpose of wireless transmission. Also, based on the above definition, and the previously defined reporting periodic, it is possible to calculate the storage capacity required to store acquired measurement data at the central application server on daily and monthly basis, as given in Table 3.10, as well for the local data logging purposes (defined by the data logging period and required storage period) on the daily and weekly basis, as given in Table 3.11.

Table 3.10: The required storage capacity for the acquired measurement data at the central application server on the daily and the monthly basis per one RBWL-MS or MCD-MS device

MS type	RBWL-MS		MCD-MS	
Per report	4 bytes (without time tag)		8 bytes (without time tag)	
Reporting mode	Regular reporting (min)	Emergency reporting (max)	Regular reporting (min)	Emergency reporting (max)
Daily	4×24×4B = 384 bytes	12×24×4B = 1152 bytes	4×24×4B+1×24×4B= 480 bytes	12×24×4B+1×24×4B= 1248 bytes
Monthly	30×384B = 11520 bytes	30×1152B = 34560 bytes	30×960B = 14400 bytes	30×1728B = 37440 bytes

Source: Authors

Table 3.11: The required storage capacity for data logging of the acquired measurement data at RBWL-MS or MCD-MS device on the daily and the weekly basis

MS type	RBWL-MS		MCD-MS	
Per logging	2 bytes		2 bytes + 3×2×2 bytes = 14 bytes	
Reporting mode	Regular reporting (min)	Emergency reporting (max)	Regular reporting (min)	Emergency reporting (max)
Daily	4×24×2B = 192 bytes	12×24×2B = 576 bytes	4×24×2B+1×24×12B= 480 bytes	4×24×2B+1×24×12B= 480 bytes
Weekly	7×192B = 1344 bytes	7×576B = 4032 bytes	7×480B = 3360 bytes	7×480B = 3360 bytes

Source: Authors

3.2.7 The basic requirements for the wireless/wired communication technology chosen to provide network connectivity (general technical specifications)

The general communication related requirements for the development of the observed measuring station devices are:

- Low duty cycle transmission of short messages in both uplink direction (from the measuring station devices to the central application server) and downlink direction (from the central application server to the measuring station devices);
- Low required data rate (0.3-5 kbps) for short transmission of the uplink report messages (with the basic application payload of 7 to 15 bytes), and the short time reception of the downlink command messages which can be scheduled only a short time after the uplink transmissions;
- The required end-to-end latency in the uplink direction does not present critical issue with acceptable values in the order of several tens of second to 1 minute. In the downlink direction latency is not an issue, since there is no critical traffic expected, and with the basic latency introduced due to possible timing mismatch of the messages sent by the central application server and the available window for the end devices downlink reception (i.e. only after the uplink transmission periodically repeated every 5 to 15 minutes);
- The secure communication should be supported by the end-to-end encryption (on application level) and supported network encryption over the wireless transmission between wireless access gateway and the end device, and on the transmission links between the wireless access gateway and the central application server, and
- The wireless connectivity, if deployed, must support high reliability through the adequate service coverage, available network capacity, the acknowledgement of the message transmission in the uplink and the downlink direction, as well as the over-the-air (OTA) activation and network access for end devices.

The comprehensive analysis of the possible technologies that can be used to provide network access connectivity for the both type of measuring stations is performed. This connectivity is necessary in order to provide the reliable and secure connection and data transmission between the measuring station devices installed on remote locations and the central application server. In this respect a high quality and capacity communication link is assumed for Internet access of this server.

The main results and conclusions of this analysis are as follows:

- The wired access technologies (such as copper and optical cable based Ethernet/IP access, xDSL access, etc.) provide the high capacity, reliable and secure connectivity, but due to the low probability of adequate existing ICT infrastructure of this type at the general locations expected for the observed measuring stations (i.e. in the remote and rural areas), these technologies can't be considered as the main choice. Optionally, if available at the some of the locations, the IP/Ethernet access with the PoE can be adopted, especially since this option resolve power supply and network connectivity issues. However, as previously specified, this optional solution should not be foreseen as the additional feature for the devices already provided with the communication interface module based on some other wireless communication technology (due to the high complexity and high increment cost), and this can be only considered for the specific devices which are developed and implemented with this technology as the main and only choice;

- The short-range and medium-range wireless technologies do not present suitable option for here observed application scenario. Thus, RFID (Radio Frequency Identification) provides access with the range of several meters, NFC access with the range of several centimeters, while the different Bluetooth technologies provide somewhat longer communication range, but also demands additional backhaul technology to be provided (such as Ethernet, Wi-Fi, LoRaWAN, cellular networks, etc.). These technologies are suitable only to achieve wireless connectivity between several spatially close sensor devices at the same location. The similar conclusion is also valid for the ZigBee and the similar short-range wireless technologies;
- The different WLAN technologies, i.e. Wi-Fi, are able to provide connectivity at the ranges of up to 100 m. This technology can be deployed if available at some locations, but under the same basic conditions as aforementioned Ethernet access technologies (with the additional minus that PoE is not available);
- The adoption of mobile cellular networks that operate in the licensed RF (Radio-Frequency) spectrum, such as GSM/GPRS, 3G (UMTS), 4G (LTE) and 5G NR wireless access technologies can provide highly reliable, secure and quality long-range Internet connectivity. However, the adoption of mobile networks generally results with the higher energy consumption, and higher operational expenditures (OPEX) due to the use of licensed RF (Radio Frequency) spectrum. Also, the spatial coverage of these network in the Republic of Serbia might not provide suitable service level and/or access, and thus their service might be unavailable in the large percent of expected measurement stations locations in the remote and rural areas (especially in case of 3G/4G networks). The previous statement is illustrated by publicly announced official data on percentile signal coverage (per population and per territory coverage) of 2G/3G/4G mobile networks, published by the RATEL for the year 2021, shown in Table 3.12. Also, the most recent benchmarking data for the 2G/3G/4G networks of all mobile operators in the Republic of Serbia for the year 2022, provided by the RATEL (url: http://benchmark.ratel.rs/sr/pokrivenost-radio-signalom) show that the service availability and coverage quality for 3G/4G networks is mostly unacceptable in the rural areas in River Drina Basin (as well as in other areas in which similar Early Warning System could be of interest). Thus, only 2G (i.e. GSM/GPRS) mobile networks can be observed as the suitable solution in most of the locations of interest;
- The wireless connectivity based on using LPWAN technologies which operate in licensed RF spectrum (i.e. NB-IoT technology deployed in networks of operators A1 Srbija d.o.o. Belgrade and Telekom Srbija a.d. Belgrade), and in unlicensed RF spectrum (the LoRaWAN technology deployed as the separate network of Telekom Srbija a.d. Belgrade), present energy efficient solution suitable for the battery power supplied measuring stations. These technologies provide long-range wireless connectivity, for the reliable access and data transmission that satisfy all previously defined requirements in term of data rate, link capacity, latency, energy efficient operation and demanded organization of communication process. Yet, the NB-IoT technology, is implemented within the 4G networks, and thus suffers from the same issues related to coverage of expected measuring station locations in remote and rural areas as the 4G mobile networks. Also, despite the higher data rate, longer communication range, better quality of service and lower latency, in comparison to LoRaWAN technology, NB-IoT technology is also characterized with

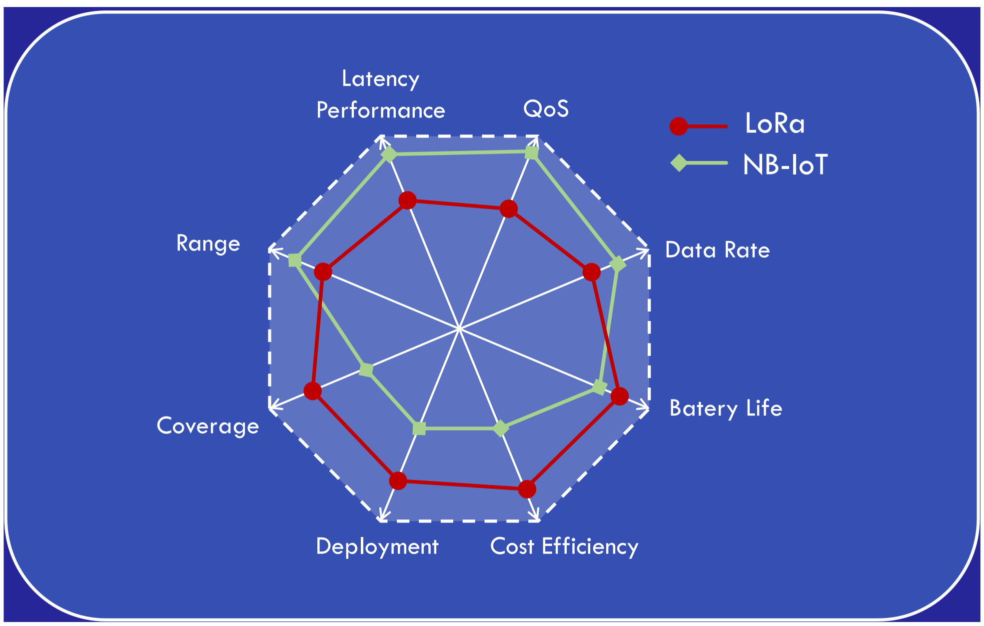
the higher end device implementation cost, higher energy consumptions, more complex deployment and worse coverage, as shown in Figure 3.3. As result, especially due to the issues related to the viability of service coverage at expected measuring station locations, higher cost and energy consumption, the LoRaWAN technology is chosen as the basic wireless connectivity technology for the development of the observed measuring station devices.

Table 3.12: The per population and the per territory coverage for 2G/3G/4G mobile networks in Republic of Serbia in the year 2021

Type of coverage	Telekom Srbija a.d. Belgrade	Telenor d.o.o. Belgrade	A1 Srbija d.o.o. Belgrade
Percentile of coverage per territory – 2G networks	91.89 %	87.23 %	89.08 %
Percentile of coverage per population – 2G networks	99.26 %	98.77 %	99.02 %
Percentile of coverage per territory – 3G networks	77.89 %	88.72 %	75.85 %
Percentile of coverage per population – 3G networks	96.92 %	98.99 %	96.72 %
Percentile of coverage per territory – 4G networks	84.51 %	74.86 %	73.93 %
Percentile of coverage per population – 4G networks	98.19 %	96.43 %	95.97 %

Source: Authors, using the publicly available data published by the RATEL (Pregled tržišta elektronskih komunikacija i poštanskih usluga u Republici Srbiji u 2021. godini)

Figure 3.3: The comparison of the NB-IoT and the LoRaWAN wireless access technologies



Source: Authors, based on the publically available data

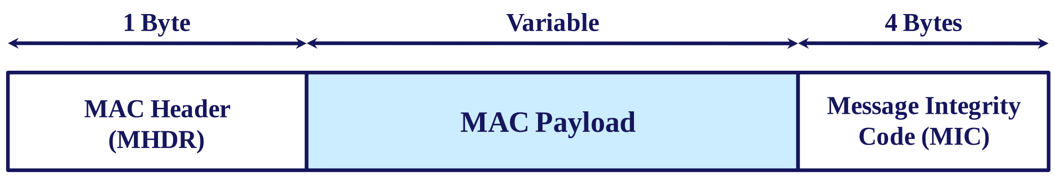
The LoRaWAN service in the Republic of Serbia is provided by the telecomm operator Telekom Srbija a.d. Belgrade, which offers SLA (Service Level Agreement) for LoRa services. The selected micro-location in Loznica and Gučevo area is covered with the existing LoRAWAN gateways, with the additional gateways for the other areas of interest in River Drina Basin, as well as in other parts of Serbia, can be deployed by customer demand if there is no suitable coverage.

Hence, the LoRaWAN technology is selected as the primary solution for the realization wireless connectivity in scope of development of measuring station devices (for both RBWL-MS and MCD-MS devices), while as the alternate solution, if the LoRaWAN coverage is not available, the GSM/GPRS technology can be observed. This decision is made based on the far superior service coverage of 2G (GSM/GPRS) networks in comparison to 3G/4G networks. However, GSM/GPRS based solutions have higher energy consumption and demand implementation of the IP based traffic for data access, which requires more complex end device implementation. Therefore, in the case of GSM/GPRS technology the use of SMS (Small Message Service) for the uplink and downlink message transmission may also be considered.

The LoRaWAN network operation is Serbia (and Europe) is supported for RF channels in 863 – 870 MHz RF band. LoRaWAN messages in the uplink and downlink direction have PHY (Physical Layer) payload comprised of MAC (Medium Access Control) frames with MAC Header (1 byte), variable MAC payload (59 to 230 bytes for RF channels in 863 – 870 MHz RF band) and 4 byte MIC (Message Integrity Code), as shown in Figure 3.4. This payload completely supports short over the air transmission of the previously defined short uplink report messages and downlink command messages. The common operation allows 1 message exchange in 5 minutes, which is in accordance with the demanded maximum 1% duty cycle and the required reporting modes (e.g. both regular and emergency reporting modes).

Notice: The maximum application level payload (user payload) for the RBWL-MS measuring station device is 9 bytes, while for the MCD-MS measuring station device this value is 13 bytes. This enables transmission of just one PHY message in the uplink for the one reporting period for the all or the most of SF (Spreading Factor) values depending on measuring station device type.

Figure 3.4: MAC frame definition for the LoRaWAN technology



Source: Authors, based on the publically available data

LoRaWAN specification defines three classes of end devices:

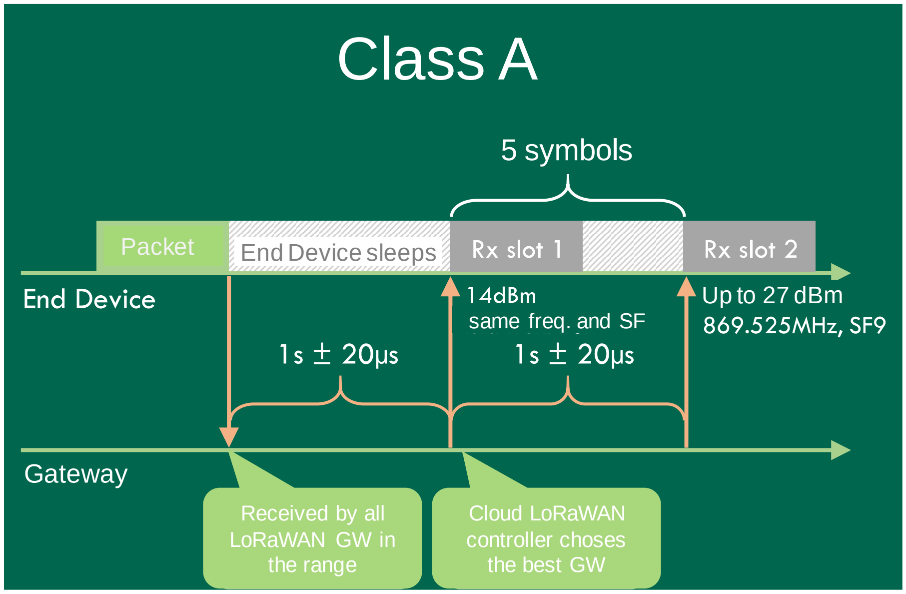
- The class A, which present default end device implementation, and is optimized for battery supply operated devices, with the downlink communication enabled only in the short period defined by two reception windows after the uplink transmission, see Figure 3.5. This is the most energy efficient device class and is therefore selected here as the required option;
- The class B, which presents experimental solution with the additional windows for the downlink reception, but demands LoRaWAN gateway synchronization; and
- The class C, which is adopted for the end devices with the continuous unlimited power supply, and is not suitable for the here observed application scenario.

The LoRaWAN specification defines six types of MAC messages, which completely cover all previously defined requirements, and these include:

- *Join request* and *Join accept* messages for OTA end device activation and network access, which enable simple deployment strategy;
- Unconfirmed (without acknowledgment) and confirmed (without acknowledgment) messages for data transmission in uplink and downlink direction.

The LoRaWAN network topology consists of end points that exchange uplink and downlink messages with the central network server over the LoRaWAN access gateway devices (as a bridge), with the backhaul links between the gateways and network server and the link between network server and the central application servers are realized as the IP/TCP SSL (Secure Sockets Layer) connections. The LoRaWAN transmission support end-to-end security based on the AES-128 application security key, as well as the separate end device to network server AES (Advanced Encryption Standard) based MAC transmission security.

Figure 3.5: The Class A device operation in uplink and downlink direction



Source: Authors, based on the publically available data

The organization of the envisioned communication model realized as LoRaWAN based network connectivity of end devices (measuring station devices) with the central application server is shown in Figure 3.6. In this model, taking into the account the specific realization of LoRaWAN network of Telekom Srbija a.d. Belgrade, the uplink report messages can be forwarded to central application server using the HTTPS (Hypertext Transfer Protocol Secure) protocol (as the default protocol), or optionally using the MQTT (Message Queuing Telemetry Transport) protocol. In this realization, network server must be provided with the specific application server IP address and port for data delivery. The uplink reporting data are appended with the time tag (in network server), and delivered to the application server in the JSON (JavaScript Object Notation) or the XML (Extensible Markup Language) file format.

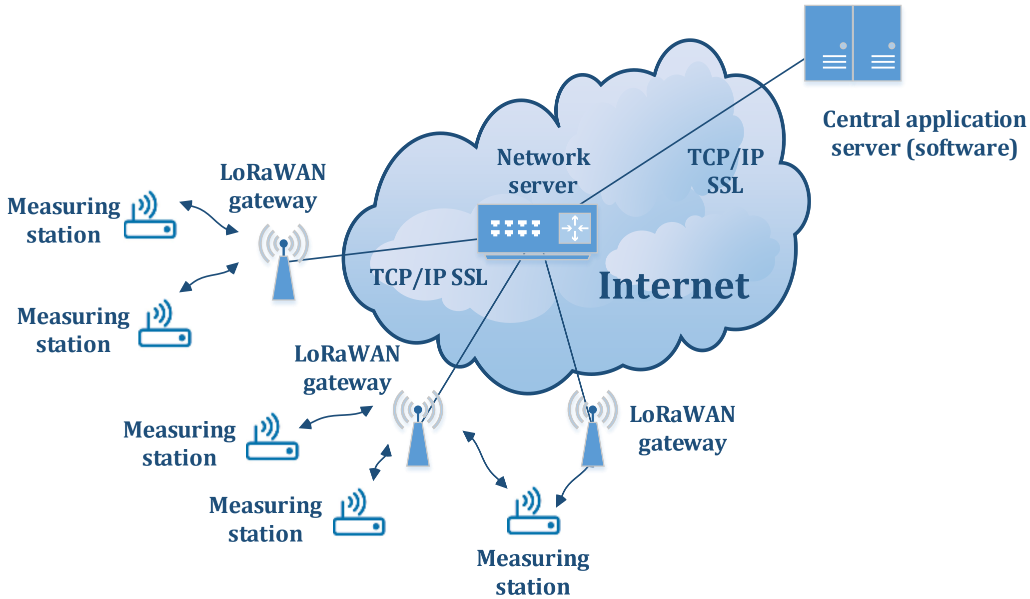
The basic requirements related to the deployment of LoRaWAN network connectivity model are summarized in Table 3.13.

Table 3.13: The general technical specifications for LoRaWAN network connectivity model

RF band	EU868: 863.0 MHz – 870 MHz
Supported mode	OTAA/ABP Class A
ADR mode support	To be decided
Maximum duty cycle	< 1% (less than 864 seconds per day)
Confirmed mode	Supported
Re-join mode	Supported
Application security	AES-128
Maximum ERP	+14 dBm (25 mW) Note: The power radiated by isotropic antenna / half-wave dipole antenna (not Tx power)
Maximum antenna gain	2.15 dBi
Network server to Application server communication	HTTPS protocol TCP/IP SSL JSON or XML file format delivery

Source: Authors, using the publicly available data

Figure 3.6: The communication model for the LoRaWAN based communication between the measuring station devices and the central application server



Source: Authors

3.2.8 The additional basic requirements related to the installation, maintenance and setting of HWS platform for measuring stations devices (general technical specifications)

Some additional requirements related to the installation, maintenance and setting for the measuring station devices are:

- The measurement station device must supporting requested mounting option, i.e. mounting on the rail, wall or pole;
- For the purpose of the wireless network access, the proper antenna must be supplied that support proper operation and required mounting on the site;
- All the required interface cables must satisfy the sensor device and the communication interface requirements, as well as the other operational requirements defined in this document;
- The measuring station device as a whole must be easily accessed, separate devices must be able to be easily disconnected and changed if necessary, while the battery unit should be easily accessed and changed on the site; and
- The measuring station devices (as a whole) must support viable access for the purpose of on premise and onsite programming, settings (i.e. definition of measurement, reporting and data logging periods/modes, alarm thresholds, etc.), and download of locally stored (data logged) data through a seamless use of the NFC interface, the USB interface (any type) or the other available digital interfaces.

3.3 The general guidelines and recommendations on the possible approaches to the design, development and implementation of the observed measuring stations

When the operation of the observed measuring stations as the integral part of the Early Warning System in Drina River Basin is considered, these sensor devices (i.e. the Data Acquisition and Measuring Devices) must enable the proper acquisition and measurements of previously defined physical parameters, the local processing and short-time storage for the acquired measurement data, periodic reporting on the measured data and other information (such as operational status of device, i.e. the current battery level, local alarms related to the measured values, etc.), self-controlled operation, communication for the purpose of remote control, and means to perform the initial pre-deployment configuration and the programming of the device (before installation) as well as the on the site fine tuning, data download and access for the purpose of maintenance and operational support (i.e. additional setting of devices during the operation).

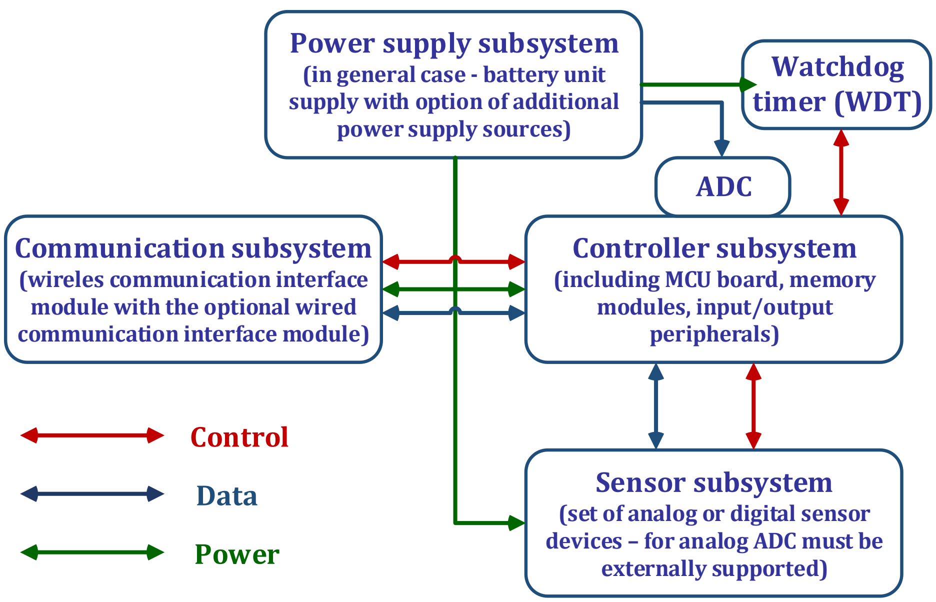
According to the common knowledge related to the remotely controlled machine-to-machine (M2M) communications based sensor networks, as well as the wireless sensor networks and/or Internet of Things (IoT) sensor networks technologies, in order to support previously defined operation requirements, the developed measuring stations in general case represent wireless sensor nodes comprising several main components:

- Sensor subsystem, which consists of required sensor devices that enable analog-to-digital conversion (ADC) and appropriate raw data processing and filtering related to the measurement process, as well as the local communication with the control subsystem in order to enable measured data acquisition and the operational control of the measurement (i.e. sensor data acquisition and measurement) process;
- Control subsystem, which is based on embedded MCU (Micro-Controller Unit) board equipped with the processor unit, memory modules, communication interfaces , and programmable analog and/or digital input/output peripherals, in order to enable viable control of measurement station operation as a whole, i.e. as an integrated hardware-software (HSW) platform, by supporting the realization of the observed measurement process (by the communication and control of sensor subsystem), local processing and storage of the collected measurement, analysis and other required operational data, and communication over the networking interface with a central application software (i.e. Data Acquisition, Distribution and Early Warning Software in Drina River Basin) for the purpose of reporting on measured data and measuring station status towards the central application software, as well as to enabling remote control of measuring station device operation by the central application software;
- Watchdog timer unit (WTU), realized in the form of computer operating properly (COP) timer as the integrated part of the MCU board or as the separate module, i.e. the real-time clock (RTC) module, in order to enable energy efficient operation of the measuring station device. The WTU controls the operational mode of the MCU board (transition between the sleep and the active periods) and the measuring station device as a whole, by restoring the system with a certain sleep time after the operating (active) mode in which the sensor measurements, data analysis, uplink reporting and downlink command communication are performed;
- Communication subsystem, realized as a separate communication module with own integrated communication controller unit, or as an integrated module with the control subsystem, in which case some communication protocols are realized by the controller subsystem. Communication subsystem enables measuring station connectivity to the outside communication access networks available at the specific measurement station location, and thus the reporting on the measured and analysis data, the reporting on the measuring station device status, as well as the remote control of measuring station operation; and
- Electric power supply subsystem, which enables continuous operation of measuring station device, and is typically realized in the form of battery supply unit, or optionally as the autonomous power supply based on solar panel technology.

  Notice: In some special cases, when the electric power distribution grid is available on the installation site location, a direct electric power supply from the grid network can be supported as an optional feature.

Taking into the account previously defined general technical requirements for the both type of measuring stations (as given in the introduction part of Section 3), and the above defined constituent components of the general measuring station device in the form of IoT sensor node, the general implementation block scheme (design scheme) of observed measuring stations is shown in Figure 3.7. In this general implementation scheme, all components are portrayed as separate modules, while the specific implementation may involve usage of wholly or the partially integrated devices, i.e. the integrated WDT within the controller subsystem (i.e. embedded in MCU board), the integrated power supply and the controller subsystems and/or the integrated controller and communication subsystems. Also, it should be noticed that the ADC component is introduced to highlight the need of collecting status of remaining battery supply capacity, which should be included in periodic reports towards the central application software in order to enable proper operation and the timely maintenance (i.e. battery replacement) for all the measuring stations on the system level – this feature can be easily realized by using the commonly supported analog inputs (with ADC) on available MCU boards. Also, WDT component may be (and usually is) already integrated in most of MCU boards designed for the implementation of IoT systems to support energy efficient operation.

Figure 3.7: The general implementation block (design) scheme for the development of the required measuring station devices

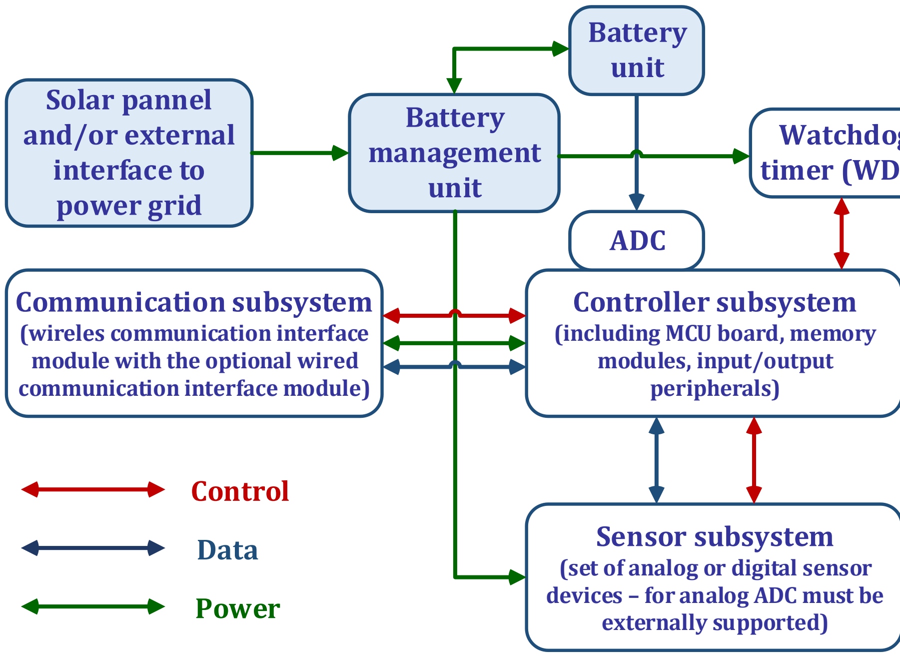


Source: Authors

However, it is very important to notice that the given general implementation scheme presumes that the specific software application that resides on the MCU board is developed for the given measuring station, by using a specific producer firmware for MCU board, WDT, communication module and sensor devices, which enables proper operation of the measuring station as a whole (in line with all defined technical specifications related to data acquisition and measuring, reporting, remote control, data storage and analysis, and the other defined functionalities of the observed measuring stations).

In the case when autonomous battery powered supply with the solar panel is provided, the general implementation block scheme in Figure 3.7, is slightly changed in order to support such power supply option, as shown in Figure 3.8. In implementation presented in Figure 3.8, the solar panel and/or the external interface to power grid is connected to the additional battery management unit, which is responsible to supply all hardware components and to manage recharging of battery unit when solar panel produce extra energy or use the stored battery capacity in the case when solar panel produce less energy. The other aspects of the original implementation scheme are not affected.

Figure 3.8: The general implementation block (design) scheme for the development of the required measuring station devices with autonomous battery powered supply with solar panel



Source: Authors

By the comprehensive overview of all the commercially available components that can be used for the implementation of the general implementation scheme given in Figure 3.7 (description of some of those are given in Appendix 1), including: MCU boards, sensor devices intended for the measurement of required physical parameters (water level in the river bed, liquid precipitation, soil moisture and air temperature), and wireless and wired communication interface modules and power supply solutions, the following conclusions are derived:

- The wide variety of possible components are commercially available on the market that allow relatively low-cost and seamless implementation of both type of required measuring stations (when hardware component cost and required technical characteristics are observed);
- The sensor devices that satisfy required measurement specifications are generally available as the separate hardware modules, realized as the digital sensor devices, while the mostly supported type of communication interface for these sensor devices is Modbus RTU RS-485 serial communication interface;
- There are different commercially available integrated solutions (see Appendix 2) that comprises controller subsystem (including WDT component), communication subsystem (with different supported wireless technologies) and the power supply subsystem, and which enable interfacing just one or the several sensor devices (the support of Modbus RTU RS-485 serial communication interface and other types of serial interfaces is generally provided). This kind of integrated devices, which are here marked as general integrated wireless sensor node devices create additional measurement station devices implementation approach, with the additional sensor devices that can be connected to this integrated platform and thus allows greatly simplified implementation, in comparison to the more general one given in Figure 3.7. The implementation block scheme (design scheme) for the development of the required measuring station devices by using such general

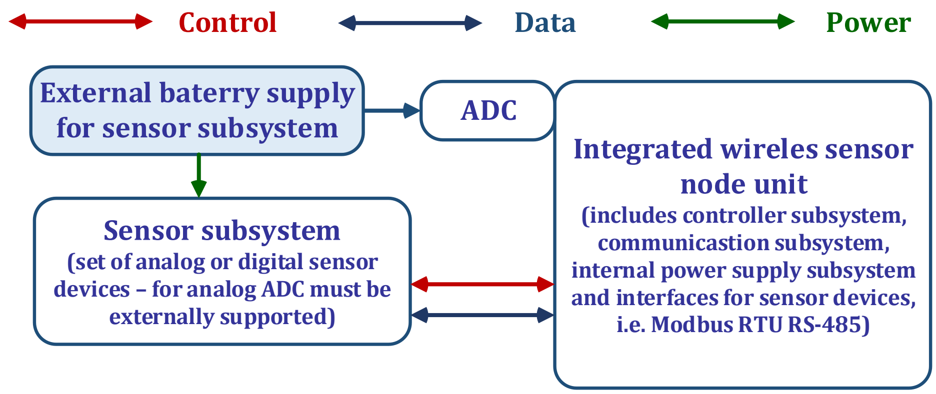
integrated wireless sensor nodes (WSN) device is shown in Figure 3.9. It should be noted that in this approach sensor devices connected to the integrated platform usually must be provided with an additional external power supply since the integrated platform already possess its own power supply. However, there are also integrated wireless sensor node device without the internal power supply subsystem (i.e. without the internal battery unit), when the external power supply must be designed and used, as shown in the implementation block scheme (design scheme) in Figure 3.10. Also, the same implementation block scheme can be modified to allow deployment of the autonomous battery powered supply with solar panel, as in Figure 3.11;

- There are several commercially available integrated solutions that present complete measuring stations devices that fulfil the required basic conditions for the RBWL-MS devices and the MCD-MS devices (some typical of these are given in Appendix 1).

Based on above given remarks and the common practice, the three basic design (implementation) approaches can be defined for the development of the observed measuring stations devices:

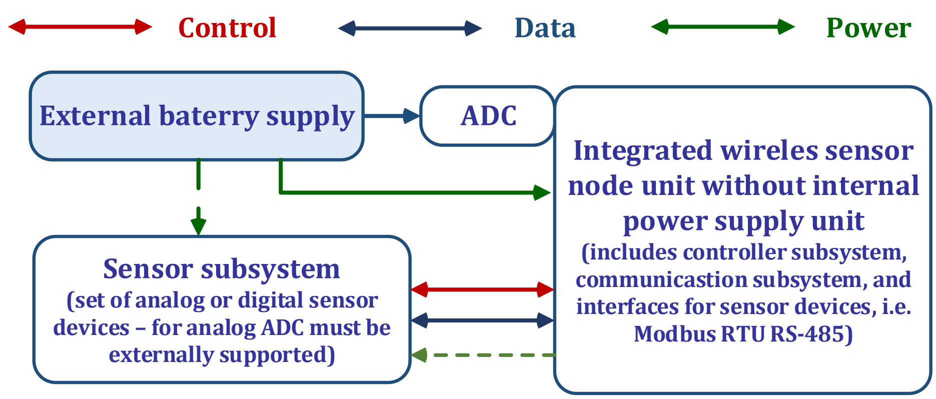
- The most general and flexible design approach according to the implementation block schemes in Figure 3.7 and Figure 3.8, depending on the power supply option, which can be fully optimized according to the envisioned operation modes, the specific requirements and available hardware components. This approach may result with the lowest production device cost per unit (in case when design and development expenditures are not included in this cost), but has potentially a highest design and development cost due to the required working hours, the more complex design of devices embedded application software, the more complex, costly and time consuming certification process (under requirements defined in subsection 3.4), and the probable necessity to design and finance production of specific enclosure solution (in line with the high environmental requirements). However, this design approach is still a viable one, and should be considered in a development and implementation phase;
- The less flexible design approach in which the already existing general integrated wireless sensor node platform is used, according to implementation block schemes in Figure 3.9, Figure 3.10 and Figure 3.11, depending on power supply options, with the required number of matching communication interfaces for connecting the separate sensor devices needed. In this case a much faster and lower-cost development and implementation phase can be expected (i.e. in terms of working hours and certification process), since only the seamless integration process should be performed in which the already available firmware and software development environment can be used, with only minor hardware adaptation and modification are expected (i.e. provision of adequate external power supply for sensor subsystem). This approach generally does not demand design of the specific enclosure (as all the basic components already have their own) and the less complex device certification can be expected; and
- Finally, the techno-economic assessment, which should be performed before the final decision on development and implementation approach, may results with the conclusion that the already available commercial solution for any of the observed measuring station can satisfy all defined operational and functional requirements, and that other two approaches do not offer sufficient enough cost reduction. In that case, the use of commercially available device can be considered. However, this approach offers the least flexible and optimized result, and expected highest cost per measuring station device (when design and development cost are excluded). This approach also support fastest and simplest realization of system as a whole, which can be useful for the fast initial proof of concept (PoC) examination on the system level without the need to wait for the development, design and testing phase to be finished before this PoC based assessment.

Figure 3.9: The implementation block (design) scheme for the development of the required measuring station devices by using general integrated wireless sensor nodes device with the internal battery supply



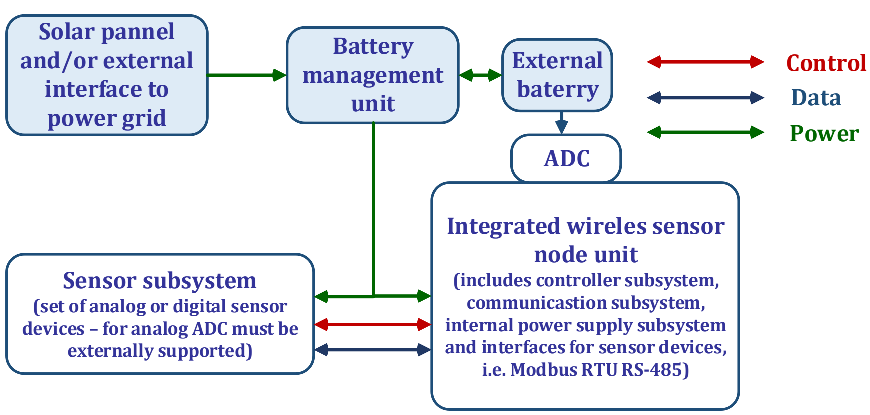
Source: Authors

Figure 3.10: The implementation block (design) scheme for the development of the required measuring station devices by using general integrated wireless sensor nodes device without the external battery supply



Source: Authors

Figure 3.11: The implementation block (design) scheme for the development of the required measuring station devices by using general integrated wireless sensor nodes device with autonomous battery powered supply with the solar panel



Source: Authors

3.3.1 The general recommendation for the design, development and implementation of the observed measurement stations

Based on the previous description and discussion of possible design and implementation a general recommendation for development and implementation of here observed measurement station device is that at the start of this process the comprehensive techno-economic assessment must be provided, taking into the account: the estimated cost of design and development of measuring stations, available financing options for the design and implementation process, a specific business plan for the deployment of measurement stations (and here observed Early Warning System as a whole), expected number of devices that could be produced for the specific project and for other customers/users of such designed Early Warning System, cost of existing commercially available solutions, possible competing solutions, as well as other factors that can have high impact on the final decision. As defined, there are three general design, development and implementation options: the design and development through the integration by using separate modules (control module, sensor devices, communication devices, power supply module, etc.) as given in Figures 3.7 and 3.8, which can be marked as “design from the scratch”, the design and development through the integration by using integrated wireless sensor nodes (with or without internal power supply) and sensor devices as given in Figures 3.9, 3.10 and 3.11, and the design through the acquirement and adjustment of existing and commercially available solutions (measuring station devices). Moreover, in all three cases we can observe the solution based on using power supply based on battery unit (internal or external), or the solution with autonomous battery powered supply with the solar panel (or other external power source).

At this moment, without the additional data regarding this, only the general comparison of previously defined design and implementation options can be given in respect to:

- design and development process such as:
  - The effort needed to design, develop and implement the final solution,
  - The time needed to design, develop and implement the final solution,
  - The level of support of all specified technical requirements, and
  - The flexibility of the final solution as needed for the further improvements and adjustment for the specific operation conditions and application scenarios;
- The level of possible risks of unsuccessful or inadequate design and development of the required measuring stations devices;
- The main factors that have important influence on the final solution cost such as:
  - The procurement cost of required hardware and software components (the procurement of commercially available measuring stations included),
  - The cost of working hours needed for the complete design, development and implementation process, i.e. engineering cost,
  - The cost of design and production of the adequate device enclosures (if needed),
  - The cost of device certification (i.e. final and during of design and development process). In the case of procurement of commercially available solutions these costs do not exist or comprise only of administrative procedure needed in order to import electronic devices and radio equipment;
- The production cost of the designed and developed measuring station devices (per unit cost) when the design and development cost are excluded.

The general comparison of previously defined design and implementation options in respect to the previously defined factors (criteria) is given in Table 3.14, with the descriptive ratings defined as:

very low, low, medium, high and very high. **Notice:** The given ratings should be observed as general ones, since the reliable rating and decision can be made only after the previously recommended comprehensive techno-economic assessment is performed, which is not possible in this stage.

Table 3.14: The general comparison of possible measuring station devices design and implementation options

Design, development & implementation options (power supply used)	Design from the scratch by using different separate modules (Figures 7 and 8)		Integration by using integrated WSN and sensor modules (Figures 9, 10 and 11)		Procurement and adjustment of commercially available solutions	
	Battery	External (solar)	Battery	External (solar)	Battery	External (solar)
Design & development engineering effort	High	Very high	Medium	High	Very low	Low
Time needed to design and develop final solution	High	Very high	Medium	Medium	Very low	Very low
Support of all specified technical requirements	Very high	Very high	High	High	Medium or Low	Medium or Low
Final solution flexibility	Very high	Very high	High	Medium	Very low	Very low
Risks of unsuccessful or inadequate design and development results	High	Very high	Low	Medium	Very low	Low
Design & development cost (procurement of hardware & software)	Low	Medium	Medium	Medium	High	Very high
Design & development cost (engineering work)	High	Very high	Low	Medium	Very low	Very low
Design & development cost (enclosure cost)	High	High	Very low	Low	No cost	No cost
Design & development cost (certification costs)	High	High	Low	Medium	No cost or very low	No cost or very low
Final product unit cost (if design & development cost are excluded)	Very low	Low	Low	Medium	High	Very high

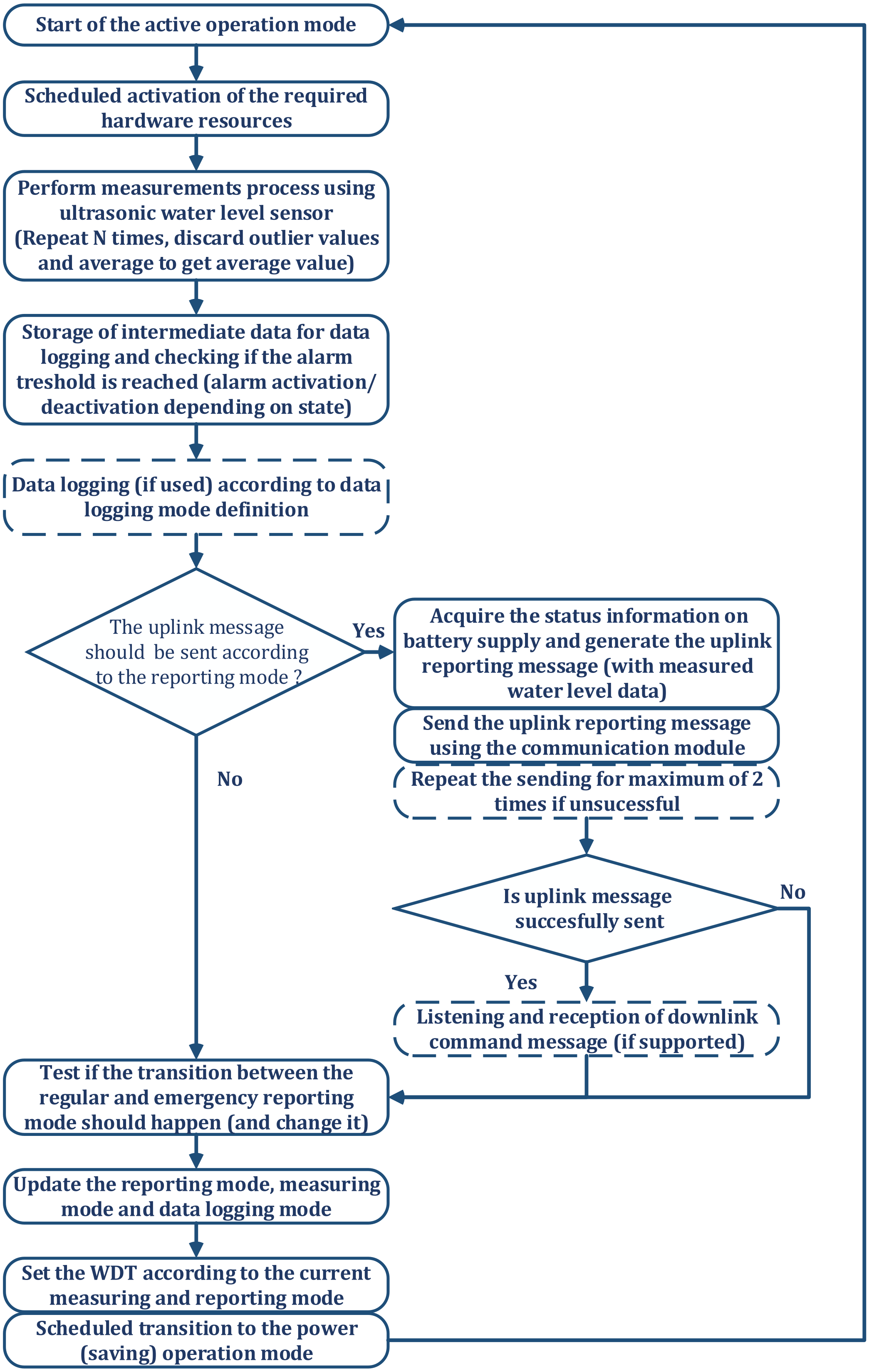
Source: Authors, based on the available data

If some general recommendation should be given in this stage, it seems that the design and development through the integration by using integrated wireless sensor nodes (with or without the internal power supply) and sensor devices presents the most safe and viable option regarding all the observed criteria. This solution may also be the most suitable option for the PoC system installation and analysis (i.e. for testing related to the defined micro-location) due to the relatively low expected time needed to design and develop final solution. However, for this purpose, despite the higher costs, the commercially available solution can also be interesting due to the fastest implementation.

3.3.2 The general flowchart for the realization of the measurement, reporting and reception cycle during the typical active operating mode

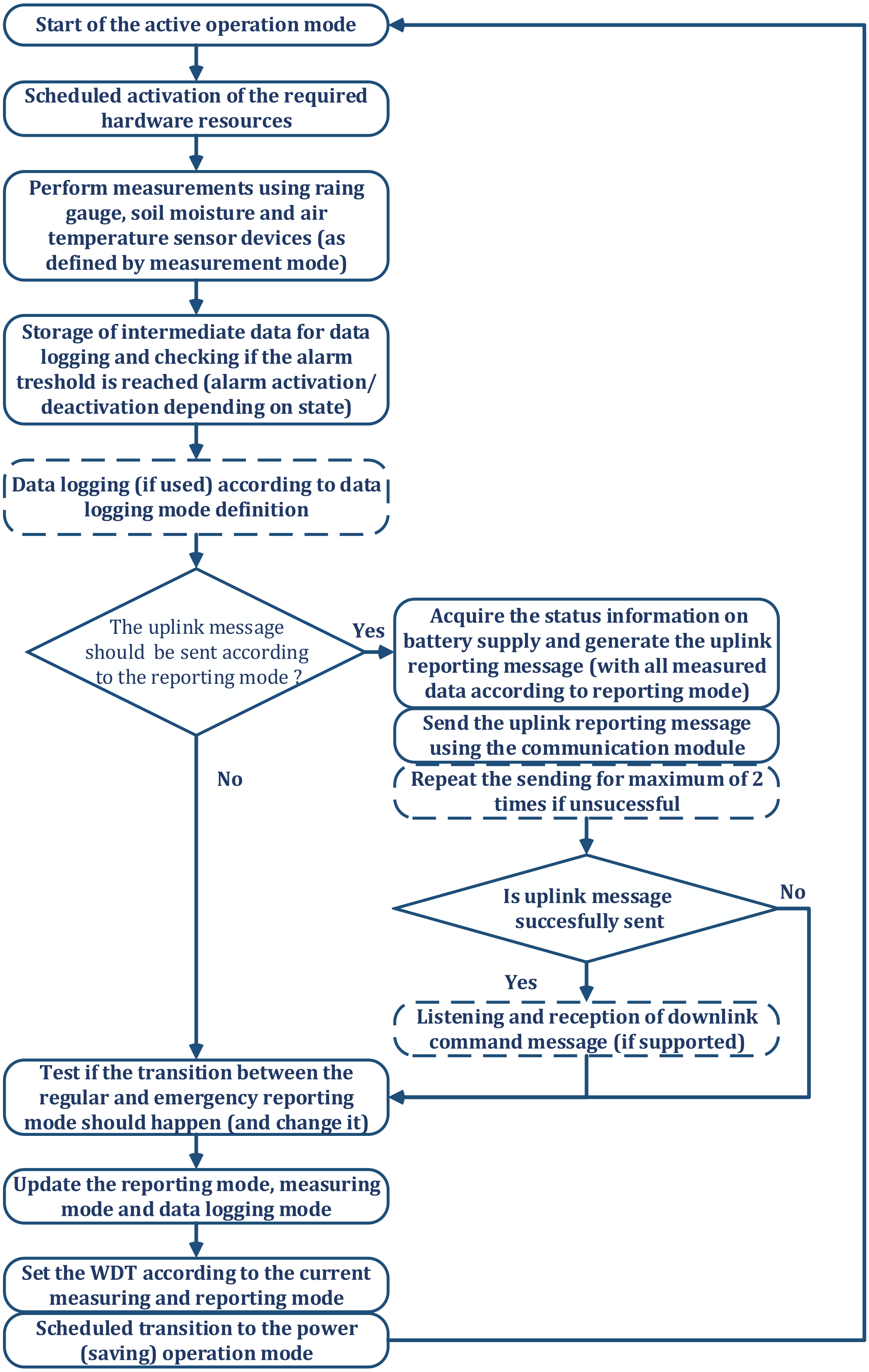
In order to properly design, develop and implement the required measuring station devices for RBWL-MS and MCD-MS device solutions, it is necessary to design and develop adequate software application (or adjust and set the existing software application) using the embedded device programming environment. The general operating flowchart of low-cost measuring station devices with the single MCU and a minimum set of required sensor devices, as required and defined by technical requirements in subsection 3.2, is shown in Figure 3.12 and Figure 3.13, for the RBWL-MS and MCD-MS devices, respectfully.

Figure 3.12: The general operation flowchart of the basic low-cost RBWL-MS device with the single MCU and only one ultrasonic-based water level sensor



Source: Authors

Figure 3.13: The general operation flowchart of the basic low-cost MCD-MS device with single MCU and set of required sensors (rain gauge, soil moisture and temperature sensor devices)



Source: Authors

3.3.3 The general guidelines and requirements on the measuring station location selection, installation, and measuring station maintenance

The general criteria, methodology and requirements related to the process of measuring station location selection, installation and construction are defined in the Section 2. In this subsection some most important requirements on this matter will be stressed, and some additional requirements related to the measuring stations installation and maintenance will be given.

The selection of location and installation of the RBWL-MS measuring stations

The proper selection of the site for the establishment of measuring station for gathering water level in the river bed data (RBWL-MS devices), as well as the satisfaction of the main installation requirements, is extremely important for the proper functioning of the Early Warning System. When choosing the major site and installing the measuring station, the following criteria and requirements should be taken into the account:

- In the torrential basins, the RBWL-MS device should be located in the center of the transit zone or torrential flow movement. This is a location between the zones of water and sediment accumulation and the zone of accumulation of torrential sediment;
- Unlike the MCD-MS device, the RBWL-MS device for measuring the water level should be placed in the immediate vicinity of the zone of lowest elevation and near the transition from the zone of lowest elevation to the zone of highest elevation. **Notice:** In the specific case, for the observed micro-location, it would ideally be placed at the transition from the 200-300 m elevation zone to the 100-200 m zone;
- The location of the RBWL-MS device should be in the sector of the low vertical relief dissection, at the transition from the high to the low vertical relief dissection. Therefore, the site should be located near the steeply sloping relief energy, i.e. near or at the reference level;
- The location of the RBWL-MS device should be in the sector with small slope angle, at the transition of the last two lowest slope classes, i.e. where the kinetic energy of the river decreases;
- The final selection of the location (profile in the riverbed) for the installation of the RBWL-MS device should be determined by field work to select the best section of the riverbed suitable for carrying out the measurement. In order for the measurement of water level and discharge to be meaningful, the selected section of the riverbed must fulfill the following conditions:
    - The flow direction has a minimum length of 5*B* (*B* is the width of the water mirror for the maximum expected flow) and that the river course is without eddies. The riverbed should have a uniform gradient with no cascades, and there should be no large boulders or other material in the bed;
    - The selected section must not have a single tributary or additional water volume;
    - The banks must be stable and free of vegetation (not overgrown);
    - If the river course is regulated, the hydrometric profile (section) should be upstream from the cascades and rapids, far enough away not to disturb the steady flow, and
    - On the selected section, the measurement profile should be in the middle. There, an automatic measurement station is installed, i.e. a sensor that registers the change of the water level in the riverbed at each point.

  From the installation point of view, the next general requirements must be satisfied:

- The sensor is placed above the riverbed at a sufficient height (in the safety zone) so that it does not come into contact with the water or with the floating sediment carried by the water during the flood wave. Generally, the sensor device should be mounted on the horizontal pole above the water bed;

- Except for measuring station device, a manually water gauge should be placed on the selected measurement profile for measurement control. If the measuring station is located in a natural, unimproved bed, a marker (benchmark) should be placed on the selected section to monitor elevation changes on the hydrometric profile after the passage of flood waves. In addition to the aforementioned marker, a control marker should also be placed;
- All profiles on the survey section (downstream, midstream and upstream) should be well anchored in the ground and their coordinates should be recorded. They should be fixed with stone or concrete markers and, if none are available, with well-buried stakes;
- After creating the hydrometric section, it is necessary to survey the section to obtain a site plan at a scale of 1:500. It is necessary to record the transverse and longitudinal profiles of the selected section;
- The river is determined on the basis of the water level in the bed (depth), the water level gradient and the cross-section using the Shezi equation for the mean profile water velocity and the continuity equation for the discharge (as defined in Section 2);
- All parts of the measuring station should be installed and mounted according the specification of the manufacturer (producer) of devices used (i.e. solar panels, battery unit, sensor devices, wireless communication module with antenna, or the complete measuring station device if so decided in the implementation phase) and according to the additional documentation produced during the self-developed measuring station design and implementation phase.

The selection of location and installation of the MCD-MS measuring stations

The proper selection of the site for establishment of the measuring station for gathering of the meteorological and climate data (MCD-MS devices), as well as the satisfaction of the main installation requirements is extremely important for the proper functioning of the Early Warning System. When choosing the location and installing the measuring station, the following criteria and requirements should be taken into the account:

- The station should be placed in the central part of the high watershed area (headwater, head of the river), because then a representative sample (result) of the maximum precipitation for the catchment area is provided. **Notice:** In the specific case, for the observed micro-location, the precipitation station should be located in the altitude zone of 700-800 m between the source of the Trbušnica River and the Gučevski potok;
- The location of the station should be in the area of low vertical dissection of the relief, but in the immediate vicinity of the highest parts of the river basin, i.e. at the transition from low to high vertical dissection of the relief;
- The site for the monitoring station should be located in a part characterized by small slope angle, but very close to the highest parts of the basin, where the largest amount of precipitation is expected and where the water is collected for surface runoff (precipitation collection area). In addition, the site must be located in a plain, in the zone above the high vertical dissection of the relief, but also at the beginning of the significant slopes of the terrain, which condition the rapid runoff;
- The viability of energy power grid (external energy source) is important if the technical characteristics and the method of data transmission require it. This is an option because most monitoring stations have self-powered panels, which is the preferred option;

- The wireless or wired network service should available at the location in order to allow network connectivity for the purpose of periodic reporting of the measured data (i.e. the site should be in the coverage zone of existing LoRaWAN gateway or other alternative network access point);
- State ownership of the land where the measuring station station is to be installed is desirable, as private ownership may result in frequent relocation of the monitoring station;
- The measuring station must be placed on the site that is not endangered by various damages (vandalism), livestock, domestic animals, etc.;
- It is necessary to ensure that the chosen location is easily accessible by car (for transport of equipment, data collection, replacement of sensors and devices, etc.);
- Regardless of the type of precipitation station installed, it is necessary to place it on a stable base; the upper edge of the receiver must be exactly at a height of 1.0 m from the base, and the area of the circular receiver should be 200 cm^2;
- Around the measuring station free space from buildings, vegetation, etc. is required If the site is located in the zone of forest vegetation, a free space with a radius of at least 15-20 m is required; and
- All parts of the measuring station should be installed and mounted according the specification of the manufacturer (producer) of devices used (i.e. solar panels, battery unit, sensor devices, wireless communication module with antenna, or the complete measuring station device if so decided in the implementation phase) and according to the additional documentation produced during the self-developed measuring station design and implementation phase.

The requirements related to the maintenance of the measuring stations

The each measuring station should be properly programmed with all the operating parameters being defined (i.e. predefined) on premises before the proper installation on the selected location. The location should be properly arranged and constructed (i.e. fence should be installed) in line with the specification of the manufacturer (producer) of devices used (i.e. solar panels, battery unit, sensor devices, wireless communication module with antenna, or the complete measuring station device if so decided in the implementation phase) and according to the additional documentation produced during the measuring station devices design and implementation phase.

Nevertheless, for the proper long-term operation the measuring stations should be periodically visited for the maintenance and repair purposes in order to:

- Change the exhausted battery unit. The information on the need to replace battery should be conveyed by the central software platform since the battery voltage level is regularly acquired – the automatic message delivery (with the information on need to change battery) to the maintenance personnel for the specific site can be easily supported;
- Perform periodical cleaning of the rain gauge in order to work properly;
- Perform periodical re-installation of soil moisture sensor since after certain period of time the probe must be taken out from the ground and re-inserted;
- Perform periodical checks on the installations (i.e. cables and interfaces) in order to prevent damage of devices and installation, sensor devices malfunction, device operation interruption and outages, and other unexpected events; and
- Perform the unplanned preventive checks after the storms and other weather disaster events, when the certain installations damage or changes can be expected.

Notice: The details regarding the maintenance and the operational support procedures should be detailed and defined in design, development and installation phase according to the specifications provided by the manufacturer of the hardware devices, and according to the additional measuring station documentation produced during self-developed design and implementation phase.

3.4 The required certification process as the integral part of design and development of the Data Acquisition and Measuring Devices

According to the EU (European Union) and the local (national) legislature framework in Republic of Serbia, there are essential requirements for electric and electronic devices (equipment) that in itself comprises radio equipment and terminal telecommunication equipment, and other requirements and conditions that must be fulfilled for placing this equipment on the market and/or using this equipment, with the prescribed conformity assessment procedures for this type of equipment. Also, there are other essential requirements, other requirements and conditions for the general electric and electronic devices (equipment) for placing this equipment on the market and/or using this equipment.

The here observed measuring stations, which present specific electric and electronic equipment that also incorporates radio equipment and terminal telecommunication equipment, must fulfill all proscribed essential requirements, as well as other defined requirements and conditions for the general electric and electronic equipment and also for the radio equipment and terminal telecommunication equipment.

Therefore, in order to use or put on the market the measuring stations developed in scope of the project the production process and equipment must be certified according to the EU and the local (national) legislature. The EU and national legislature in Serbia is mostly harmonized (including appropriate standards) except for the radio equipment and terminal telecommunication equipment, where the national legislature in Serbia is still not updated with the latest framework in EU (the national legislature is still defined as in repealed *Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity*), but is expected to be harmonized in the near future. Therefore, the developed solutions for both type of measuring stations must be properly certified according to the following:

- The EU Low Voltage Directive (LVD) - *Directive 2014/35/EU*, which ensures that electrical equipment within certain voltage limits provides a high level of protection, and benefits fully from the single market. The national legislature framework in the Republic of Serbia is completely harmonized with this EU directive. Notice:
- The EU Electromagnetic Compatibility (EMC) Directive - *Directive 2014/30/EU*, that ensures that electrical and electronic equipment does not generate, or is not affected by, electromagnetic disturbance. The national legislature framework in the Republic of Serbia is completely harmonized with this EU directive.
- The EU Restriction on Hazardous Substances in electronic and electrical equipment (EEE) directive (RoHS 2) - *Directive 2011/65/EU*, that restricts the use of certain hazardous substances (polybrominated diphenyl ethers, lead, mercury, cadmium, hexavalent chromium, and polybrominated biphenyls) in electrical and electronic equipment (EEE). Thus, the technical documentation for EEE should be compiled in order to declare compliance with the applicable substance restrictions (Standard EN 50581:2012), in accordance to EU *Decision 768/2008/EC*.
- The EU Radio Equipment Directive (RED) - *Directive 2022/30/EU*, that establishes a regulatory framework for placing radio equipment on the market. This directive ensures a single market for radio equipment by setting essential requirements for safety and health, electromagnetic compatibility, and the efficient use of the radio spectrum, and provides the basis for further regulation governing some additional aspects. Additional aspects cover interoperability, access to emergency services, and compliance regarding the combination of radio equipment and software.

This directive includes previously stated directives for the case of radio equipment with the additional essential requirements related to use of radio frequency spectrum.

Notice: According to the above mentioned EU directive specific harmonized EU standards (EN standards), which results with corresponding SRPS EN standards, are defined (listed) depending on the type and category of electrical devices and radio communication and terminal equipment employed. In the final document of these technical specifications only the general notice regarding the required standard compliance should be given, but the final list of standards can be resolved only during the development and implementation process for the specific device.

Also, in the part of the production process the requirements of the EU Waste Electrical & Electronic Equipment Directive (WEEE II) – *Directive 2012/19/EU*, should be respected.

In order to allow the developed measuring station to be used or put on the market of the EU the CE marking must be obtained and EU Declaration of conformity must be issued.

The certification process can be simplified if the development of the measuring stations is done as integration of the already certified components (with CE marking), but even in this case it has to be performed since the usage of already certified components does not automatically mean that the produced equipment is certified.

The required certification procedures, including laboratory examinations (testing) and technical documentation preparation can be very complex, demands certain time period and incurs the substantial cost that must be factored in the development cost (especially if some examinations must be repeated). Also, it is important to state that some of the required laboratory examinations (tests) are not available locally in the Republic of Serbia, which may demand for these tests to be performed abroad (with the additional transport and administrative costs and time consumption).

3.5 Concluding remarks

Here defined technical specifications for the required Data Acquisition and Measuring Devices for the Early Warning System in Drina River Basin are given in line with the defined scope of work, as well as with the information and additional requirements defined in the observed Project. These technical specifications define general requirements for the observed measuring stations regarding the environmental (operational) conditions, measuring station devices power supply options, set of supported sensor devices, operation, measurement, data logging and reporting modes, types and formats of transmitted uplink messages (including calculations of required storage capacity of local and central platforms), communication interface module that provides measuring stations network connectivity on the system level, and other additional factors.

Also, the general guidelines and requirements on the possible approaches to the design, development and implementation of the observed measuring stations are given, with three general approaches defined, and with a subsequent analysis regarding the factors that determine the design, development and implementation process as well as the associated costs and final development results. However, in this stage only the general guidelines could be given.

Additionally, the general operational flowchart for the observed low-cost measuring station devices are proposed, which should facilitate the design and development of required HWS platform in the next stage, but these are not considered as mandatory. Finally, the general requirements on the measuring station location selection, installation, and measuring station maintenance are specified, as well as some general requirements regarding the mandatory certification process for developing measuring station devices (when these are observed as electronic equipment and radio equipment).

4. SYSTEM FUNCTIONALITIES FOR THE DATA ACQUISITION, DISTRIBUTION AND EARLY WARNING SOFTWARE IN THE DRINA RIVER BASIN

4.1 Input data

Based on the Methodological guidelines for establishment of early warning system in Drina River basin and technical specifications for data acquisition and measuring devices for the early warning system in Drina River basin - back-end should provide a mechanism for real-time acquisition, storing and processing of following parameters:

1. Amount of liquid precipitation - acquired with the use of either rain gauge or pluviometer station. Data is obtained 24/7/365 i.e. (constantly, every day throughout a year). Despite continuous acquisition of data, the CAS (Central application server) will receive the information periodically where this period between two measurement data reception is predefined. The period should be no longer than 60 minutes in case of regular report. In case of emergency reporting, the interval should decrease to 15 minutes (although it might be 5 minutes and this parameter can change depending on the final calculations). Length of the time period in between two measurement reports depend on the measured parameters. Proposed precision for the amount of liquid precipitation is 0.5mm. The required precision might differ depending on the final calculation for that particular location.
2. Air temperature - Measurements are obtained 24/7/365 (i.e., constantly, every day throughout a year) by sensor nodes installed at the location of interest according to the methodology defined in the Methodological guidelines section of this document. Central application software should be able to handle the reception of air temperature report every 60 minutes (once every hour) in case of non-emergency reporting. In case of emergency reporting the report, period should decrease to the proposed 15-minute interval or less. Proposed precision in case of air temperature measurements is 0.1 degrees Celsius. Proposed reporting intervals as well as the required precision might differ depending on the necessary calculations.
3. Relative air humidity – This will not be measured, however in case the measurement is needed in the future, for the more precise and detailed information, software system will be able to support additional parameters such as this one.
4. Soil humidity (soil moisture) - Measurements are obtained 24/7/365 (i.e., constantly, every day throughout a year) by sensor nodes installed at the location of interest according to the methodology defined in the Methodological guidelines section of this document. In case of non-emergency reporting, Central application software should be able to process soil humidity (soil moisture) reports once an hour and the interval can decrease to the proposed 15-minute interval in a case of an emergency. Central application software should be able to handle both cases in terms of being able to process the provided data even in the case of highest proposed report reception frequency. Proposed resolution of soil humidity (soil moisture) measurements is 5%. Proposed reporting intervals as well as the required precision might differ depending on the necessary calculations.
5. Water level in the river channel - Measurements should be performed 24/7/365 (i.e., constantly, every day throughout a year) by sensor nodes installed in the area of interest (key torrent locations). Central application software should expect water level measurement reports

every fifteen minutes in case of regular reporting. In case of emergency reporting the interval is planned to decrease to five minutes. In case of water level measurements, we differ required measurement resolution and the requested measurement accuracy. The proposed required measurement resolution is 1 mm and the requested measurement accuracy is 1cm. The stated parameters can be adjusted based on the calculations and the precise location of the measuring device.

Sensor nodes are to be installed in remote locations where we face the issue of constant power supply. In the Technical Specification for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin it is pointed out that we need a mechanism of battery monitoring in case of autonomous battery powered supply with the solar panel. There is a possibility of powering the installed sensor nodes in the field by attaching them to the local power grid or by using PoE (Power over Ethernet), but these options are likely to not be available in remote locations. Central application software must be able to track/monitor currently available power supply capacity (i.e., the remaining battery capacity level for battery power supply of rechargeable battery in case of autonomous battery powered supply with the solar panel). Battery capacity level measurement and reporting should be supported via MCU (Micro-controller unit) boards and reported regularly with the other measurement data - according to the Technical Specification for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin. This applies to the both following case scenarios:

1. Battery power supply - details presented in Table 1
2. Autonomous battery powered supply with the solar panel - details presented in Table 2

Table 1 - The general technical specifications related to the electric power supply requirements for RBWL-MS measuring station device

Power supply option	Battery power supply
Required battery lifetime	Built-in replaceable battery should work for the minimum 5 years and the expected 10 years period without replacement in case of the regular 15 minutes reporting interval
Power supply	In general: DC 12 V/50 mA DC (Should be defined according to the sensor device used)
Battery type (recommended)	Li-SOCI2
Measurement and reporting of battery capacity level	Should be supported via MCU (Micro-Controller Unit) board, and reported regularly with the other measurement data
Additional	CE marking certification must be supported

Power supply option	Autonomous battery powered supply with the solar panel
Required autonomous power supply lifetime	At least 5 years without the replacement of the rechargeable battery unit
Power supply	In general: 6 – 12/15 V DC charging battery with AC adapter (Should be defined according to the sensor devices used)
Solar panel	2 – 15 W, 0.3 - 1 A (Should be defined according to the power consumption)
Battery capacity level measurement and reporting	Should be supported via MCU (Micro-Controller Unit) board, and reported regularly with the other measurement data

Additional	CE marking certification must be supported

Table 2 - The general technical specifications related to the electric power supply requirements for MCD-MS measuring station device

More about the format and how this information will be sent over the network will be discussed later in the document.

Additionally, back-end application (central application software) should take data from the existing meteorological stations in the area of interest. These are fixed stations places by the Republic Hydro-meteorological Service of Serbia. Provided these stations feed data to data server, integration with such servers is possible from the point of view of backend software. Interface details and ways of connecting to such data will be further described in the frontend section.

Important notice: In order to lower the capital expenditures (CAPEX) and operational expenditures (OPEX) for the Early Warning System for the Drina River basin (as stated in technical specifications for data acquisition and measuring devices for early warning system in Drina River basin) the main storage and data processing as well as alarming capabilities of the system as a whole should be realized on the system level in the form of a Central application software. This does not mean that installed sensor nodes should not be able to store any data at all. Installed sensor nodes can, and arguably should be able to temporarily store measured data in case of a connection loss. Once connection between sensor nodes and the central application software is re-established, we can pull all the previously stored data from sensors and prevent permanent data loss. Also, the installed sensor nodes in the field might, and arguably should be able to, do minimal data processing meaning being able to, for example, recognize that the measured values have surpassed the predefined threshold and issue an alarm. Nevertheless, future modifications are headed in a direction of further off-loading of all the sensor nodes which should, still, periodically perform measurements and send reports. This might differ during the implementation stage. The proposed further sensor node off-loading is done in order to ensure additional energy savings, reduction of required capacities of wireless communication links, reduction of CAPEX and OPEX - all without the loss of measurements and reporting performance at system level (central application software).

4.2 General sensor node specifications

In the following section we present the general technical specification of the sensor nodes to be installed in the field. Specifications are as presented in the technical specifications for Data Acquisition and Measuring Device for Early Warning System in Drina River Basin for the Water level measuring station device. It presents a brief overview of all parameters that a software developer might consider (i.e., keep in mind) during the planning and development stage.

Measurement period is expected to be 5 minutes although this might be subject to change based on the calculations and the position of the device. Uplink messages are sent according to the defined reporting period (whether the sensor nodes operate in regular of emergency reporting mode). Download command messages should be considered only in case hardware supports such functionalities These provide central application software with a possibility of remote sensor node control (for instance reporting period change). Additionally, we might be able to turn on and/or off remote devices in the field using the central application software. For the time being, a sensor node should be able to, locally and when needed, switch between regular and emergency reporting mode.

Measured water level threshold are stated as 300-500 mm. Any measurement value received by the central application software that is out of bound of the stated threshold should indicate an incorrect measurement value and potential issues in the operation of sensor nodes in the field. Battery capacity is, as expected, in the range of 0-100%. Needless to say, that any reported value outside the stated scope represents an incorrect value and possibly indicated an issue in operation of a sensor node.

For each measurement piece of data collected a sensor node should perform subsequent reporting attempts in case the initial reporting fails (suggested number of attempts is 3). On the central application software side and in case we use downlink commands messages, there should exist a similar mechanism of subsequent command issuing attempts in case the initial downlink command fails to reach a target device.

In case of regular reporting the reporting period is expected to be 15 minutes which is expected to decrease to a 5-minute reporting period in case of emergency reporting. All sensor nodes should be able to independently switch from regular to emergency reporting and vice versa. This is done based on comparison of measured data and predefined thresholds and is done locally by the sensor node itself. Additionally, we might introduce the option of remote reporting period change where such parameter is set by the central application software as mentioned in the paragraph above.

Central application software can, accept only one measurement per active operation period (this means sensor performs one measurement and sends it over to the central application software). It is possible to have multiple measurements done in one active operation period where the central application software ends up receiving the average of all measured values (with detection and discarding of outlier samples). The exact number of measurements per active operation period is to be defined by: the chosen sensor device, achieved estimation performance, time needed for the successful measurements and the optimization between a measurement performance and energy efficiency. It may be possible, depending on the type of a sensor node, to support downlink commands that would allow the central application software to modify such parameters remotely.

Each sensor node should be able to perform data logging with a pre-defined logging period and logging value (i.e., minimum, maximum or average value). Parametrization of this functionality can be done manually and a sensor node should be able to, locally, take care of all logging activities. However, if hardware capabilities allow, the central software application can support downlink commands to: turn the logging functionality on and/or off, set the data logging period on a remote device and set the data logging value on a remote sensor node device.

General specifications for the measuring station device	
Complete active operation mode/power saving operation mode cycle duration	Measurement period: 5 minutes
Sending uplink reporting message	Defined by the reporting period: Regular reporting – every third cycle Emergency reporting – every cycle
Maximum number of subsequent reporting attempts (if unsuccessful)	3
Maximum active period duration	1 minute for the successful reporting, maximum 2 minutes for the maximum 2 subsequent unsuccessful reporting

<table>
<tr><td colspan="2">Radio communication duty cycle (Tx/Rx)</td><td colspan="4">1% (maximum)</td></tr>
<tr><td colspan="2">Download command messages reception</td><td colspan="4">After successful uplink report message
Listening period 5 seconds (max)
Supported commands: Device On/Off, Regular/Emergency transition (optional)</td></tr>
<tr><td colspan="2">Reported measurement data and status info</td><td colspan="4">Measured water level (300-5000 mm), and remaining battery capacity (0-100%)</td></tr>
<tr><td colspan="6">Separate specifications for the sensor devices</td></tr>
<tr><td colspan="2">Reporting mode supported</td><td colspan="2">Regular reporting</td><td colspan="2">Emergency reporting</td></tr>
<tr><td rowspan="6">Water level sensor device</td><td colspan="2">Reporting period</td><td colspan="2">15 minutes</td><td>5 minutes</td></tr>
<tr><td colspan="2">Supported reporting mode transition mechanism</td><td colspan="3">Local alarm activation/deactivation
Optional: Downlink command message</td></tr>
<tr><td colspan="2">Measurement period</td><td colspan="2">5 minutes</td><td>5 minutes</td></tr>
<tr><td colspan="2">Multiple measurements – N</td><td colspan="3">10-20 (to be specified during the development and implementation phase)</td></tr>
<tr><td colspan="2">Data logging period</td><td colspan="2">15 minutes</td><td>5 minutes</td></tr>
<tr><td colspan="2">Data logging value</td><td colspan="3">maximum value</td></tr>
</table>

Table 3 - The general technical specifications for the default operation, measurement, data logging and reporting modes related to the set of sensor devices for the Water level measuring station device

In the following section we present the general technical specifications for the meteorological and climate data measuring station device. We present a brief overview of all parameters that a software developer might consider (i.e., keep in mind) during the planning and development stage.

Suggested value of complete operation mode is 15 minutes that is to be decreased to 5 minutes (optionally) in case of emergency reporting. All uplink messages (i.e., measurement reporting messaged sent from sensor nodes to the central application software) should be done every fourth cycle in case of regular reporting and every cycle in the case of emergency reporting. The central application software must be able to receive and process the measurement data within this timeframe. Each sensor node has a mechanism of subsequent reporting attempts in case the initial reporting messages fails to reach the central application software. Similar (or same for that matter) mechanism should be implemented on the central application software side in case of downlink commands messages being sent to a remote sensor node (i.e., in case the initial downlink command message fails to reach a target sensor node). Proposed number of subsequent reporting attempts is 3.

Central application software should be able to remotely control the turning on and/or off of a remote sensor node device via downlink command messages. Additionally, it should support reporting mode transition via download command message option (i.e., be able to switch the reporting mode from regular to emergency and vice versa on a remote target sensor node device).

Exact scope of valid rain falls values (expressed in mm), soil moisture (expressed in percentages) and air temperature (expressed in degrees of Celsius) should be known before the central software application implementation. These will help the central software application in recognition of incorrect values that are to be discarded and might event point to a failure in a sensor node operation. The remaining battery capacity is to be expressed in percentages (i.e., in range of 0-100%) and any data exceeding the proposed scope should be discarded and might indicate a malfunctioning sensor node.

In general, for all measurements data received on the central application software side, there should be a strict pre-defined scope of valid values. Aside from discarding incorrect data it might help us pinpoint a failing/malfunctioning remote sensor node in the field. That way we might be able to do timely replacement of a failing/malfunctioning node or fix it if possible (through recalibration or otherwise).

For all meteorological and climate data measuring station devices (i.e., raining gauge sensor device, soil moisture sensor device and atmospheric temperature sensor device) the central application software should provide support for both regular and emergency reporting mode. In case of regular reporting mode, reporting is done once an hour where measurement period is suggested to be 15 minutes and the same 15-minute period is suggested as a data logging period. In case of emergency reporting the central application, software is expected to receive measurement report once every fifteen minutes with measurement period suggested to be 15 minutes and can optionally be decreased to a 5-minute period. Data logging period in case of emergency reporting remains the same as in the case of regular reporting - 15 minutes. In both reporting scenarios the data logging value is suggested to use the maximum value.

For the time being, sensor is to be able to, locally, perform alarm activation/deactivation. Central application software, if so decided, should support a downlink command messages to set the local alarm activation/deactivation parameter to a remote sensor node. Multiple measurement parameters, explained earlier in the document, is suggested to be 1 but is to be further defined during the development and implementation phase. Central application software might be requested to provide a downlink commands messages to set such a parameter to a remote sensor node. Same remote-control mechanism can be used, if so decided, to set the data logging value parameter to a remote sensor node so that we can transition between maximum, minimum and average logging values if needed.

<table>
<tr><th colspan="4">General specifications for the measuring station device</th></tr>
<tr><td colspan="2">Complete active operation mode/power saving operation mode cycle duration</td><td colspan="2">Measurement period: 15 minutes (optionally 5 minutes for emergency mode)</td></tr>
<tr><td colspan="2">Sending uplink reporting message</td><td colspan="2">Defined by the reporting period:
Regular reporting – every fourth cycle
Emergency reporting – every cycle</td></tr>
<tr><td colspan="2">Maximum number of subsequent reporting attempts (if unsuccessful)</td><td colspan="2">3</td></tr>
<tr><td colspan="2">Maximum active period duration</td><td colspan="2">1 minute for the successful reporting, maximum 2 minutes for the maximum 2 subsequent unsuccessful reporting</td></tr>
<tr><td colspan="2">Radio communication duty cycle (Tx/Rx)</td><td colspan="2">1% (maximum)</td></tr>
<tr><td colspan="2">Download command messages reception</td><td colspan="2">After successful uplink report message
Listening period 5 seconds (max)
Supported commands: Device On/Off, Regular/Emergency transition (optional)</td></tr>
<tr><td colspan="2">Reported measurement data and status info</td><td colspan="2">Measured water rain fall (in mm), soil moisture (in %), temperature (in ℃), and the remaining battery capacity (0-100%)</td></tr>
<tr><td colspan="4">Separate specifications for the sensor devices</td></tr>
<tr><td colspan="2">Reporting mode supported</td><td>Regular reporting</td><td>Emergency reporting</td></tr>
<tr><td></td><td>Reporting period</td><td>60 minutes</td><td>15 minutes</td></tr>
</table>

Rain gauge (precipitation) sensor device	**Supported reporting mode transition mechanism**	Local alarm activation/deactivation Optional: Downlink command message	
	Measurement period	15 minutes	15 minutes (5 minutes optionally)
	Multiple measurements – N	Default value: 1 (to be specified during the development and implementation phase)	
	Data logging period	15 minutes	15 minutes
	Data logging value	maximum value	
Soil moisture sensor device	**Reporting period**	60 minutes	60 minutes
	Supported reporting mode transition mechanism	Local alarm activation/deactivation Optional: Downlink command message	
	Measurement period	15 minutes	15 minutes
	Multiple measurements – N	Default value: 1 (to be specified during the development and implementation phase)	
	Data logging period	60 minutes	60 minutes
	Data logging value	Maximum, minimum and average values	
Reporting mode supported		**Regular reporting**	**Emergency reporting**
Atmospheric temperature sensor device	**Reporting period**	60 minutes	60 minutes
	Supported reporting mode transition mechanism	Local alarm activation/deactivation Optional: Downlink command message	
	Measurement period	15 minutes	15 minutes
	Multiple measurements – N	Default value: 1 (to be specified during the development and implementation phase)	
	Data logging period	60 minutes	60 minutes
	Data logging value	Maximum, minimum and average values	
Notice: The measurement period for the rain gauge sensor device may be defined as 5 minutes if needed (in emergency mode or for both modes). The measurement period may be defined as 60 minutes for soil moisture and air temperature sensor devices if needed to achieve better energy efficiency.			

Table 4 - The general technical specifications for the default operation, measurement, data logging and reporting modes related to the set of sensor devices for the meteorological and climate data measuring station device

In case of local (i.e., automatic) reporting mode switch from regular to emergency and vice versa, sensor nodes are expected to do so after comparison of measured data against pre-defined threshold. These can be set manually and hardcoded for each of the sensor nodes installed in the field. However, an additional (and for that matter optional) mechanism for re-configuration of those threshold values may be introduces as the device remote control activity by using the specific downlink command messages. The eventual implementation of such mechanism should be done in accordance to the Methodological Guidelines for Establishment of Early Warning System. The only drawback related to the introduction of this mechanism is the higher complexity of the central application software (that must provide monitoring and control of all sensor node devices in the field), and the higher complexity and memory consumption of application software implemented on the measuring station devices.

4.3 Sensor node operation modes

Central software application must be aware of, and successfully handle, two possible sensor node operation modes as mentioned in the Technical Specification for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin:

First is the active operation mode triggered by the scheduled activation of all hardware resources and marks a transition from the second (i.e., power saving) mode to the active operation mode. The transition is to be triggered internally for the time being, but if decided, the corresponding downlink commands message can be implemented to trigger this transition for the central application software. In this mode all measurement processes are realized by using all connected sensor devices.

In active operation mode all sensor nodes can perform local processing, analysis and data logging of the acquired data as defined by data logging mode (local data logging may be an optional feature - the decision to support this feature or not will depend on its importance on the system level meaning the central application software). Local logging allows local sensor nodes to preserve data for a limited period of time. This data can then be sent at once to the central software application in case of re-connection event that follows a transitional loss of connection. All parameters defining the work of logging functionality can be potentially set from the central application software via downlink command messages as stated in the previous chapter of this document.

In this, active operation mode, all sensor nodes are expected to report the acquired measured data and status information (i.e., own battery capacity status) to the central application software (i.e., sending of generated uplink report messaged over embedded communication interface module).

In active operation mode sensor nodes await any potential upcoming downlink command message issued by the central application software via the network access gateway and the embedded communication interface module. According to the type and contents of a downlink command message, a sensor node is expected to perform update of the reporting, measurement and data logging modes.

It is mentioned before that a transition from active to the power saving (i.e., sleep) mode is handled by a sensor node itself. For this the sensor nodes set the real-time clock i.e., watchdog timer unit (WTU) for the next transition to the active operation mode followed by the scheduled transition to power saving (i.e., sleep) operation mode realized as the deactivation of all unnecessary hardware components. This is done without any sort of supervision from the central application software the is an option to provide an additional downlink which will perform a forced operation mode transition (i.e., active operation to power saving mode and vice versa) if needed (i.e., if there are such use cases where this feature might be of help and if it supported by the selected type of a sensor node). This will, of course, be completely dependent on the ability of the software system and the possibilities of the hardware components.

Power saving (sleep) operation mode marks a mode in which only the necessary hardware resources are powered while the other are in the power saving state. This is to achieve optimal operation and energy efficiency. During the power saving mode, the watchdog timer unit must remain active in order to generate trigger for the next transmission to the active operation mode. The central application software is not expected to receive any data when sensor nodes are in this operation mode. This information can be used to further optimize the execution of the central application software.

The additional requirements regarding measurement data transmission are:

1. The uplink report message transmission should be acknowledged by the network access gateway (in general case). In the case of the unsuccessful transmission of the uplink report message additional 2 transmission attempts are allowed (if needed)
2. The maximum duration of the active operation mode is 2 minutes (in case of the unsuccessful uplink transmission), and 1 minute for the regular successful uplink transmission when the initial attempts passed successfully
3. If the chosen wireless technology supports such operation, the reception of downlink command messages should be allowed only after a successful uplink report message transmission, with the specified maximum duration of the listening window (i.e., the period that starts after the transmission), e.g., around 2 seconds for LoRaWAN.

Central application software must, in general, handle two reporting modes (as mentioned previously in the document):

1. Regular reporting mode, in which device less frequently sends periodic uplink report messages (i.e., when a reporting period of longer duration is adopted);
2. Emergency reporting mode, in which device more frequently sends periodic uplink report messaged (i.e., when a reporting period of lower duration is adopted).

In case several measurement periods are elapsed between the two subsequent uplink report messaged being sent, the maximum value recorder between these two messages is sent.

4.4 Data transmission

All sensor nodes are capable of performing A/D conversion, so all data will be presented to the application server/central software application as digital data. The exact format, resolution, and scope of the values will depend on the sensor node of choice. It is possible that sensor do not send ready-to-use data and that minimal conversion will have to be done on the central application software side. This is expected to be detailed in the sensor node datasheet for chosen sensor nodes.

All sensor nodes have a communication subsystem facilitating connectivity in case of long-range wireless communication. Technical Specifications for Data Acquisition and Measuring Devices for Early Warning System in Drin River Basin offers a comprehensive comparison of all practically available sensor nodes supporting such wireless communication technologies. It is, within the mentioned document, stated that the wireless communication technology of choice should be LoRaWAN. More elaboration on why it is the optimal solution is available in the Technical Specification for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin. There is, even, an option of sending data over Ethernet in case the location of interest provides such an option.

There are several possible configurations when it comes to data transmission between the sensor node in the field and the application server (the one hosting the central application software):

1. Application software communicates directly with the gateways over the Internet. This option includes an application server with internet access. The application server in this sense can either be a machine operated and maintained directly or it can be a cloud-based solution that hosts the central application software;
2. Data is stored in one of the Internet Service Provider's central server(s) and passed over to the Application Server via standard IP connections. This means that the application server does not have a direct communication link with Wireless access gateways but in turn utilizes an

already existing Internet Service Provider's central server(s) as a proxy. The application server in this sense can either be a machine operated and maintained directly or it can be a cloud-based solution that hosts the central application software

3. Data is stored in one of the Internet Service Provider's central server(s) but with the central software application provided by the Internet Service Provider. This is a viable option and it is thoroughly described in Technical Specifications for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin. It is important to note that this is the least likely option as it, to a great extent, limits the kind of information offered to the end user and additionally fully prevents the development of the central software application. It might, though, be used in the early stages of implementation as a substitute for the actual central software application to serve as a proof that the measuring equipment and communication links are in place before all hardware resources are integrated with the custom central application software.

Two possible backend architectures that can support the proposed configuration are presented in the following section.

4.5 Backend architecture

Backend application and data can be managed on-premise, cloud or hybrid.

In order to provide the high availability (98% and more), scalability, flexibility, reliability, and security of the system it will be much safer to host application using cloud provider. Cloud infrastructure has global reach so it can be significant when it comes to approaching to other countries and regions.

When we come to cloud services for handling infrastructure and data, two main cloud options can be considered:

1. Non-serverless architecture (monolith or microservices);
2. Serverless architecture.

Comparison of both approaches is given in the following table:

Category	**Serverless**	**Non-serverless**
Infrastructure	The infrastructure is managed by the cloud provider.	The development team has to manage the infrastructure, including servers, load balancers, and scaling.
Scaling	Automatic scaling is handled by the cloud provider, so we don’t need to worry about scaling up or down.	The development team has to configure and manage scaling based on demand.
Cost	Paying for the actual usage of resources, which can be more cost-effective than non-serverless.	The cost of maintaining servers and infrastructure can be high, especially if resources are underutilized.
Development	Serverless architectures can be quicker and easier to develop since the infrastructure is abstracted away, and developers can focus on writing code.	Non-serverless architectures require more planning and configuration which can be time-consuming.

Measurement data can be, in general, passed to the central application software by the two following means:

1. Wireless access network - (i.e., GSM/GPRS, UTMS/3S, LTE/4G, NB-IoT/4G, 5G, LoRaWAN, WLAN, etc.);
2. Wired access interface - this mean of data transportation is used exceptionally i.e., if wired connection is available.

General concept of the Early Warning System in Drina River Basin (from the communication point of view) as presented in the Technical Specification for Data Acquisition and Measuring for Early Warning System in Drina River Basin is shown on the following diagram:

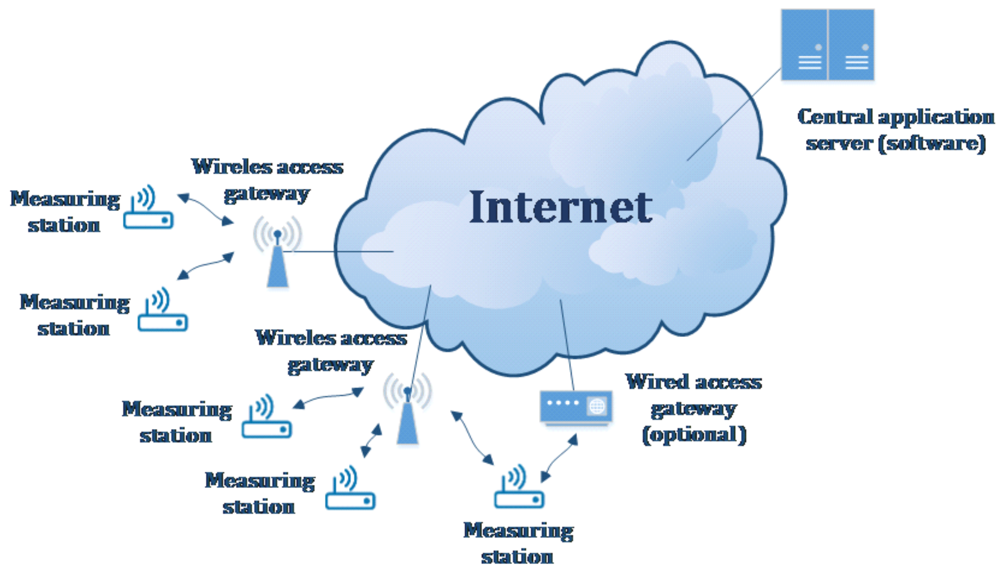


Figure 1 - The general concept of the Early Warning System in Drina River Basin from the communication point of view

Based on the proposed communication architecture the central application software must be able to provide:

1. The reliable and timely reception of all measured data and sensor device status information (e.g., remaining battery supply capacity) with a specified reporting period, reporting modes, latency, reliability, the adequate support for the remote control, configuration (re-configuration) and management of all the measuring station devices in the system;
2. The support for remote control of one or more sensor devices connected to a measuring station, support for received data storage, processing and analysis (i.e. measurement data averaging, alarm detection, emergency state detection base on the predefined threshold values) for the specified reporting periods as required by the specific measurement procedures (depending on the type of the particular sensor device) and/or the reporting modes (i.e. the regular periodic reporting mode and the emergency reporting modes triggered by the locally generated alarm or the remote downlink commands sent to the measuring station by the central application software).

Further, the general technical solution for the development of the required measuring stations defines the adequate technical specifications for the central software application and which must enable:

1. The seamless local connection (interfacing) with all of the sensor device units within the measurement station (by the supported wired or wireless communication interface module);
2. If decided, the remote configuration of operational parameters (i.e., reporting parameters, local processing, storage and/or alarm detection parameters) and the communication settings for the

development of measuring station devices - aside from the default pre-deployment and onsite configuration of sensor devices.

Additional requirements that should be supported from the point of view of the central application software related to the operational, functional and economical aspects of the observed Early Warning System in Drina River Basin are:

1. Developed and implemented central software application must be a solution that is as low-cost as possible;
2. The developed and implemented central application software should be available for as much time as possible;
3. The developed and implemented central software application should be available to handle the possible changes made to equipment physically installed in the field (different sensor manufacturers but the same type of sensors) - as long as this equipment use the same underlying communication protocol. This is not a likely scenario. Possibility of seamless integration of different kinds of possible sensors with the central application software will add up to its robustness and its commercial value altogether.
4. The developed and implemented central software application must be extendible in the sense of providing new output, based on the same input. New output might be requested by consultants or by the customer. In this case the Consultants in charge of Methodological Guidelines for Establishment of Early Warning System define the algorithms for data processing. Requested output is likely to change by the time the software is developed, but is important as it will be basis for the development of a central application software that will be easily modifiable in the future which will add up to its robustness and its commercial value altogether.

It was mentioned earlier that according to the Technical Specification for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin the LoRaWAN was marked as the communication protocol of choice for this project for the reasons listed in the mentioned section. This might, differ until development stage is reached, but it seems unlikely.

On the provided diagram it stated that all (in this case LoRaWAN) gateway data is being IP Tunneled. It is expected that physical gateways are provided by the Internet Service Providers of choice through SLA (Service Level Agreement). The physical gateway is provided with software that facilitates communication and performs IP tunneling.

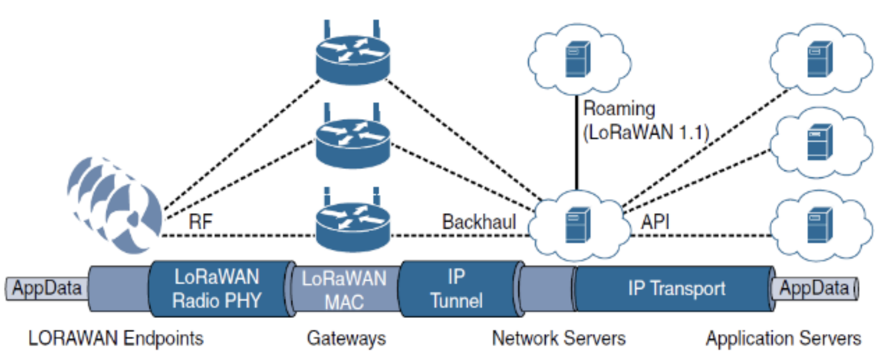


Figure 2 - The general concept of LoRaWAN communication in case of Early Warning System in Drina River Basin project

In the Technical Specification for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin, there are a few devices listed that may be used for the development of the observed measuring stations. All of those are typically available with integrated wireless sensor node and gateway devices based on LoRaWAN wireless technology, capable of porting corresponding sensor devices to be used for development and implementation of the observed measuring stations.

These devices are, which is important to notice, capable of collecting data detected by the sending devices (i.e., sensor nodes) and performing transmissions to the application server for the further analysis and monitoring.

In case of Service Level Agreement and storing data on one of the Internet Service Provider's central server(s) - we must define the interface needed to support the communication between the central application software and the mentioned central server, but this is to be done in coordination with the Internet Service Provider. It is expected that data will be passed to the central application software via either HTTPS or MQTT packets and provided to the Application Server in a form of either JSON or XML file. Received data is expected to be precisely defined in the future during the development planning stages. If possible, the central application software should provide a mechanism of dealing with unstructured or semi-structured data.

In case of gateways providing information directly to the Application Server (i.e., decision is not to use the Internet Service Provider's central server(s)) - it is necessary to decide on the format of such data provided.

Cloud solutions such as AWS or Azure are available - each with their own advantages and drawbacks. When making a decision cost must be taken into consideration. Service cost tend to change and such decision should be made at a later stage as prices might differ at a later point. In general AWS is considered to be a leader in the field and it is easier to find developers acquainted with the services AWS provides. On the other hand, if there is a need for integration with some Microsoft systems then Azure might be a preferable choice. Exceptionally, if there is a possibility of striking a deal for free use of Azure it might also be more lucrative to choose Azure.

Here we must point out potential use of AWS and their serverless service where the entire infrastructure can be scaled and is paid by principle pay-as-you-go (depends on the traffic bandwidth). Benefit is the build-in LoRaWAN support and in general IoT support. In general AWS IoT Core for LoRaWAN offers the benefits such as: elimination of need to develop or operate an LNS, reduction of gateway and device onboarding friction, acceleration of IoT application development, reduction of the cost of connection and managing LoRaWAN device fleets at scale. AWS IoT Core for LoRaWAN supports all devices that comply to the 1.0.x or 1.1 LoRaWAN specifications standardized by LoRa Alliance. IoT Core for LoRaWAN supports both of the approved ways of device activation as specified by LoRa Alliance: OTAA (Over the air activation) and ABP (Activation by personalization). LoRaWAN devices can send uplink (device-to-cloud) messages at any time. However, listening for downlinks (cloud-to-device) messages can consume battery capacity and reduce a battery’s lifetime. To support a variety of application requirements with different trade-offs between listening behavior and battery consumption, the LoRaWAN protocol supports three classes of devices (A, B, C). IoT Core for LoRaWAN supports all the three classes. Lastly, IoT Core for LoRaWAN also supports device profiles so that you can define device data rates, channels, and other settings which will be used when the IoT Core for LoRaWAN network server communicates with the device. AWS IoT Core for LoRaWAN customers can use US902-928, EU863-870, AS923-1 or AU915 frequency bands to connect LoRaWAN gateways and devices that are physically present in countries that support the frequency ranges and characteristics of these respective bands. US902-928 and EU863-870 bands are commonly used in the North America and European regions respectively, with EU863-870 being the one we primarily discussed so far. More details can be found at https://aws.amazon.com/iot-core/lorawan/.

4.6 Message format

Due to reasons stated in the Technical Specification for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin LoRaWan is selected as the primary solution for the wireless connectivity realization in the scope of development of measuring station devices (both for water level and meteorological and climate data sensor nodes). The central application software should consider GSM/GPRS in case LoRaWAN is not available. However, GSM/GPRS based solutions have higher energy consumption and demand implementation of the IP based traffic for data access, which requires more complex end device implementation. Therefore, in the case of GSM/GPRS technology the use of SMS (Small Message Service) for the uplink and downlink transmission may also be considered from the point of view of the central application software. Solutions such as AWS can provide support in case of working with GSM/GPRS systems.

The LoRaWAN network in Serbia (and Europe) is supported for Radio-Frequency (i.e., RF) channels in 863 - 870 MHz band. LoRaWAN messages in the uplink and downlink direction have PHY (i.e., Physical layer) payload comprised of MAC (i.e., Medium Access Control) frames with MAC Header (1 byte), variable MAC payload (59 to 230 bytes for RF channels in 863 - 870 Radio-frequency range) and 4-byte MIC (i.e., Message Integrity Code), as shown in the Figure 3 below. This payload completely supports short over-the-air transmission of the previously defined short uplink report messages and downlink command messaged. The common operation allows 1 message exchange in 5 minutes, which is in accordance with the demanded maximum 1% duty cycle and required mode (both regular and emergency report modes).

Notice: Maximum application-level payload (user payload) for the water level measuring station device is 9 bytes, while for the meteorological and climate data measuring station device this value is 13 bytes. This enables transmission of just one PHY (i.e., Physical layer) message in the uplink for the one reporting period for the all or the most of SF (i.e., Spreading Factor) values depending on measuring station device type.

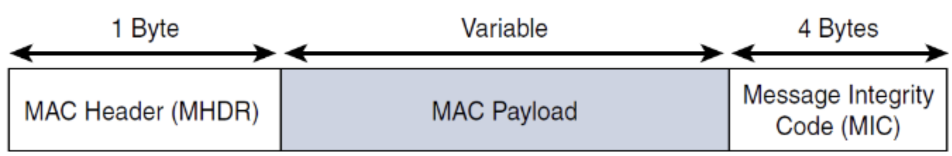


Figure 3 - LoRaWAN message format on MAC level

LoRaWAN specification defines three classes of end devices:

Class A, which presents default end device implementation, and is optimized for battery supply operated devices, with the downlink communication enabled only in the short period defined by two reception windows after the uplink transmission. This is the most energy efficient device class and is therefore selected here as the required option;

Class B, which presents experimental solution with the additional windows for the downlink reception, but demands LoRaWAN gateway synchronization;

Class C, which is adopted for the end devices with the continuous unlimited power supply, and is not suitable for the here observed application scenario.

The LoRaWAN specification defines six types of MAC messages, which completely cover all previously defined requirements, and these include:

- *Join-request* and *Join-accept* messages for Over-The-Air end-device activation and network access, which enable simple deployment strategy
- Unconfirmed (without acknowledgment) and confirmed (with acknowledgment) messages for data transmission in uplink and downlink direction

A full list of messages standardized messaged to be used with LoRaWAN 1.0.x and LoRaWAN 1.1. is given in the following Figure:

LoRaWAN 1.0.x	LoRaWAN 1.1	Description
Join-request	Join-request	An uplink message, used by the over-the-air activation (OTAA) procedure
Join-accept	Join-accept	A downlink message, used by the over-the-air activation (OTAA) procedure
Unconfirmed Data Up	Unconfirmed Data Up	An uplink data frame, confirmation is not required
Unconfirmed Data Down	Unconfirmed Data Down	A downlink data frame, confirmation is not required
Confirmed Data Up	Confirmed Data Up	An uplink data frame, confirmation is requested
Confirmed Data Down	Confirmed Data Down	A downlink data frame, confirmation is requested
RFU	Rejoin-request	1.0.x - Reserved for Future Usage 1.1 - Uplink over-the-air activation (OTAA) Rejoin-request
Proprietary	Proprietary	Used to implement non-standard message formats

Figure 4 - LoRaWAN message list as defined for LoRaWAN 1.0x. and LoRaWAN 1.1

The LoRaWAN network topology consists of end points that exchange uplink/downlink messages with the central network server over the LoRaWAN access gateway devices (as a bridge), with the backhaul links between the gateways and network server and the link between network server and central application server are realized as IP/TCP SSL (Secure Sockets Layer) connections. The LoRaWAN transmission support end-to-end security based on AES-128 application security key, as well as the separate end device to network server AES (Advanced Encryption Standard) based MAC transmission security.

As suggested in the Technical Specifications for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin, the basic organization of envisioned communication model realized as LoRaWAN based network connectivity of end devices (measuring station devices) with the central application server is shown in the Figure 5 below. In this model, taking into the account specific realization of Telekom Serbia LoRaWAN network, the uplink report messages can be forwarded to central application server using the HTTPS (i.e., Hypertext Transfer Protocol Secure) protocol (as default) or optionally using the MQTT (i.e., Message Queuing Telemetry Transport) protocol. In this realization, network server must be provided with the specific application server IP (i.e., Internet Protocol) address and port for data delivery. The uplink reporting data are appended with the time tag (in network server), and delivered to application server in JSON (i.e., JavaScript Object Notation) or XML (i.e., Extensible Markup Language) file format.

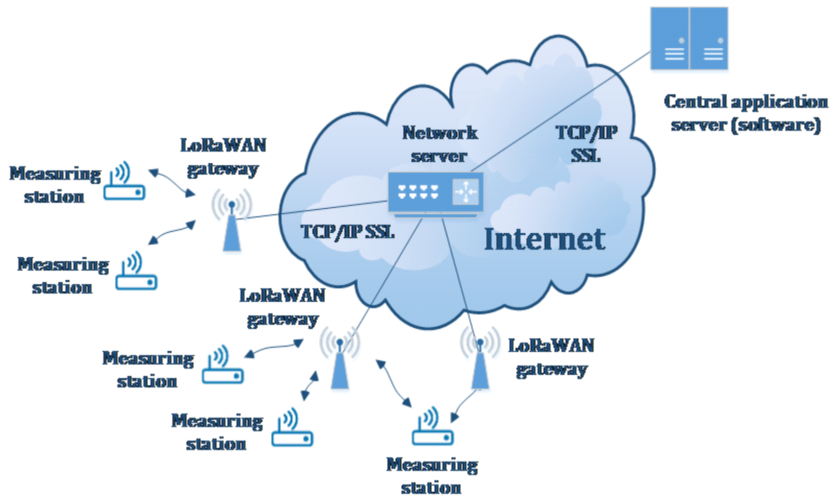


Figure 5 - The communication model for the LoRaWAN based communication between measuring station devices and central application server

In order to support energy efficient operation with the low duty cycle (1% maximum) of the wireless communication interface, the so-called push-up communication model is adopted. In push-up communication model, the end devices (i.e., IoT sensor nodes, e.g., measuring station devices in the observed application scenario) automatically sends the uplink report messages, containing the required measured data and the device status information, towards the central application server. In this specification, the automatic transmission of these uplink report messages is triggered (initiated) periodically with defined reporting period, which is determined by the current reporting mode for the given measuring station device (i.e. actually 5 minute or 15 minute reporting period is deployed for the emergency and regular reporting mode of water level measuring device, and 15 minute or 60 minute reporting period is deployed for the emergency and regular reporting mode for meteorological and climate data measuring devices).

Specified push-up communication model allows very simplified definition of the types and formats for the uplink and downlink messages that are being transmitted between the measuring station devices, as the systems end points, and the application server (hosting the central application software), as the systems central point.

According to previous discussion and the previously defined requirements, the following uplink and downlink messages are required to be supported by the central application software:

Uplink report messages that contain all required measured data and the predefined device status information. These messages do not contain the timing information, which should be appended during transmission over the access network (i.e., by the wireless/wired access gateway or the other network device responsible for the forwarding of these messages to the central application software), or optionally by the application server (based on the timing of the messages reception);

Downlink command messages, which contain specific command identifier (i.e., e ID) and the optional command parameters predefined for the specific command messages. This command messages are used to remotely control measuring station devices, i.e., to power on/off device or to change reporting period (i.e., the reporting mode as previously specified). The additional command messages may be specified as needed for the proper system operation;

The other access network supported messages maybe exchanged in order to allow measuring station device activation (i.e., join and re-join messages) in the observed wireless access network. These are defined differently depending on the selected communication technology and are not part of this document;

Optionally activated, uplink and downlink acknowledgment (ACK) messages for the purpose of acknowledgement of downlink and uplink messages reception.

The format of the uplink report messages for both measuring station device types can be commonly defined. These messages are relatively short with the application payload of 9 to 13 bytes.

The general format of these uplink report messages is specified as shown in Figure 6, with the following fields:

- Header, with the length of 5 bytes, consisting of:
    - The field Version (1 byte) reserved to specify the application protocol version;
    - The field Device ID (2 bytes) reserved to specify measuring station device ID (the given filed length enable addressing a maximum number of 65535 end point devices that can be considered as more than enough);
    - The field Flag (2 bytes) reserved to indicate optional status information and if the respective sensor data are included (as being optional). The first byte containing 8 bits that can be used to indicate if the message contains status info, i.e., flag 15 the MSB (i.e., most significant bit), and up to 7 measurement data (if the flag is set to 1 the data is sent), i.e., flag 14 to flag 8, while the lower byte, i.e., flag 7 to flag 0 – LSB (i.e., least significant bit), can be used to indicate additional status info (such as regular/emergency reporting mode, certain operating issues, etc.);
- Status info data (2 byte) is always sent (flag 15 = 1), and it is used to report on remaining battery capacity (in % or the battery voltage);
- Sensor data 1 to 7 (2 bytes each) reserved for the reporting of up to 7 sensor devices (the reserve is included), of which only one (Sensor 1 data) is used for water level measuring devices and three (Sensor 1 data to Sensor 3 data) are used for meteorological and climate data measuring devices.

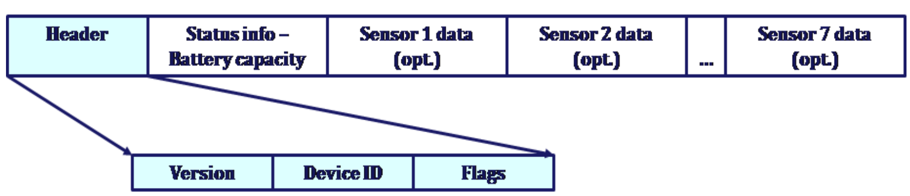


Figure 6 - The general format of the uplink reporting message

Based on the above description the minimum uplink report message length is 7 bytes (Header and Status info), while the maximum length is 21 bytes. However, for the so far specified measuring station devices, maximum length for water level measuring devices is just 9 bytes (only Sensor 1 data is used), while the maximum length for meteorological and climate data measuring devices is 13 bytes (Sensor 1 data to Sensor 3 data are used). The example of uplink report message for the water level and meteorological and climate data measuring devices are given in the Table 5 and Table 6, respectfully (according to the Technical Specifications for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin).

Field	Parameter name	Type	Conversion	Unit
Header	Version	uint8		
	Device ID	uint16		
	Flags (15-0)	uint16		
Status info	Battery voltage	uint16	x/1000	V
Sensor 1 data	Measured distance/level	uint16	x	mm

Table 5 - The general specification of the uplink message format for the water level measuring station device

Field	Parameter name	Type	Conversion	Unit
Header	Version	uint8		
	Device ID	uint16		
	Flags (15-0)	uint16		
Status info	Battery voltage	uint16	x/1000	V
Sensor 1 data	Measured precipitation data	uint16	x	mm
Sensor 2 data	Measured soil moisture data	uint16	x	%
Sensor 3 data	Measured air temperature data	uint16	(10x-400)/10	℃

Table 6 - The general specification of the uplink message format for the meteorological and climate data measuring station device

The periodic reporting requires very short messages, and thus requires relatively low energy consumption for the purpose of wireless transmission. Also, based on the above definition, and the previously defined reporting periodic, it is possible to calculate the storage capacity required to store acquired measurement data at the application server on daily and monthly basis, as given in the Table 7, as well for the local data logging purposes (defined by the data logging period and required storage period) on the daily and weekly basis, as given in the Table 8.

MS type	**Water level data**		**Meteorological and climate data**	
Per report	4 bytes (without time tag)		8 bytes (without time tag)	
Reporting mode	Regular reporting (min)	Emergency reporting (max)	Regular reporting (min)	Emergency reporting (max)
Daily	4×24×4B = 384 bytes	12×24×4B = 1152 bytes	4×24×4B+1×24×4B= 480 bytes	12×24×4B+1×24×4B= 1248 bytes
Monthly	30×384B = 11520 bytes	30×1152B = 34560 bytes	30×960B = 14400 bytes	30×1728B = 37440 bytes

Table 7 - The required storage capacity for the acquired measurement data at the central application server on the daily and on the monthly basis per one water level MS (i.e., measurement station) device and per one meteorological and climate data MS (i.e., measurement station) device

MS type	**Water level data**		**Meteorological and climate data**	
Per logging	2 bytes		2 bytes + 3×2×2 bytes = 14 bytes	
Reporting mode	Regular reporting (min)	Emergency reporting (max)	Regular reporting (min)	Emergency reporting (max)
Daily	4×24×2B = 192 bytes	12×24×2B = 576 bytes	4×24×2B+1×24×12B= 480 bytes	4×24×2B+1×24×12B= 480 bytes

Weekly	7×192B = 1344 bytes	7×576B = 4032 bytes	7×480B = 3360 bytes	7×480B = 3360 bytes

Table 8 - The required storage capacity for data logging of the acquired measurement data at water level MS (i.e., measurement station) or meteorological and climate data MS (i.e., measurement station) device on the daily and weekly basis

4.7 Data storage

In the following section presented are the advantages and drawbacks of possible data storage solutions. Here we have two main options: serverless and non-serverless databases. Each of the approaches is described more in detail in the table below.

Category	**Serverless Database**	**Non-Serverless Database**
Scaling	Automatically scales up and down based on demand	Must be manually provisioned and scaled
Cost	Pay-as-you-go pricing model, only pay for what is used	Fixed pricing model based on provisioned capacity
Management	Managed by the cloud provider, requires minimal management effort	Requires significant management effort, including maintenance, backups, and updates
Performance	May experience cold start delays for infrequently accessed data	Always-on and immediately available, consistent performance
Flexibility	Provides flexibility to quickly scale resources up or down	Limited flexibility due to provisioned capacity
Security	Offers robust security features and compliance certifications	Security features depend on the specific database solution selected
Use Cases	Best for applications with unpredictable or infrequent demand	Best for applications with predictable and consistent demand

It's important to note that both serverless and non-serverless databases have their own set of advantages and disadvantages, and the best choice for your application depends on your specific needs and requirements. Serverless databases can provide cost savings, scalability, and ease of management, while non-serverless databases offer consistent performance and greater control over infrastructure.

In general, when dealing with serverless technologies, databases have to be serverless as well. In this case solutions such as AWS offer two types of serverless databases:

1. Amazon DynamoDB - used for non-structured data (NoSQL);
2. Auror - used for structured data (SQL).

In case of non-serverless technologies, non-serverless databases are recommended such as Amazon RDS (for example PostgreSQL) in case of structured data or some of NoSQL services (for example MongoDB) in case of non-structured data.

In this case it is necessary to take into account the number of connections as well as the storage size.

In addition to all, cloud solutions offer automatic data back-up services.

As a general remark here is mentioned AWS S3 offering a possibility of storing received data in files that can later be backup-ed to private servers.

4.8 Specific parameters defined in the Methodological - sensor node location deduction

The Methodological guidelines specifies formulas to calculate certain indexes of interest. These are of interest to the software developers as are likely to be supported by the central application software. However, it must be noted that all of these calculations were done in order to decide on the possible installation locations for the sensor nodes. This opens an entire new aspect of the central application software. So far, we described the central application as a mean of storing the sensor node and measurement data and a tool that helps notify the end users and raise alarms in case of an upcoming emergency. The central application software can, however, in the future be used to help deduce the location on which sensors should be installed by applying the defined geographical methodology. In general, this process is manual, takes a lot of effort and time. All of these can be automated with software tools such as the central application software. The entire process of deducing the sensor node location is also costly and the central application software can cut such costs which further increases its importance and value.

In the Methodological guidelines a set of indexes listed used to determine the future locations of sensor nodes as well as to justify the currently chosen location as the viable one. Following is a quick representation of some of these calculations that helped develop the Methodological guidelines.

It is important to point out that to make all of these calculations we need the data used in the Methodological guidelines. This has to be either added manually to the software, or to be imported from the external 3rd party system in accordance to the Methodological guidelines.

First of them is the FFPI (Flash flood potential index) which help determine the susceptibility of the basin to the occurrence of torrential floods. More details on the premises taken into account for this particular index can be found in Methodological guidelines. Calculation of FFPI is performed according to the formula:

$$FFPI = \frac{a_1 \cdot M + a_2 \cdot S + a_3 \cdot L + a_4 \cdot V}{\sum_{n=1}^{4} a_n}$$

where: M – slope index; S – soil type index; L – land use index; V – vegetation density index; an – sum of weightings. Index values are within the range 1 to 10 (from least to most susceptible). In this case all weightings had value of 1, which means that the next formula is used:

$$FFPI = \frac{M + S + L + V}{4}$$

The slope index is calculated according to the following formula:

$$M = 10^{n/30}$$

where: n – slope in %. If n is greater or equal to 30%, then M value is 10.

Soil erosion intensity is important as torrential floods are closely related to the intensity and spatial distribution of erosion processes in the research area. The analytical equation of the annual volume of detached soil (gross erosion) due to water erosion is:

$$W_{year} = T \cdot H_{year} \cdot \pi \cdot \sqrt{Z^3} \cdot F$$

where Wyear is average annual gross erosion (m3/year), T is temperature coefficient, Hyear is the average yearly precipitation (mm), F is the river basin area (km2), and Z is the erosion coefficient.

The soil erosion coefficient (Z) can be estimated using corresponding tables or can be calculated from the following equation:

$$Z = Y \cdot X \cdot (\phi + \sqrt{I})$$

in which, Y is the soil erodibility coefficient, X is soil protection coefficient, phi is erosion and stream network developed coefficient and I is average slope steepness of the basins in degree.

According to the Methodology guidelines a suitability assessment of meteorological station installment location was done. Factors that were taken into account for suitability assessment of meteorological station installment location are altitude of the terrain, the terrain slope, the land cover and the distance to roads. Calculation of suitability is then performed according to the formula:

$$Suitability = \frac{a_1 \cdot A + a_2 \cdot S + a_3 \cdot L + a_4 \cdot Dr}{\sum_{n=1}^{4} a_n}$$

where: A – altitude index; S – slope index; L – land cover index; Dr – distance from roads; an – weight coefficients.

A number of other hydrological characteristics are listed in the Methodological guidelines document and the reader is advised to take a closer look at the mentioned document for further details.

In order for the central application software to become a tool for sensor node installment prediction/deduction we need to solve the issue of lack of data. Are locations going to be deducted based on the provided map that might contain metadata of interest. In this case the central application software might have to do image processing of the provided maps which would in fact mean potential use of machine learning. This opens an entire class of problems starting from the choice of technology to machine learning algorithm training etc. This is expected to be covered in the future stages of the project development. Of course, using available maps, weather those are open-source maps, or maps provided by the Republic Geodetic Authority of Republic of Serbia, using their developed web services with available metadata software can easily cross-reference necessary data with the data defined by the methodology guidelines and provide an approximate location for the sensor note. It should be noted that anthropological factors should be taken into account and their impact on the overall accuracy of the both methodology and software system precision. This is the data which should be analyzed more closely in the future, with the emphasis on the maps by the Republic Geodetic Authority of Republic of Serbia, showing buildings, urbanized areas, infrastructure, etc.

4.9 Possible sensor development

The Technical Specifications for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin dedicated an entire chapter to the idea of potential hardware/sensor node development.

A future measuring station should, minimally, comprise of: a sensor subsystem, a control subsystem, a watchdog timer unit, a communication subsystem and an electric power supply subsystem. In some special cases, when the electric power distribution grid is available on the installation site location, a direct electric power supply from the grid network can be supported as an optional feature.

It is very important to state that such software development presumes that the specific software application that resided on MCU (i.e., Micro-controller unit, the before-mentioned control subsystem is based on such embedded MCU) board is developed for the given measuring station, by using specific producer firmware for MCU boards, WDT, communication module and sensor devices, which enables proper operation of the measuring station as a whole. Details of software development in that case are tightly coupled with the very choice of hardware and hardware components and can be fully described only after such a decision has been made.

Development of such system gives a customization freedom and could, potentially, lead to cost reduction. However, chances for significant cost reductions are low as the market is already saturated with such systems. The development itself, on the other hand, could take a significant amount of time and can be costly.

Software development for sensors from scratch can stretch from providing an MCU application that integrates the available hardware components to providing full-fledged firmware support for the brand-new hardware components and should be a subject of further assessments in the future.

For detailed presentation of all possible direction of development and issued the reader should refer to the section "The general guidelines on the possible approaches to the design, development and implementation of the observed measuring stations" of the Technical Specifications for Data Acquisition and Measuring Devices for Early Warning System in Drina River Basin.

4.10 Output - Frontend software system

The purpose of processing all the necessary data within the Central software system is with a single aim, which is to provide tangible human readable (user friendly), precise and timely information. To achieve desired outcome, detailed user interface should be created with purposely created design for all the functionalities, allowing easy information management.

4.10.1 Design

When talking about design, there are two key aspects which should be distinguished:

1. User experience design;
2. User interface design.

Although both of these designs will be defined in detail at a later, pre-development stage, their purpose is to provide enough elements for the end user to be able to use the software with ease.

User experience design covers the experience the user has with the software, meaning the flow it goes through while using certain functionalities. This is something we should, in particular, have in mind when providing the design, as receiving information in a timely manner, with the ability to read that information precisely and unambiguously, will be of the most paramount importance. Of course, to make the software complete, other than the main functionalities, all the other functionalities need to be covered in a way that they do not clutter the space and impact the usability, but also to be in the vicinity of the related functionalities, offering more detailed and defined aspect on the requested information and/or action. Danger would be to clutter the space with large number of on-screen information, overwhelming the user with data, ultimately causing him to stop using the application altogether.

User design covers the aspect of providing the interface of the software with shapes, tones and purposely selected color palette, in order to further simplify the usability of the software system form an end user viewpoint. User design is something which should be done once the details of the software are fully defined, and the development of the system enters final stages of production.

4.10.2 Adding devices (sensor nodes)

To be able to add devices (sensor nodes), with the ability to communicate with the central software system, and ultimately be able to show them to the end user, it should go through the wizard in the application.

Wizard is a series of sequential actions, allowing user to fill the necessary data in several steps. The exact data which should be added through the wizard should be determined during the development, however, right now we know that it would have to be the type of device, location with all the metadata, intervals of reporting and expected measurement values. If it would be pre-determined hardware (known type for each sensor node), than the software can automatically set hardware parameters, upon adding the type of device, creating an open gateway channel between the device and the central software system, through the series of protocols (explained in the backend section), allowing the end user to only adjust and select location, intervals of reporting and expected measurement values.

Location of the device (sensor nodes) will be added and selected manually, based on the Methodology guidelines, however as mentioned in the backend section, there is an option to further digitalize this process, with the right data set (i.e., proper maps with all the necessary digital information in accordance with the Methodology guidelines, like elevation, terrain, soil structure, anthropomorphically features, etc.). This would require a number of information gathered from different sources, as well as entering the field of machine learning (explained in the backend section), however for the end user, it will only simplify things, allowing him to only choose what early warning information is needed, with all the necessary values, location and the exact position determined by the central software system.

4.10.3 Notifications (warning system)

All values gathered by the devices (sensor nodes) in the field, should be displayed to the end user, respectfully shown in correlation with the pre-determined measurement values, whether it is soil humidity, temperature, amount of rainfall, etc. All gathered information will be stored in an archive for further analysis, which will ultimately, once enough data is gathered, allow the central software system to be able to, with the assistance of machine learning software, create predictive analytical functionality. This functionality would be able to determine whether it needs to sound of a warning or not, even before the measured values exceed pre-determined measurement limit. This shows that the system will have, practically, two methods of displaying warning notifications, simply by showing exceeded values based on the measurement limits of pre-determined levels, or by predicting the possibility of exceeding those limits even before it happens.

In both cases, once the system, based on the Methodological Guidelines, determines that values exceeded the measurement limits, or that they are on the trajectory to do so, it will send of the notification to the end user. Notification will be shown in-app, through push notification, and if necessary, via alternative methods by sending SMS, e-mail or in a direct connection with the Public warning system. The later, however, should be determined in accordance with the possibilities of such systems, adjust the methodology to avoid alarming the public unnecessarily (at least until the machine learning functionality is fully integrated within the central software system).

In accordance with the Methodological Guidelines, warning notifications should be shown for each sensor node, and cumulatively for all measurement devices, designed to be quickly readable (i.e., no color meaning no warning, yellow color low warning, orange color medium warning, red meaning high warning). This level of differentiation of the warning notification, should be only determined by Methodological Guidelines, and presented in a user-friendly way for easy understanding.

Archived values, gathered over time should have an option to be exported in a document, weather it would be .pdf, .xls, .txt, etc. This will allow the information sharing with the relevant institutions not having access to the software, however suggestion would be to predict such users, once development starts, to allow access to the 3rd party users (3rd party users, are users which are neither the end user of the software nor the persons responsible for software maintenance).

4.10.4 Software users

Primary users of the system are representatives of the Local Self-government, through their assigned and dedicated data administrator. Administrator should have full access to the system, with the ability to manage all information available to him. Administrator account should be created with the Local Self-government addition to the system; however, this should be determined once development stage starts. If needed other representatives of the Local Self-government could be added to the system with the same level of access as local administrator, or with a less level of access, up until the view only mode. The level of different users access to the system should be determined in the early stages of development.

To be able to differentiate users, system will recognize each user by their individual account. Each account will consist out of certain details specific to that particular user. User will be able to access the system using standard log in functionalities, and for security reasons, using two-step verification method. Detailed aspects of such methods are to be determined during the early stages of development. Forgotten system credentials will be automatically reset and sent to the user via forgot password functionality.

Other than the Local Self-government, we anticipate that other subjects should have access to the system, subjects like Srbijavode, Republic Hydrometeorological Service of Serbia, scientific communities and others if necessary. The level of data access should be determined in the early stages of development, however, technical possibilities here are very wide. We anticipate that they will request the access to the system either to provide more tangible information, make it far more accurate, or to improve on the methodology based on the real-world data gathered over time.

4.10.5 Interconnection of multiple measured locations

Once devices are set on a single location, system will start to generate data for that location, and area of impact (i.e., surrounding area). Having multiple locations fully covered, system should cross-reference the data, process all the received data for far more accurate measurements, improving the predictive behavior of the system, creating an advanced level of precision based on the Methodological Guidelines with analytical analysis. This will not only be done by analyzing historic values, but by also inducing the reduction of measurement intervals in case other locations are faced with an increased measurement level, and vice versa, reduction of measurement, even though locally data shows differently, in order to save battery.

System should also be structured in a way to provide support for the 3rd party data, e.g., Srbijavode measurement stations placed on the first-order watercourses, as well as Republic Hydrometeorological Service of Serbia weather stations. Gathering data from such systems will provide necessary information which will in communication with the devices via downlink, provide and ability to increase intervals on time increase precision with more accurate information, and vice versa, reduction of measurement, even though locally data shows differently, in order to save battery.

Interconnecting all the devices will create a powerful network of measuring stations, each with their own settings and values, populating database with information and values, necessary for the deep machine learning capabilities of the central software system.

All locations should be grouped within each river basin, being natural areas sharing similar risks, basins are also a solid ground for joining of several Local Self-government units in a single disaster risk reduction entity for faster response time in the case of a warning or reaction.

Covering all basins, will serve as a foundation for implementation of the system on a Republic level together with 3rd party systems.

4.10.6 Devices (sensor nodes) locations, area and the cost of potential impact

Having enough metadata for any single device allows us to not only know where that device is located, but to accurately pinpoint that device on the map. Technically, it is possible to use any open-source map, Google maps, or to use specific and the most accurate maps from the Republic of Serbia Republic Geodetic Authority using their sophisticated web services.

Location can be applied to any type of digital map, whether it is topographic, hypsometric or hydrographic map, as long as it comes with enough metadata. Each location will consist of multiple devices (sensor nodes), where each sensor node can be pinpointed individually. All locations will be shown on a single map view, with the ability to present details of selected location showing type of the device, with latest measured levels.

Knowing all locations, and comparing this with various maps, especially anthropological maps, economic or resource maps, etc., from the Republic of Serbia Republic Geodetic Authority, central software system can predict, using data from those maps, based on the Methodological Guidelines, the area of potential flood impact, calculating extent and the cost of such impact. Of course, the technical details will further be defined in the early stages of development, however, what we can safely say even now is that technically this is possible, and the only limit is whether this will be shown numerically, graphically in 2D or graphically in 3D. The advantage of this functionality is that it will offer user visual representation of potential impact, reducing reaction time, or even providing mandatory information crucial when triaging the highest priority location for reaction.

It will also allow simulations and exercises as a method of prevention, before such event occurs.

Financial cost of impact is important, as this can not only calculate potential damage, but also calculate the reaction cost vs material cost, justifying such reaction.

4.10.7 Remote control of the device

Although this has been described in details in the backend section, from end-user perspective, representative from the Local Self-government should be able to have the ability to adjust intervals remotely, increase or decrease, with such ability depending on the selected hardware with such options. From the technical point of view, such functionality will be supported.

Central software system should check battery level, device status and notify user if any of those are within the normal reading. If the battery level drops beyond reasonably defined level, end user should know on time and should be notified so that the reaction can be timely. As for the status of the device, several mechanisms should be established in the system, each checking latest received corresponding data. If there are several non-corresponding information, i.e., interval is missed between device and network gateway, between network gateway and network server, network server and application server and finally between application server and the device, device should provide such message notifying user to react. Of course, sophistication of such errors will be dependent on the selected model of hardware, precisely detecting the type of error, however this is to be determined in the early stages of development.

4.10.8 Technology and platforms

Software should cover wide variety of platforms, and as such technology used for those platforms should be appropriate. Frontend application should cover both mobile and desktop systems, while mobile should be iOS and Android, for desktop systems we should cover both Windows and Web platforms, as the most widely used platforms.

Technology used can be cross-platform, however we advise that the native technology for each corresponding platform be considered. Although short term development requires more engineers, long term maintenance is reduced and stability of such implementation is quite superior.

Desktop and web version of the software will be used for office use, and for command and situational centers, while mobile version of the software will be use on field and out-of-office work.

As for the backend there is also a wide variety of options for different technologies, however suggestion would be to use Java Spring Boot technology, with AWS cloud-based server.

All platforms a technology will be decided upon early stages of development and will not have greater impact on the final solution, rather than the availability of the engineers, development cost and time.

APPENDIX 1 - THE OVERVIEW OF SOME TYPICAL COMMERCIALLY AVAILABLE SENSORS DEVICES, WIRELESS SENSOR DEVICES AND MEASURING STATIONS THAT SATISFY BASIC REQUIREMENTS FOR THE OBSERVED MEASURING STATIONS (RBWL-MS AND MCD-MS)

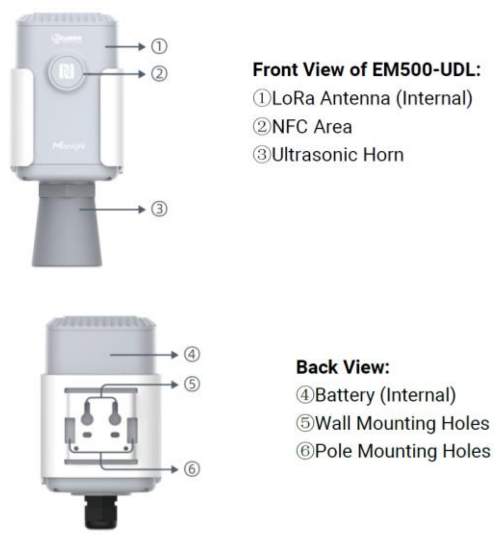
The following section presents some of the typical available sensor devices and wireless sensor devices for the required measurements (i.e. water level, liquid precipitation, soil humidity and air temperature) as well as the complete measuring stations (RBWL-MS and MCD-MS devices) that cover all demanded measurements. The sensor devices are selected based on the previously defined measurements requirements. Notice: The description of typical sensor devices for ultrasonic water level sensors is not included here, due to the very high number of these devices on the market with the similar and adequate performances (i.e. that satisfy all requirements for this type of sensor devices).

A1 .1 Ultrasonic water level wireless sensor devices

A1.1.1 Milesight ultrasonic distance/level wireless sensor device EM500-UDL

The wireless sensor device EM500-UDL that comprises wireless LoRaWAN interface an ultrasonic distance/level sensor, shown in the Figure A1.1, is the product of company Milesight from China (url: https://www.milesight-iot.com/lorawan/sensor/em500-udl/).

Figure A1.1: The Milesight EM500-UDL wireless sensor device



Source: The official web site of the manufacturer, Milesight from China

The distance/level measurement process is based on ultrasonic waves transmitted and reflected back from nearby objects. Depending on requirements there are two versions of the device in which changes in the water level can be monitored up to 5 m and up to 10 m. The data measured by the ultrasonic sensor is sent via the LoRaWAN network to the application server. This wireless sensor device is equipped with NFC interface and can easily be configured by a smart phone or a PC (Personal Computer) software. Sensor data are transmitted in real-time using standard LoRaWAN® protocol. The LoRaWAN wireless interface enables encrypted radio transmissions over long distance while consuming very little power. The main technical characteristic of the Milesight EM500-UDL wireless sensor device are given in Table A1.1.

Table A1.1: The technical characteristics of EM500-UDL wireless sensor device

Measurement range	0.3-5 m or 0.3-10 m
Measurement resolution	1 mm
Protection	IP66 (IP67 as required)
Battery	19000 mAh Li-SOCI2 battery battery (ER34615)
Battery lifetime	Built-in 19000 mAh replaceable battery and work for 10 years without replacement (10 min interval)
Communications	LoRaWAN®, modes of operation OTAA/ABP Class A
Operating frequencies	CN470/RU864/IN865/EU868/US915/AU915/KR920/AS923
Measurement accuracy	±1% of FS (Full Scale)
Working temperature	-30°C to +65°C
Mounting	DIN rail, wall, pole
Regulatory	CE, FCC, RoHS, LoRaWAN® Certified

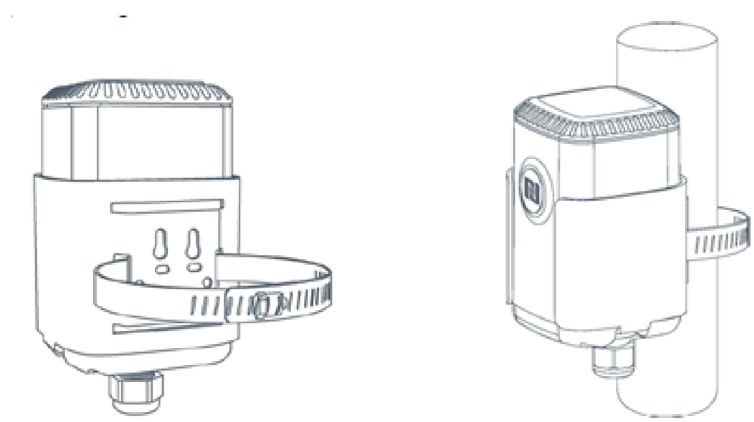
Source: Authors, based on the publically available data from manufacturer official web site

The additional features of this wireless sensor device are:

- The ultra-wide-distance transmission up to line of sight of 10 km,
- The device is equipped with NFC interface for easy configuration via smart phone or via PC (USB connection),
- The device is compliant with standard LoRaWAN® gateways and network servers, and
- The Reporting interval of transmitting data to network server can be defined. Default value is 10 minutes, and the possible range is form 1 minute to 1080 minutes. Also, the measured level threshold can be defined – if this level is crossed the measured level is instantly sent towards the server.

The wireless sensor device is provided to be mounted on the pole, and the example of pole mounting is given in Figure A1.2.

Figure A1.2: The pole mounting of Milesight EM500-UDL wireless sensor device



Source: The official web site of the manufacturer, Milesight from China

A1.1.2 Dragino ultrasonic LoRaWAN distance detection wireless sensor device LDDS75

The LoRaWAN wireless sensor device LDDS75 (url: https://www.dragino.com/products/distance-level-sensor/item/161-ldds75.html), shown in the Figure A1.3, is a product of company Shenzhen

Dragino technology development Co. Ltd. from China. This is LoRaWAN based distance detection sensor designed as the IoT solution, and is generally used to measure the distance between the sensor and the flat object. The distance detection sensor is a module that uses ultrasonic sensing technology for a distance measurement, while the temperature compensation is performed internally to improve the reliability of the measured distance data.

Figure A1.3: The Dragino wireless sensor device LDDS75

Source: The official web site of the manufacturer, Dragino technology development Co. Ltd., China

The measurement process is based on ultrasonic waves transmitted and reflected back from nearby objects. The data measured by the sensor is sent via the LoRaWAN network to the application server. The user can configure LDDS75 wireless sensor device via AT Command or LoRaWAN downlink communication (i.e. the wireless sensor device can be remotely controlled by server application). LDDS75 wireless sensor device supports AT Command set in the stock firmware. For using AT command a USB interface to TTL (time-to-live) adapter should be used to connect to LDDS75 device. The LDDS75 device by default sends measured data to the uplink (over LoRaWAN network) every 20 minutes, but the user can change this interval using AT Command or through LoRaWAN downlink command. The main technical characteristics of Dragino LDDS75 wireless sensor device are given in Table A1.2.

Table A1.2: The technical characteristics of Dragino LDDS75 sensor device

Measurement range	280 mm – 7500 mm
Measurement resolution	1 mm
Protection	IP66
Battery	4000 mAh or 8500 mAh battery for long term use
Battery lifetime	It is designed for long term use up to 10 years. Actually, battery life depends on the use environment, update period.
Communications	LoRaWAN 1.0.3 Class A
Operating frequencies	CN470/EU433/KR920/US915/EU868/AS923/AU915/IN865
Measurement accuracy	Accuracy: ±(1 cm + S×0.3%) (S: Distance)
Working temperature	-15°C to +60°C
Mounting	Wall, pole
Regulatory	CE, LoRaWAN® Certified

Source: Authors, based on the publically available data from manufacturer official web site

The additional features of this sensor device are:

- Ultra low power consumption,
- The LoRa wireless technology used in LDDS75 sensor device allows device to send data and reach extremely long ranges at low data-rates,
- Distance detection is performed by ultrasonic technology,
- AT Commands are available to change parameters of the sensor device,
- The measured data are periodically sent in the uplink direction, and
- There is a possibility to configure a device by using downlink commands (i.e. the device can be remotely controlled by the application server).

A1.2 Precipitation sensor devices

A1.2.1 The Pessl Instruments rain gauge device

The Pessl Instruments rain gauge device, shown in Figure A1.4, is a product of company Pessl Instruments Gmbh from Austria (url: https://metos.at/en/precipitation-sensors/), and presents typical sensor device of this kind.

Figure A1.4: The Pessl Instruments rain gauge device

Source: The official web site of the manufacturer, Pessl Instruments Gmbh from Austria

The mechanically sensor device consists of a magnet, which moves past a reed switch and opens or closes the circuit. The double spoon tips left or right and does not lose any water due to a very fast switching mechanics. The resolution with a surface of 200 cm^2 is 0.2 mm, while the resolution with the 80 cm^2 is 0.5 mm. The rain gauge can also be equipped with the heating. The main technical characteristic of the Pessl Instruments rain gauge device are given in Table A1.3.

Table A1.3: The technical characteristics of Pessl Instruments rain gauge device

Sensor Type	Double tipping bucket rain gauge
Output	Switch signal
Switch	Reed contact, solid state
Sensitivity	1 tip per 0.2 mm or 1 tip per 0.5 mm
Collector Surface	200 cm^2
Evaluation	Digital
Maximum Rain	12 mm/minute
Accuracy	±5%
Dimensions	185 mm diameter x 250 mm height

Source: Authors, based on the publically available data from manufacturer official web site

A1.2.2 MeteoRain® 200 Compact rain gauge wireless sensor device

The rain gauge MeteoRain® 200 Compact, shown in the Figure A1.5, presents another typical solution of this kind of sensor device, and is the product of company Barani Design Technologies s.r.o. from Slovakia (url: https://www.baranidesign.com/meteorain-200-compact).

Figure A1.5: The MeteoRain® 200 Compact rain gauge device

Source: The official web site of the manufacturer, Barani Design Technologies s.r.o. from Slovakia

The MeteoRain® 200 Compact rain gauge device with 200 cm² capacity is an automatic rain gauge for hydrology, urban-meteorology, agriculture, smart cities, and resilient city projects. This device can be combined with the wireless interface (LoRaWAN or SigFox) in order to form MeteoRain® 200 IoT Compact wireless rain gauge device that offers more than 4 years delivery of wireless data by using the one replaceable battery (url: https://www.baranidesign.com/meteorain-iot-compact). The sensor device requires very low-maintenance and is field serviceable with the long-term measurement stability due to the new MeteoRain® 200 Compact self-balancing magnetic tipping bucket mechanism. The main technical characteristic of the MeteoRain® 200 Compact rain gauge device are given in Table A1.4.

Table A1.4: The technical characteristics of Barani Design Technologies s. r. o. MeteoRain® 200 Compact rain gauge device

Measurement resolution	0.20 mm/tip (0.2 liters per square meter)
Rain catchment opening area	Industry standard 200 cm^2
Measurement accuracy	+/- 2 %
Battery lifetime	4+ years (for MeteoRain® IoT Compact)
Working temperature	-33°C to +80°C
Mounting	Pole, fence or wall

Source: Authors, based on the publically available data from manufacturer official web site

The additional features of this sensor device are:

- High-reliability self-balancing tipping bucket measuring mechanism,
- More than 4 years of useful battery lifetime,

- Device maintains measuring accuracy up to rain rates of 10 mm/min (0.4”/min), 600 mm/hr (24”/hr) or 50 tips per minute,
- The sensor is highly resistant to wind induced vibrations compared to standard tipping bucket rain gauges,
- The sensor is resistant to drift and measurement error from dirt accumulation,
- The sensor is magnetically stabilized for easy adjustment and consistent measurement in all non-freezing temperatures, and
- The field calibration is performed with a single screw driver

The sensor device by default supports factory standard calibration of 0.2 mm (0.2 liters per square meter) per tip with +/- 2 % accuracy, but other calibration options are available, such as:

- 0.10 mm/tip (0.004"/tip) – by special order,
- 0.20 mm/tip (0.008"/tip) – this is factory default (World standard),
- 0.25 mm/tip (0.01"/tip) – by special order (USA standard), and
- 0.50 mm/tip (0.02"/tip) – by special order.

A1.3 Soil moisture sensor devices

A1.3.1 The Pessel Instruments PI54-D soil humidity sensor device

The PI54-D soil moisture (humidity) sensor is a typical sensor device of this kind, shown in Figure A1.6, (url: https://metos.at/tr/portfolio/pessl-instruments-soil-moisture-sensor-pi54-d/), is product of company Pessl Instruments Gmbh from Austria.

Figure A1.6: The Pessl Instruments PI54-Dsoil moisture sensor device

Source: The official web site of the manufacturer, Pessl Instruments Gmbh from Austria

The PI54-D soil moisture sensor has a larger volume of influence, and it determines volumetric water content (VWC) by measuring the dielectric constant of the soil using capacitance technology and soil temperature. It is 10 cm long and thus measures 1 liter of soil, while high frequency minimizes salinity and textural effects which makes PI54-D accurate in most soils. The main technical characteristic of the Pessl Instruments PI54-D soil moisture sensor device are given in Table A1.5.

Table A1.5: The technical characteristics of Pessl Instruments PI54-D sensor

Volumetric water content (VWC)	Range: 0−0.57 m^3/m^3 (0 %−57 % VWC) Resolution: 0.0008 m^3/m^3 (0.08% VWC) in mineral soils from 0−0.50 m^3/m^3 (0%−50% VWC) Accuracy: With standard calibration equation the accuracy is 0.03 m^3/m^3 (3% VWC) in typical mineral soils, which have solution electrical conductivity lower than 10 dS/m. Note: With soil-specific calibration, ±0.02 m^3/m^3 (±2% VWC) is typical in any soil.
Dimensions	16.0 cm (6.3 in) length; 3.3 cm (1.3 in) width; 0.8 cm (0.3 in) height
Probe length	10 cm (3.94 in)
Operating temperature range	-40°C to 50°C
Cable length	5 m
Supply voltage (VIN to GND)	Minimum: 3.6 VDC at 12 mA Maximum: 15 VDC at 20 mA
Measurement duration	Maximum 10 ms
Temperature accuracy	±0.3℃
Output	Digital

Source: Authors, based on the publically available data from manufacturer official web site

A1.3.2 JXCT Soil Moisture Measurement sensor device

The JXCT Soil Moisture Measurement sensor device, shown in Figure A1.7, is a typical soil moisture sensor device, which is a product of Weihai JXCT Electronic Technology Co., Ltd. from China (url: http://www.jxct-iot.com/product/showproduct.php?id=189).

Figure A1.7: The JXCT Soil Moisture Measurement soil sensor device

Source: The official web site of manufacturer, Weihai JXCT Electronic Technology Co., Ltd., China

This soil moisture measurement sensor is equipped with the temperature sensor and humidity detector with 3 pins. The soil moisture meter is a high functional and digital display soil tester, which can quickly test the moisture of different kinds of soil. The soil meter is precision, quick, stable, wide range, display clear, portable and easy to test. The main technical characteristic of the JXCT soil moisture measurement sensor device are given in Table A1.6.

Table A1.6: The technical characteristics of JXCT Soil Moisture Measurement sensor device

Power Supply	12 V – 24 V DC
Output Signal	RS-485/4-20 mA/0-5 V/0-10 V
Installation method	Fully embedded or all probes inserted into the test medium
Protection Level	IP68
Response time	<1 s
Moisture Range	0-100 %
Moisture Accuracy	±3 % of reading (0~53 %), ±5% of reading (53%~100%)
Temperature Range	-40 - 80℃
Temperature accuracy	±0.5℃

Source: Authors, based on the publically available data from manufacturer official web site

A1.4 Air temperature and relative humidity sensor devices

A1.4.1 The Pessl Instruments air temperature and relative humidity sensor

The Pessl Instruments air temperature and relative humidity sensor device presents a typical device of this kind, shown in Figure A1.8 (url: https://metos.at/en/temperature-sensors/), and is a product of Pessl Instruments Gmbh from Austria. The main technical characteristic of the Pessl Instruments air temperature and relative humidity sensor device are given in Table A1.7.

Figure A1.8: The Pessl Instruments air temperature and relative humidity sensor device

Source: The official web site of manufacturer, Pessl Instruments Gmbh from Austria

Table A1.7: The technical characteristics of Pessl Instruments air temperature and relative humidity sensor device

Sensor	HYT221
Operating temperature range	-40°C to +125°C
Humidity range	0% to 100% RH
Accuracy	±0.2°C (0°C to +60°C) ±2 % RH at +23 °C (0% to 90% RH)
Operating voltage	2.7 V to 5.5 V
Digital interface	I²C, address 0x28 or alternative address
Operating voltage (limit data)	0.3 V to +6 V
Storage conditions	-20°C to +50 °C

Source: Authors, based on the publically available data from manufacturer official web site

A1.4.2 JXCT CC-E01 atmospheric temperature and humidity sensor device

The JXCT CC-E01 atmospheric temperature and humidity sensor device, which is shown in Figure A1.9 (url: http://www.jxct-iot.com/product/showproduct.php?id=189), is a typical sensor device of this kind, and is a product of company Weihai JXCT Electronic Technology Co., Ltd. from China. This sensor of atmospheric temperature and relative humidity presents a mean for the professional measurement of air temperature and relative humidity, and is built-in the water-proof and anti-UV shelter.

The main technical characteristic of the JXCT CC-E01 atmospheric temperature and humidity sensor device are given in Table A1.8.

Figure A1.9: The JXCT CC-E01 atmospheric temperature and humidity sensor device

Source: The official web site of manufacturer, Weihai JXCT Electronic Technology Co., Ltd., China

Table A1.8: The technical characteristics of JXCT CC-E01 atmospheric temperature and humidity sensor device

Operating temperature range	-40°C to +60°C
Humidity range	0 % to 100 % RH
Resolution	0.01°C, 0.1 %RH
Accuracy	≤ ±0.2°C (25°C) ≤ ± 0.4°C (-25 to +60°C) ≤ ±2% RH (20 to 60%) ≤ ±3% RH (< 20%) ≤ ±4% RH (> 60%)
Power Supply	DC 12 V
Output Signal	SDI-12
Operating Temperature	-40°C to +60°C
Storage	10-60°C@20%-90%RH
Shelter material	Anti-UV engineering plastics
Cable connection	Cable length 8 meters with differentiated conductors: Colors

Source: Authors, based on the publically available data from manufacturer official web site

A1.5 Weather measurement stations with the rain gauge, soil moisture, air temperature and relative humidity sensors

A1.5.1 The Pessl Instruments µMETOS® NB-IoT HL7802 weather station

The µMETOS NB-IoT device is a LPWAN weather station that supports LTE-M (LTE Cat M1) and NB-IoT (LTE Cat NB1) mobile network connectivity, and enables field monitoring in remote locations. This automatic weather station is a product of company Pessl Instruments Gmbh from Austria (url: https://metos.at/tr/micrometos-nbiot/#technicalspecifications), and is shown in Figure A1.10

Figure A1.10: The Pessl Instruments µMETOS NB-IoT weather station

Source: The official web site of manufacturer, Pessl Instruments Gmbh from Austria

This weather station is designed to monitor climate parameters (rain and temperature), soil characteristics (soil moisture, soil temperature and electrical conductivity), water pressure, and is equipped with multi-sensor sdi12 probes. This device is capable of providing everything what the standard user needs with the possibility for further expansion. Station has low cost, low power consumption and long range connectivity.

The measured data is by default consistently measured in 15 minute intervals and being sent every 60 minutes to the server, but these setting can be changed to fit the specific monitoring needs. For mitigating mobile network connectivity issues, the station stores data of last few days internally and resends the measured values to the cloud when the mobile network is back online.

All the data is synchronized and stored on Pessl Instruments FieldClimate platform, integrated with all additional services from Pessl Instruments and available for further integrations via Pessl Instruments API (Application Programming Interface). In order to perform the setting up of the parameters, updating the firmware and observing the sensors and communication process, user need to connect the motherboard to the Windows OS PC using the micro USB cable. The device supports an external antenna option and it has a build in GPS (Gloval Positioning System) sensor.

The main technical characteristic of the Pessl Instruments µMETOS NB-IoT weather station are given in Table A1.9.

Table A1.9: Technical characteristics of Pessl Instruments µMETOS NB-IoT weather station

Housing	UV resistant polycarbonate plastic (Protection class IP65)
Dimensions	L × W × H: 30 cm × 16 cm x 19 cm
Weight	1.6 kg
Connectivity	NB-IoT/CatM1: Category: Cat-M1/NB1 Frequency Band: B1, B2, B3, B4, B5, B8, B9, B10, B12, B13, B14, B17, B18, B19, B20, B25, B26, B27, B28, B66
Battery	6 V charging battery with solar panel
Solar panel	Dimensions: 13.5 × 13.5 cm, 2 W solar panel
Measuring interval	15 minutes
Logging interval	15 minutes

Source: Authors, based on the publically available data from manufacturer official web site

The additional features of this automatic weather station are:

- The multiple sensors can be connected to the same base unit,
- The long range mobile connectivity is supported,
- The low power consumption is supported,
- The device is a long term product with guaranteed updates,
- The same hardware is used to support CatM1 or NB1 wireless connectivity,
- The version with the HL7802 modem also supports the 2G network connectivity fallback in case when the LPWAN network is not available,
- The device is remotely configurable (i.e. can be remotely controlled),
- The station is linked with all existing services within FieldClimate platform, and
- The weather station supports different sensors: precipitation sensor, solar radiation sensor, pressure switch sensor, air temperature sensor, soil temperature sensor, relative humidity sensor, watermark sensor, hygroclip sensor, ultrasonic wind speed and direction sensor, and soil moisture PI54-D sensor.

A1.5.2 Rika RK600-07B Data Logger of Automatic Weather Station (AWS)

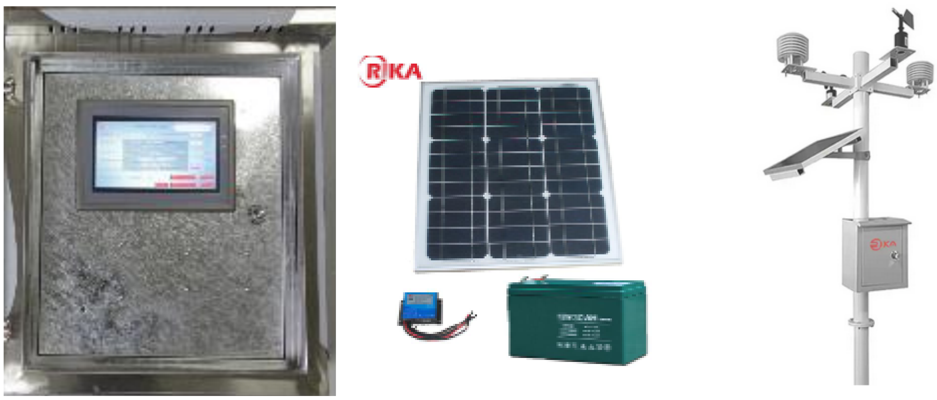
The RK600-07B Data Logger of Automatic Weather Station (AWS), is a product of Hunan Rika Electronic Technology Co. Ltd. from China (url: https://www.rikasensor.com/rk600-07-data-logger.html), and is shown in Figure A1.11.

This automatic weather station is equipped to enable reliable data acquisition, storage, transmission and management, and other functions, and presents a core component of automatic weather station, which can connect 32 parameters at the same time. The station has the settings and color LCD display, and enables a communication with PC via cable or wireless connection, uses the provided communication protocol, convenient for the secondary development.

The AWS device can communicate with the center workstation by RS-232 or RS-485 interface, while if communication distance is lower than 20 m, RS-232 communication is recommended, but if communication distance is within 20 m to 800 m, the RS-485 communication is recommended. The device supports GPRS wireless communication in scenarios when cable routing is inconvenient, in which case the data can be transferred by GPRS wireless communication.

The main technical characteristic of the Rika RK600-07B Data Logger of Automatic Weather Station are given in Table A1.10.

Figure A1.11: The Rika RK600-07B Data Logger of Automatic Weather Station



Source: The official web site of manufacturer, Hunan Rika Electronic Technology Co. Ltd., China

Table A1.10: The technical characteristics of Rika RK600-07B Data Logger of Automatic Weather Station

LCD	7” color touch screen
Weight, Dimensions	10kg, 55*31*51 cm (Data logger)
Storage type	Internal storage or external U_disk is optional
Internal storage	48 M (If set to store every 1 hours can store data for more than 6 years, If set to store every 10 minutes can store data for approximately 1 year, If set to store every 1 minute can store data for 3 months)
Data interface	RS232 or RS485 (customized)
Communication mode	Ethernet (add RS232 to Ethernet converter); GPRS (add RS232 to GPRS converter),data flow consumption: <100 MB/month Wi-Fi (add RS232 to Wi-Fi converter)
Communication protocol	Modbus-RTU (Open communication protocol, the user can convenient for secondary development)
Supply	12 VDC with 100 – 240 VAC adapter, solar power supply system option
Solar panel	5 kg, 67*57*5 cm, 50 W
Record interval	1 min – 240 min adjustable. Default 10 min, it can be modified by touch screen.
Measurement parameters	32 Max
Power consumption	< 5 W
Operating temperature	-40°C to +75°C

Source: Authors, based on the publically available data from manufacturer official web site

The additional features of this automatic weather station are:

- The real-time display is supported,

- The station supports multiple sensor interface,
- The device has a large local storage,
- The different types of communication interfaces are supported,
- There is an optional U disk external storage,
- There is optional wireless connectivity,
- The device supports real time data display and storage,
- The data storage interval is adjustable,
- Device support remote viewing and exporting data in CSV (comma-separated values) format,
- Sensor communication status indication are supported,
- The device supports exporting data in specified time period,
- The device is characterized with the low power consumption design which support solar power supply,
- The device has compact design, the solar power supply system and battery that can be installed in the protective box,
- The producer Hunan Rika Electronic Technology Co. Ltd. provide open service of cloud platform with multi-device management, and
- The Windows Operating System (OS), iOS (iPhone Operating System) and Android OS are supported, i.e. remote monitoring software is available for Windows OS, iOS, and Android OS.

APPENDIX 2 - THE OVERVIEW OF SOME TYPICAL INTEGRATED WIRELESS SENSOR NODE DEVICES THAT MAY BE USED FOR THE DEVELOPMENT OF THE OBSERVED MEASURING STATIONS

The following section presents some of the typical available integrated wireless sensor node and gateway devices based on LoRaWAN wireless technology, capable of porting corresponding sensor devices, which can be used for the development and implementation of the observed measuring stations (RBWL-MS and MCD-MS devices).

A2.1 Dragino long range wireless LoRa sensor node LSN50 v2

The LSN50 v2 long range wireless LoRa sensor node, shown in Figure A2.1, is product of company Dragino technology development Co. Ltd. from China (url: https://www.dragino.com/products/lora-lorawan-end-node/item/155-lsn50-v2.html).

It is designed for outdoor use and powered by Li/SOCl2 battery for long term use, power consumption and secure data transmission. It is designed to facilitate developers to rapidly deploy industrial level LoRaWAN and IoT solutions. LSN50 v2 is based on SX1276/SX1278 and allows the user to send data and reach extremely long ranges at low data-rates. It provides ultra-long range spread spectrum communication and high interference immunity whilst minimizing current consumption, and targets professional wireless sensor network applications such as irrigation systems, smart metering, smart cities, smart phone detection, building automation, and so on.

The LSN50 v2 comprises ultra-low-power STM32L072xx microcontrollers that incorporate the connectivity power of the universal serial bus (USB 2.0 crystal-less) with the high-performance ARM® Cortex®-M0+ 32-bit RISC core operating at a 32 MHz frequency, a memory protection unit (MPU), high-speed embedded memories (192 Kbytes of Flash program memory, 6 Kbytes of data EEPROM (electrically erasable programmable read-only memory), and 20 Kbytes of RAM, plus an extensive range of enhanced I/O and peripherals. The main technical characteristic of the Dragino long range wireless LoRa sensor node LSN50 v2 are given in Table A2.1.

Figure A2.1: The Dragino long range wireless LoRa sensor node LSN50 v2

Source: The official web site of manufacturer, Dragino technology development Co. Ltd. from China

Table A2.1: The technical characteristics of Dragino long range wireless LoRa sensor node LSN50 v2

MCU data	MCU: STM32L072CZT6 Flash: 192KB, RAM: 20KB, EEPROM: 6KB Clock Speed: 32 MHz
LoRa data	LoRa Chip: sx1276/sx1278 Frequency Bands: EU433, EU868 68 dB maximum link budget +20 dBm – 100 mW constant RF output vs. +1 dBmHE PA Programmable bit rate up to 300 kbps High sensitivity: down to -148 dBm LoRaWAN 1.0.3 Specification, Class A
Power Supply	Li/SOCI2 unchargable battery, capacity: 4000 mAh Max continuously current: 130 mA
Power Consumption:	STOP Mode: 2.7µA/3.3v LoRa Transmit Mode: 125mA / 20dBm, 44 mA/14dBm
Interfaces	2×12 bit ADC, 1 × 12bit DAC I^2C, LPUSART1, USB 18 × Digital I/O I/O pins: 0.5V - VCC+0.5V
Operating Temperature	-40°C to +85°C
Ingress Protection	IP68

Source: Authors, based on the publically available data from manufacturer official web site

The additional features of this device are:

- The ultra low power consumption,
- AT Commands are available to change parameters of the sensor device,
- Open source hardware/software, and

- There is a possibility to configure device by using downlink commands (i.e. the device can be remotely controlled by the application server).

A2.2 Dragino RS485/UART to LoRaWAN converter RS485-BL

The RS485-BLRS485/UART to LoRaWAN converter device, shown in the Figure A2.2, is the product of company Dragino technology development Co. Ltd. from China (url: https://www.dragino.com/products/lora-lorawan-end-node/item/167-rs485-bl.html).

Figure A2.2: The Dragino RS485/UART to LoRaWAN converter RS485-BL

Source: The official web site of manufacturer, Dragino technology development Co. Ltd. from China

By using this device user can connect RS-485 or UART (universal asynchronous receiver transmitter) sensor to RS485-BL converter, and configure RS485-BL to periodically read sensor data and perform upload via LoRaWAN network to IoT server. It can interface to RS485 sensor, 3.3 V/5 V UART sensors or interrupt sensors, and can provide a 3.3 V output and 5 V output to power the sensors. Both output voltage are controllable to minimize the total system power consumption.

RS485-BL device is IP67 water proof and powered by 8500 mAh Li-SOCI2 battery, and is designed for long term use for several years. The RS485-BL device operate as standard LoRaWAN 1.0.3 Class A end point device, and can reach long transfer range and is easy to integrate with LoRaWAN compatible gateway and IoT server. Each device pre-loads with a set of unique keys for LoRaWAN registrations, register these keys to the local LoRaWAN server and support auto connect.

The additional features of this device are:

- The ultra low power consumption,
- RS485 interface for RS-485/Modbus sensor,
- High capacity 8500 mAh Li-SOCI2 battery,
- AT Commands to change parameters,
- Periodic uplink data, and
- Downlink can be used to change configuration.

A2.3 Wintec LoRa wireless gateway WW-3C28

The WW-3C28LoRa wireless gateway device, shown in the Figure A2.3, is a product of company Wintec Co., Ltd. from Taiwan (url: https://www.win-tec.com.tw/portfolio-item/ww3c28/#tab-id-1). WW-3C28 device is the outdoor wireless gateway for LoRa to RS-485, which is suitable for widespread area and outdoor environments when the the long-range, low data, and high latency communication is required. This is an industrial wireless gateway that can be used for a variety of applications, and is suitable for outdoor and indoor environment, and meet the requirements of IP68 standard. As an integrated wireless sensor device, it is designed as energy efficient solution with the low power consumption. It is capable to collect data detected by the sensing devices, and perform transmission to the application server for the further analysis and monitoring. The main technical characteristic of the Wintec LoRa wireless gateway WW-3C282 are given in Table A2.2.

Figure A2.3: The Wintec LoRa wireless gateway WW-3C28 device

Source: The official web site of manufacturer, Wintec Co., Ltd. from Taiwan

Table A2.2: The technical characteristics of Wintec LoRa WW-3C28 GW device

Product Type	Outdoor
Air Stream Protocol	LoRa Wireless Protocol
Frequency Range	410 – 525 MHz / 862 – 1020 MHz
Maximum ERP	25 mW
Transmit RF Power	Maximum 2W
Sensitivity	Up to -136 dBm/SF=7 / 10.4KHz bandwidth
Interfaces	RS-485 x 1 / Analog or Digital Input x 1 / Digital Output x 1
RS-485 Protocol	Modbus RTU
Serial Interface Baud Rate	1200bps / 2400bps / 4800bps/ 9600bps / 19200bps /38400bps 57600bps / 115200bps / 230400bps
Analog Input	Analog Input Support 0~10V/0~20mA/4~20mA/ADC (0~10 V)
Digital Input	Digital Input Support High / Low Signal Judge
Digital Output	Digital Output Support PWM / Latch Mode
Transmit Encryption	AES 128 / 256 Encryption Function
Operating Temperature	-40°C to +85°C
Ingress Protection	IP 68
Input Power Supply:	12V - 36V DC / 1A
Output Power Supply	5V DC / 200 mA (max.)
Power Consumption	24V, 15mA /868 MHz Rx, 24V, 400mA/868 MHz Tx, 2W

Source: Authors, based on the publically available data from manufacturer official web site

A2.4 Wintec LoRa wireless gateway WW-3D28

The WW-3D28 LoRa wireless gateway device, shown in the Figure A2.4, is a product of company Wintec Co., Ltd. from Taiwan (url: https://www.win-tec.com.tw/portfolio-item/ww3c28/#tab-id-1). WW-3D28 device is the outdoor wireless gateway for LoRa to RS-485, which is suitable for widespread area and outdoor environments when the the long-range, low data, and high latency communication is required. It is similar to wireless gateway WW-3C282 device, but it supports 4 additional analog/digital inputs. The main technical characteristics of the Wintec LoRa wireless gateway WW-3D282 are given in Table A2.3.

Figure A2.4: The Wintec LoRa wireless gateway WW-3D28 device

Source: The official web site of manufacturer, Wintec Co., Ltd. from Taiwan

Table A2.3: The technical characteristics of Wintec LoRa WW-3D28 GW device

Product Type	Outdoor
Air Stream Protocol	LoRa Wireless Protocol
Frequency Range	410 – 525 MHz / 862 – 1020 MHz
Maximum ERP	25 mW
Transmit RF Power	Maximum 2W
Sensitivity	Up to -136 dBm/SF=7 / 10.4KHz bandwidth
Interfaces	RS-485 x 1 / Analog or Digital Input x 5 / Digital Output x 5
RS-485 Protocol	Modbus RTU
Serial Interface Baud Rate	1200bps / 2400bps / 4800bps/ 9600bps / 19200bps /38400bps 57600bps / 115200bps / 230400bps
Analog Input	Analog Input Support 0~10V/0~20mA/4~20mA/ADC (0~10 V)
Digital Input	Digital Input Support High / Low Signal Judge
Digital Output	Digital Output Support PWM/Latch Mode
Transmit Encryption	AES 128 / 256 Encryption Function
Operating Temperature	-40°C to +85°C
Ingress Protection	IP68
Input Power Supply:	12V - 36V DC / 1A
Output Power Supply	Main Port: 10 V DC / 100mA (max.) AUX 2 - AUX 5: 10V DC / 0mA (max.)
Power Consumption	24V, 15mA /868 MHz Rx, 24V, 400mA/868 MHz Tx, 2W

Source: Authors, based on the publically available data from manufacturer official web site