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RESEARCH PAPER

PHYSICAL-GEOGRAPHICAL CHARACTERISTICS OF THE UNA RIVER BASIN – CONTRIBUTION TO THE ANALYSIS OF THE STATE AND POSSIBILITIES OF RADIOACTIVE WASTE DISPOSAL IN THE BORDER ZONE

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ABSTRACT. The selection of a location for the disposal of radioactive waste, used sources and spent nuclear fuel in the Republic of Croatia began to be considered as early as 1988. However, in the last 10 years, intensive activities have been undertaken regarding the selection of this location. One possible location is Čerkezovac in the Trgovska Gora area, which is located in the Una River basin and less than 1 km away from the border with Bosnia and Herzegovina. It is planned to establish a Radioactive Waste Management Center in Čerkezovac, where all spent radioactive sources located at two sites in Croatia, all institutional waste owned by Croatia, as well as low and intermediate level radioactive waste from the Krško Nuclear Power Plant, would be accommodated. According to the ESPOO Convention (Art. 1, paragraph VIII), transboundary impact implies any impact, not exclusively of a global nature, within the jurisdiction of the signatory state caused by a planned activity, whose physical origin is wholly or partially within the jurisdiction of another signatory state. The majority of the influential surface area of the radioactive waste disposal site (assuming a distance of 5 km from the Čerkezovac site in the Trgovska Gora area) is located within the territory of Bosnia and Herzegovina. This influence could have negative implications on the natural values and protected areas in the Una River valley in Bosnia and Herzegovina, as well as the life of the population.

In this paper, based on the analytical-synthetic research approach, the basic physical-geographical characteristics of the Una River basin have been determined. During the analysis, it was concluded that the connection of physical-geographic components within the Una River basin created a series of natural values that formed the basis for the designation of protected areas. This refers to the fluvial and karst landforms that dominate this area, as well as phytogeographic formations, which stand out for their uniqueness and irreplaceability, morphography and morphometry, and the degree of preservation of physical-geographic phenomena and processes. The results of the research can contribute to a better understanding of the potamological characteristics of the Una, its hydrological significance, as well as the need for environmental protection in the context of the possibility of nuclear waste disposal in the border zone of the Una basin. The processing of all parameters relevant to the study and cartographic representation in this paper were performed in the ArcGIS software package.

KEYWORDS: Una River basin, physical-geographical characteristics, nuclear waste, border area

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INTRODUCTION

The presence of radioactive nuclides generated by nuclear power plants or diverse civilian and military applications constitutes a substantial environmental challenge in the contemporary era (Delić et al. 2016) and the optimal approaches to handle radioactive waste and spent nuclear fuel progresses together with advancements in engineering knowledge and technologies (Veinović, 2016). Radioactive waste includes a range of materials that maintain heightened levels of radioactivity even after being used and disposal, while spent nuclear fuel comprises the leftover radioactive substances utilized as fuel within nuclear power plant reactors. According to (Đurić et al. 2021), the lifetime of radioactive waste repositories is 60 years, while the period for the cessation of radioactive impact extends beyond 250 years.

Following the assessment of Croatian territories in 1993, seven locations with potential for the disposal of radioactive waste were identified: Petrova gora, Trgovska gora, Zrinska gora, Moslavačka gora, Bilogora, Papuk-Krndija, Psunj, and Požeška gora. At a subsequent phase, utilizing the PROMETHEE analysis (Preference ranking organization method for enrichment evaluations) dating back to 1997, four potential sites for establishing the repository were identified: Moslavačka gora, Trgovska gora, Papuk, and Psunj. According to (Lalić et al. 2023), research on the construction of a radioactive waste repository in Croatia was conducted based on studies by various authors (Jurković et al. 2000; Trontl et al. 2010; Trontl et al. 2020; Mostečak et al. 2012; Pevec et al. 2017; Jakić and Filipin, 2018). Ultimately, as per official strategic documents regarding radioactive waste management, the Government of the Republic of Croatia designated the Čerkezovac site on Trgovska gora as the exclusive preferred location. This indicates that it is the sole site where additional investigations will be carried out to evaluate the possibility of building and establishing a repository and disposal site for radioactive waste (Samardžić et al. 2021).

Radioactive waste, mostly low and medium-level radioactive waste from the Krško nuclear power plant, as well as spent nuclear fuel, should be placed at this location. In addition to this, all radioactive waste (RAW II) generated in medical institutions, industry and research institutes for which the Republic of Croatia is responsible will be stored. Based on the quantities generated so far, it is estimated that the amount of low and medium-level radioactive waste produced by the Krško nuclear power plant until 2043. It is considered that the total volume of this waste that should be stored and then disposed of at the Čerkezovac site is about 5,000 m^3. According to the Strategy for the Disposal of Radioactive Waste, Used Sources and Spent Nuclear Fuel of Croatia, the surface type of disposal is preferred, whereby the contents of the disposal site are isolated from people and the environment by a system of barriers (Fund, 2015).

Trgovska gora is located in the Una River basin, which mostly covers the territory of Bosnia and Herzegovina. In Bosnia and Herzegovina, there are 594 settlements with 339,790 inhabitants in this basin according to the 2013 census. The territory of 12 municipalities within the Una River basin belongs either entirely or partially to the entity of Republika Srpska, where 164,498 inhabitants reside, while 10 municipalities belong to the Federation of Bosnia and Herzegovina with 175,292 inhabitants, which is about 10% of the total number of inhabitants of Bosnia and Herzegovina. Research on the impact of the construction of radioactive waste disposal sites on Bosnia and Herzegovina by authors from Bosnia and Herzegovina, published in scientific journals and professional conferences (Delić et al. 2016; Samardžić et al. 2021; Đurić et al. 2021; Mandžić et al. 2021; Trbić and Đorđević, 2021; Lalić et al. 2023), nevertheless showed that the location in Trgovska Gora does not meet ecological and safety standards. According to (Mandžić et al. 2021), the previous assessment of the available documentation upon which the location of Trgovska gora was chosen indicates that the designated criteria for site selection were not sufficiently respected. Also, the cross-border impact on Bosnia and Herzegovina was superficially addressed, although about 70% of potential negative impacts could affect the territory of Bosnia and Herzegovina. Lalić et al. (2023) analyzed the impact on seven areas of human security in the local community of Novi Grad in Bosnia and Herzegovina. The research showed that potential disposal of radioactive waste in Trgovska Gora in the Republic of Croatia, in the border area near the Una River and without the consent of the neighboring state would have negative implications and set a dangerous precedent. All mentioned researches indicate, among other things, to the fact that there are still unknown characteristics of the terrain, which are essential for the construction of facilities for the disposal of radioactive waste. In this regard, it is necessary to conduct adequate additional research in the territories of the Republic of Croatia and Bosnia and Herzegovina.

This paper is also a contribution to the analysis of the physical-geographical characteristics in the Una River basin, particularly in terms of their influence on the water balance regime of the Una. Tsang et al. (2015) emphasize that significant progress has been made in hydrology, especially in subsurface flow and transport of dissolved substances, in the last 35 years due to continued interest in assessing the impacts of proposed nuclear waste repositories. Research has been conducted in various geological formations to explore the effectiveness and safety of these potential disposal sites. Progress in hydrological research can find application in other areas as well, particularly in environmental protection and spatial planning. Almost all hydrological characteristics fundamentally depend on physical-geographical factors, and they are considered the main factors of the creation, existence, maintenance, and nourishment of a watercourse (Korjenić, 2020). Certainly, separate physical-geographical entities form a component structure of factors, in the formation and development of a watercourse. These characteristics are mainly expressed through geological, geomorphological (morphographic and morphometric), climatic, hydrographic, pedological and phytogeographic peculiarities of the observed basin.

The study area

The Una River system and its catchment area is the object of research in this paper. The basin of the Una River extends mostly over the territory of Bosnia and Herzegovina, while a smaller area includes part of the neighboring Republic of Croatia. The Una River system drains water from the area, partly or entirely, 22 municipalities in Bosnia and Herzegovina, while in neighboring Croatia, this area includes 8 municipalities. Trgovska gora, i.e. the Čerkezovac site, designated by the Republic of Croatia for the disposal of radioactive waste, is located in the Sisak-Moslovačka County and the municipality of Dvor (Fig. 1). The location of the planned landfill is a former military storage complex, occupying an area of about 0.6 km^2 (60 hectares). It is situated at an altitude of 319.4 meters, in the eastern part of the Trgovska Gora massif, not far from the valley of the Una River and the state border with Bosnia and Herzegovina (mingor.gov.hr). Although there are indications for postponement, the start of construction of the center is planned for 2025, while the planned start of work is scheduled for 2026.

Analysis of the river system and morphometric indicators were obtained using Arc GIS software, from topographic maps at a scale of 1:25,000. According to (Korjenić, 2018), considering all permanent and the largest intermittent streams, the total length of the watercourses in the area of the Una basin is 10,190.6 km. The length of the intermittent streams is 6,012.8 km, and the permanent 4,177.8 km.

From its source, where it is formed by numerous karst springs all the way to Bihać, the Una flows in the Dinaric direction, i.e. from southeast to the northwest. Then the river's course turns towards the northeast directions and continues to flow through a deeply incised, wide and spacious valley. It maintains this direction all the way to Kostajnica, from where it flows eastward to Kozarska Dubica. From that part to its mouth in Jasenovac, the Una River takes a meridian direction. The spring of the Una, has typical karst characteristics, which is why the upper part of its stream is classified as karstic. From its spring to Adrapovci, the Una flows through karst terrain and has the hydrographic characteristics of karst, i.e. the absence of a large number of tributaries and sparsely branched tributary valleys. The springs mostly appear near the contact of water-permeable Cretaceous limestones and impermeable Miocene clastites, they are of a concentrated type and have an ascending-overflow mechanism of emergence (Institute for Water Management, 2009). From the Bihać to Bosanska Krupa, the Una flows through a canyon and there are no major tributaries in this part. From Bosanska Krupa towards Rudice, the Una receives larger tributaries from

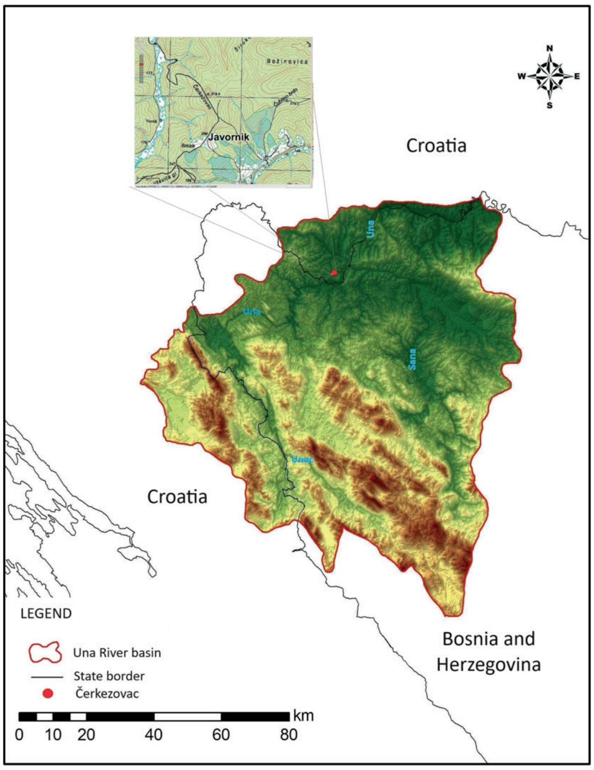

Fig. 1. The location of the Una River basin and Čerkezovac site

the right side: Krušnica, Bukovska and Vranovina, and from the left: Ljusina, Baštra and Glodina, as well as other smaller streams. Downstream towards Novi Grad, the Una receives Vojskova and Vidorija on the right side and Javornik, Crni Potok and Svinjica on the left, as well as numerous smaller streams. In this lower part of the basin, the tributaries of the Una are widely branched in their upper courses.

The southern part of the Čerkezovac location drains through local stream valleys, both east and west of the main ridge, into the aforementioned Crni Potok. At Novi Grad, on its right side, receives its largest tributary, the Sana. In this catchment area, significant accumulations of groundwater have formed, which discharge at the karst springs of the Sana, Ribnik, Okašnica, Sanica, Korčanica, Dabar and Zdena. After the confluence with the Sana, from Novi Grad towards Kostajnica, Una receives the water of several larger and smaller streams. Tunjica, Strižna and Strigova flow into the Una on the right, while tributaries Žirovnica near Dvor, Divuša, Lorić and Volinja on the left side of basin. Going further downstream towards Kozarska Dubica and the confluence of the Una and the Sava, several tributaries can be distinguished that feed Una in its lower course. Vučijak and Petrinjica with narrow and deep, and Slabinja, Mlječanica and Binjacka with wide valleys on the right side, while on the left side Krivaja and Ivančevac flow into Una.

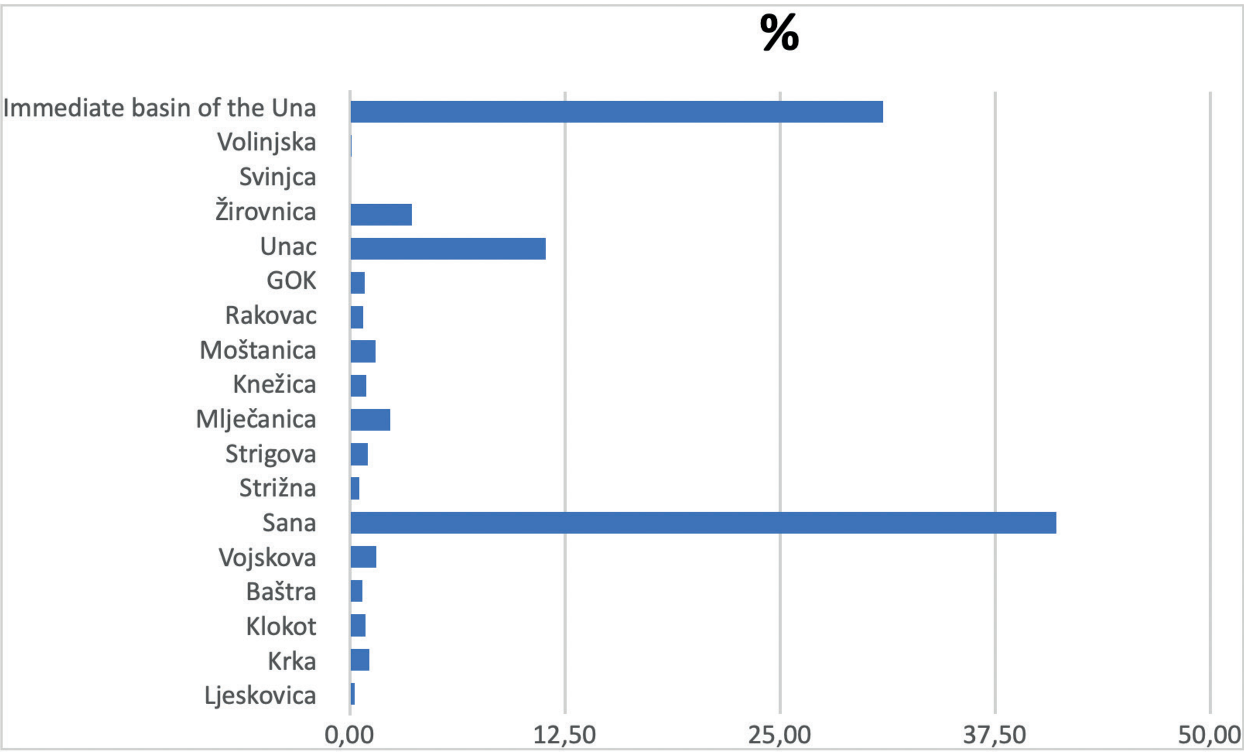

Diagram 1. Percentage participation of the larger tributary basin in the total Una basin

MATERIALS AND METHODS

The study involves synthesizing various component research along with additional field studies of the given area. To determine the general hydrographic characteristics of the area of the Una basin, phase surveys were used, which sought to determine quantitative-qualitative features in the spatio-temporal dynamics of the main elements of the river regime and water balance. In the first phase of the work, it was necessary to determine and separate, and then thoroughly analyze the identified physical-geographical factors. All considerations were directed towards the mechanism of modifying influences on the hydrographic specificities of the Una River basin. For this purpose, various thematic maps were created, which, in addition to visualization, further contributed to a better understanding of the presented theoretical positions. During the second phase of the work, basic meteorological and hydrographic-statistical data were collected, obtained on the basis of direct instrumental measurements of meteorological and elements of the river regime in the Una River basin. The classification and methods of processing these data are based on the established criteria of meteorological and hydrographic statistics and adapted for the realization of the goals and objectives of this study. All data were brought to the same length of the time observation series of thirty years for the period 1961–1990. This period was taken into consideration due to the fact that meteorological stations and measurements were interrupted during the war in Bosnia and Herzegovina during the 90s of the last century, so that the next climatological series 1991-2020 is not complete and continuous. By applying the analytical-synthetic method, in the third phase, a quantitative-qualitative comparison of the above-mentioned characteristics was made between all water-meter stations, and based on them, the physical-geographic regularities in the temporal and spatial dynamics of each element of the river regime were determined. In this regard, thematic maps were created for visual representation of the spatial distribution of analyzed hydrological parameters.

During the work, various computer programs were used for cartographic processing, graphic, tabular and textual representation. Morphometric measurements and cartographic analyzes in the Una River basin were performed by computer, using the ArcGIS software, on geocoded and digitized topographic maps at a scale 1:25,000 for the Una River basin. According to (Medeiros et al. 2023), landscape cartography facilitates the evaluation of geosystemic units by considering their environmental, social, economic, and cultural roles. Overexploitation of these functionalities can lead to environmental issues and irreversible impacts on the natural system.

RESULTS AND DISCUSSION

Physical-Geographical Characteristics of the Una River Basin

Various data can be found in the professional literature regarding the surface area covered by the Una River basin. It is mostly reported that the basin covers 9640 km^2 (Spahić, 1991), 9368 km^2 in the territory of Bosnia and Herzegovina, of which 5020 km^2 is within the territory of the Federation of Bosnia and Herzegovina (Žigić et al. 2010). Most of the data is related to the orographic or topographic watershed, which, due to the predominant terrains with aquifers of fissure-cavernous porosity, does not constitute a real watershed between the neighboring basins and the Una basin, so they should be taken with caution. It is difficult to determine the concrete and precise watershed, and thus the area of the basin, until direct hydrogeological research is carried out in the area of the entire basin. In recent times, such research has been conducted in the area of the western and southwestern parts of the watershed. The geological structure of the terrain, diversity of rocks with different permeability, and tectonic characteristics of this area have resulted in a surface watershed that separates in the northwest, north, and northeast, and in the southern part of the basin near Bosansko Grahovo. The watershed further extends into the interior and does not coincide with the orographic watershed. At the same time, it should be noted that the majority of the territory covered by the watershed is made of carbonate, water-permeable rocks, and that the area is abundant in fault-line fractures, which has influenced the mismatch between surface and underground watershed. According to (Bošnjak, 1938), the upper part of the Una valley is cut into a series of Mesozoic limestones, i.e. a deep karst between Grmeč in the east and Plješevica in the west. The area of deep karst descends towards the north and near Bihać transitions into an area of shallow karst that belongs to the rim of the Pannonian basin. The middle course of the Una up to Arapovac (downstream from Novi Grad) is developed in the karst plane, while the lower part of the Una course is in the Paleozoic and flysch zone. The area around the mouth of the Una River into the Sava River is of the youngest origin and was formed during the Diluvium, constructed from diluvial and alluvial sediments. The polymorphism and polygenetic structure of the Una valley are reflected through a series of smaller and larger valley interconnected by gorges and canyons. The valley represents tectonic depressions lowered along faults, formed in the middle of the Tertiary period during the Oligo-Miocene uplift of the Dinaric system (Spahić, 1988).

The canyons in the valley of the Una River were formed by the erosion of the lake islands, at the end of the Pliocene, during the drainage of the lake from the Pannonian Basin. Fluvial and lacustrine terraces are represented along the entire length of the Una River and generally maintain the same relative height along the river's course, while their absolute height increases upstream. The polyphasic nature of the Una valley is also indicated by travertine barriers, which have divided the longitudinal profile of the Una into sections.

In the Una River basin, the presence of 5 deep faults and a series of first and second-order fractures has been determined. According to the seismotectonic map (Fig. 2), the deep faults are: Una, the Novi Grad - Banja Luka (Olovo - Višegrad), Kozara, Kozara - Spreča and Sava faults. By comparing these faults with the surface geological formations and structures, it is noted that they generally coincide with the paleogeographic and larger tectonic units in the Dinarides, as pointed out by numerous authors (Herak, 1986). First-order faults, both longitudinal and transverse, are young (neotectonic) faults with lengths exceeding 10 km, and they are associated with the epicenters of previous earthquakes.

Trgovska gora is located approximately 1 km from the active fault zone. The tectonic conditions indicate the existence of an assumed fault running almost west-east. According to (Delić et al. 2016), the fault trace is about 450 m south of the Čerkezovac military facility. The geological structure significantly influences on the maintenance of rainwater on the surface and its absorption into underground. It determines the depth of erosion processes and the incision of river valleys. Geological factors also play a significant role in the movement of underground water. They determine the conditions for groundwater formation, its position, flow velocity, depth of hydrological isolator and the character of the hydrological collector. Among other things, hydrogeological relations also influence the density of the river network.

The area of the Una River basin considering its spatial

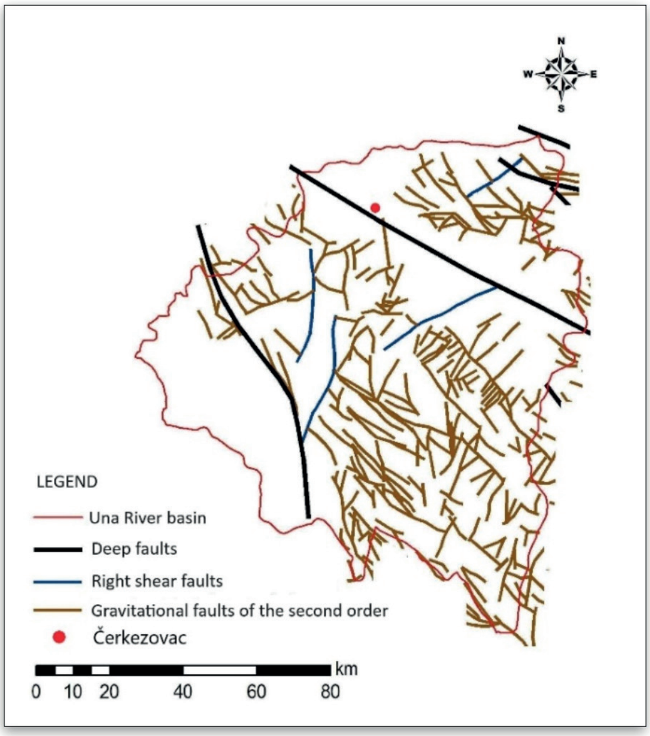

Fig. 2. Location of faults in the Una basin

Source: GIS database of FB&H Spatial Vulnerability Studies

extent, directionality, and significant differences in altitude, is characterized by a complex geological structure and lithological composition. This is a direct consequence of a long and complex geological past as well as complex geotectonic movements. In the preparation of this study, during the analysis of the geological composition of the terrain, the geological map a scale 1:500 000 was used, as well as 1:100 000, sheets Bihać, Kostajnica, Bosanska Krupa, Prijedor, Banja Luka, Ključ, Drvar, Glamoč, Udbina and their interpreters. Paleozoic rocks, as the oldest, are part of the Sana - Una and Paleozoic of Ključ. In the Una River basin, the rocks of the Sana-Una Paleozoic extend from the right tributaries of the Una: Vojskove, Čađavica and Vidorija in the northwest, and within the area of Piskavica – Bronzani Majdan – Kozica valley – Sanski Most – Budimlić Japra – Rudice (Una valley) – Novi Grad. A part of the Una basin in the northwest, specifically the right side of the Žirovnica basin, belongs to the Banija Paleozoic. The border between the Banija and Sana - Una Paleozoics is formed by the river Una. The oldest Paleozoic rocks of this basin belong to the Lower and Middle Carboniferous. Carboniferous deposits are represented by sandstones, conglomerates and shales, and interlayers of dolomite and ankeritic limestones.

Trgovska Gora is mainly composed of clastic Paleozoic deposits of the Lower Devonian - Carboniferous period, represented mainly by shales (clay shale), marls, sandstones, less often conglomerates, limestones and dolomites.

The Lower Triassic formations, in their classic facies development of verfen layers, are widespread in all structural-facies units. The composition of the Lower Triassic deposits mainly includes clastic rocks: sandstones, marls and clays, and carbonate rocks: limestones and less often dolomites. All these rocks are affected by metamorphic processes of a lower degree, so they represent, in fact, semi-metamorphic rocks. The Middle and Upper Triassic formations, in some parts of the observed area, could not be separated, and as undivided, these formations are represented by limestones, dark gray cherts and marls.

The tectonized ophiolitic mélange is part of the Central Ophiolitic Zone, and in the area of the Una River basin it is registered on the geological map, sheets Kostajnica and Prijedor. The formations of this mélange represent a paleo-relief in younger Tertiary sediments, tectonically separated from Eocene flysch and Triassic deposits, often overlain discordantly by Miocene sediments. They consist mainly of sandstones, clays, marls and cherts. Along with these rocks, conglomerates occur, as well as igneous rocks with serpentinites, diabases, gabbros, and occasionally granites.

The Paleogene is represented in the Una River basin by formations from all three of its epochs: Paleocene, Eocene and Oligocene. The Paleocene and Eocene are characterized by the carbonate type of sediments, initially freshwater sheet and layered marly limestones (Paleocene, lower Eocene), followed by marine bank foraminiferal limestones. Towards the end of the Eocene, clastites of the typical flysch series dominate the sedimentation, while during the Oligocene layered conglomerates, sandstones and marls play a leading role. Flysch deposits are also registered in the northwestern part of the basin, in the area of Zrinjska Gora, and form a watershed in this area of the basin.

The Quaternary is represented by various clastic sediments in the area of the Una River basin. These deposits are identified across fields, their peripheries, and river valleys. They consist of deluvial slope sediments, proluvium, scree and slope breccias, quartz sand, marsh and lake sediments, river terraces, alluvial deposits and travertine.

Over 40 different stratigraphic units can be distinguished in the area of the Una basin, indicating the complexity and specificity of the terrain, and therefore the complexity of geological, hydrogeological and hydrological relations in this area (Korjenić et al. 2017). The lithological composition of the rocks, their position and the depth of aquifer layers largely influence the conditions of accumulation in the basin and the outflow of groundwater, which feeds the main flow of the Una River. The greatest influence of the geological structure on precipitation runoff occurs in basins whose larger or smaller surfaces are exposed to the process of karstification, as is the case in the Una River basin. Such influence is most intense in the upper part of the basin, where there are no large number of surface watercourses.

In catchments constructed of hydrological isolators, precipitation water is retained on the surface, thus, among other favorable conditions, influencing surface runoff, whereas in catchment areas constructed of hydrological collectors, surface runoff is limited and transferred into the groundwater (Spahić, 2013). This mainly refers to the karstified carbonate part of the catchment, which affects the disorganization of surface runoff into underground drainage.

Based on the previous analysis, seven hydrogeological units of different permeability and transmissivity can be distinguished in the area of the Una basin:

1. aquifers of fissure-caverous porosity,
2. highly karst aquifers,
3. hydrogeological complexes predominantly without aquifers,
4. aquifers of intergranular porosity,
5. aquifers of fissure porosity,
6. non-aquiferous rocks,
7. hydrogeological complexes with aquifers of mixed porosity.

Geomorphologically, Trgovska gora is a separate unit of Zrinjska gora, the larger part of which is composed of Eocene flysch and volcanogenic-sedimentary layers of the "ophiolitic mélange" type (sandstones, clayey and argillaceous shales, breccias, conglomerates, limestones, eruptives, cherts and serpentine).

According to (Samardžić et al. 2021), the complexity of the geological structure in the area of Trgovska gora primarily manifests in the fact that it is located at the forefront of a large regional nappe, where Paleozoic rocks, with poorly water permeability, overlay Triassic carbonates. Triassic carbonates represent the main groundwater aquifers in the lower course of the Una River, thus artesian and possibly thermal waters can be expected in this area. The mentioned authors consider that the geological structure and the proximity of the Una River represent unfavorable circumstance from the aspect of hydrogeology for the storage and disposal of radioactive waste at the Čerkezovac location. The Trgovska gora area and the Čerkezovac locality belong to the grouped water body of the Una groundwater (lower course of the Una).

The Una River basin is predominantly hilly - mountainous in character. If hypsometric zones are analyzed as geomorphological categories, it can be concluded that all levels are represented in this area. Of the total area of the Una basin, the lowest, flattened hypsometric levels cover 1157.73 km^2. The slightly undulating and hilly relief, with its area, participates with 36.23% of the total. When it comes to the area above 500 m above sea level, which refers to foothill steps and mountainous dissected structures, this area encompasses 52.17% of the basin area. The largest share in the area, 3632.88 km^2, has structures from 500 to 1000 m above sea level.

Zrinjska Gora, where the locality Čerkezovac is situated, is intersected by faults of various orientations and likely represented a structural axis in the geological past, extending either E - W or NE - SW. It belongs to the category of remobilized fault-folded rock massive structures of Paleozoic-Tertiary orogeny. It consists of relatively low-medium mountain masses of highly heterogeneous geological composition. Zrinjska gora rises between the Glinska Depression and the Sava Basin. It is located between the rivers Kupa, Sava, Una, Glina and Glinica. The highest peak, Piramida, is 616 meters above sea level. The relief of Zrinska Gora is branched out with several relatively separate units: Zrinska Gora, the hills of Trgovska Gora or Bužimska and the hills of Hrastovička Gora.

By analyzing the basic meteorological parameters in this study, a fundamental picture of the climatic characteristics in the basin area was obtained, which significantly affects the river regime of the Una. The lowest average monthly temperature for a multi-year period in this area is -1.1ºC (January), indicating that it belongs to the C climate or a moderately warm climate, because this climate includes areas with the lowest average monthly temperature ranges between 18 ºC and -3 ºC. The annual air temperature fluctuation is 20.4 °C, which is another characteristic of this climate because, according to Spahić M (2002), in the interior of the continents (areas with a Cfb climate), the fluctuations increase to 18.7 °C, or 22.2 °C. If we consider the highest average monthly temperature of 19.3 ºC (July), and the fact that as many as 6 months have temperatures above 10 ºC (May, June, July, August, September, and October), we can determine the subtype of climate. In this case it is

Table 1. Percentage participation of aquifer types on the of the Una River basin surface

Type of aquifer	Water permeability	%
Aquifers of fissure-caverous porosity	Well permeable rocks	34.1
Highly karst aquifers	Impermeable rocks	19.6
Hydrogeological complexes predominantly without aquifers	Well permeable rocks	10.3
Aquifers of intergranular porosity	Poorly permeable to impermeable rocks	5.7
Aquifers of fissure porosity	Well permeable rocks	20.4
Non-aquiferous rocks	Impermeable rocks	8.3
Hydrogeological complexes with aquifers of mixed porosity	Permeable rocks	1.6

Korjenić i dr. 2017.

Table 2. Surface areas of represented morphogenetic relief types and their proportions in the total area of the surveyed terrain

Morphogenetic type of relief	Area (km^2)	Participation (%)
Karst relief	4429,2	44,4
Fluviokarst relief	665,9	6,7
Fluvial denudation relief	3368,1	33,7
Fluvial accumulation relief	1516,3	15,2

b-subtype climate or climate with warm summer. Analyzing the distribution of precipitation, it is noticed that precipitation occurs throughout the year. There is no dry period in this area, which is precisely characteristic of the f-type climate or humid climate. A larger amount of precipitation occurs in the warmer part of the year, while it is less in the colder period. This is also one of the regularities of the Cfb climate, and it depends on cyclone activity.

The modification of the climate occurs with the increase in altitude, which caused the formation of a submountainous (Cfbx) and mountainous (Df) climate in the south of the basin, specifically in the regions of Grmeč, Osječenica and Plješevica. The humid climate is further confirmed by the analysis of the rainfall factor for the Una River basin area, which amounts to 118.2. According to (Lang, 1915), humid areas are those where the rainfall factor ranges from 100 to 160. By comparing the data on the average annual precipitation and temperatures, data on the drought index according to (De Marton, 1926) were obtained, based on which it is concluded that the entire area of the Una basin has an index greater than 40, specifically 58.2. This value corresponds to areas with extremely good humidity and abundant runoff. All four seasons are clearly expressed. The annual temperature cycle expressed by seasons shows that the average winter temperature is 1.8°C, and the summer temperature is 18.5°C. In addition to warmer summers and colder winters, transitional seasons can also be felt.

The dynamics of the pluviometric regime is greatly influenced by the intensity and frequency of high and low-pressure barometric fields of large and medium scales. In relation to their influence are the characteristics of the thermal regime, relative humidity, cloudiness and windiness, which directly affect precipitation. The total amount of precipitation in the area of the Una River basin of 1273.77 mm was obtained based on the isohyet method, and for the purposes of this study, a map of the average annual precipitation according to the Atlas of Climate of the SFRY was used. The average amount of precipitation between two isohyets multiplied by the area between them is calculated for all isohyets on the basin surface, and the sum of the these obtained multiplications gives the average amount of precipitation in the basin.

Inflow from the basin is also significantly affected by the intensity of precipitation. Heavy rains impact rivers with smaller basins, causing them to rise very quickly and intensively increase the water level in the bed. Steady rains gradually raise water levels and such water levels can last for days, which is very favorable from the point of view of the hydrological balance. Heavy rains, in hydrological practice, usually mean intense precipitation lasting from a minute to 24 hours. The average intensity of precipitation

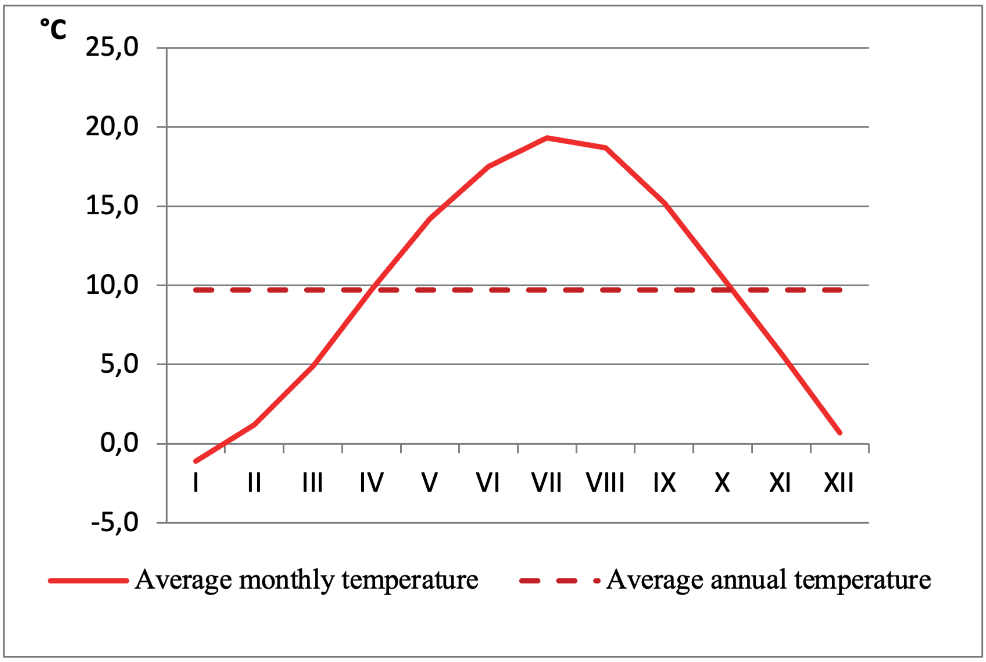

Fig. 3. The graph of the annual course of average temperatures for the Una River basin

Table 3. The annual amount of precipitation in the Una River basin by the isohyetal method

Isohyet in Una River basin	α_i (km^2)	$P = \sum_{i=1}^{n} \frac{\alpha i P i}{A}$
800 - 900	11,9	1,02
900 - 1000	700,6	66,50
1000 - 1250	4844,2	540,00
1250 – 1500	2999,8	412,50
1500 – 1750	1055,7	178,75
1750 – 2000	367,3	75,00
Σ		1273,77

**P - average amount of precipitation, ai - surface area between two isohyets, Pi – the average precipitation that corresponds to the elemental surface ai, and is determined as the mean value of the height of two isohyets, A- total area of the basin, n- total number of elementary surfaces ai Korjenić i dr. 2017.*

is the result of the relationship between the average height of precipitation and the average number of days with precipitation.

Local showers during the summer are of high intensity and can deliver over 5 l/h/m2 of surface area within one hour. Although cyclone activity is significantly weaker in summer, in the northern half of the Una basin it has a significant impact and accounts for approximately half of the total amount of summer precipitation. Unlike the northern part, cyclonic activities in the southern part of the basin pass almost unnoticed. The probability of rain occurring during the summer is below 50%, which is consistent with predominantly clear weather. At the beginning of autumn, cyclonic activity begins to dominate, and over 50% of the total number of cyclones, in this period, affects the catchment area from the southern side. Autumn precipitation is extremely frontal in nature: the rain is usually moderate and long-lasting. The maximum duration of autumn rains, especially in the western parts, can reach up to 20 days. Considering that, autumn has only about 40 rainy days, it follows that half of the total number of days can have consecutive occurrence of rainfall. Regarding the activity of baric centers during the winter, the polar atmospheric front reaches the Mediterranean region, and its baric depressions strongly influence the Una River basin from the south, about 65% of the total number of depressions. Winter cyclone activity noticeably changes the character of the pluviometric regime. The amounts of winter precipitation gradually decrease from the southern parts of the basin towards the northern ones. Winter precipitation, like autumn ones, is frontal, often long-lasting and moderate. Unlike autumn, winter precipitation comes in the form of snow, making this season considerably poorer in terms of precipitation quantity compared to autumn. Spring precipitation is extremely frontal, and local precipitation is observed only in the second half of the season.

Trbić and Đorđević (2021), through an analysis of three five-day indices of extreme precipitation, have determined that they show positive anomalies for the periods 2021-2050. and 2071-2100. By the end of the analyzed period, it is expected that the number of episodes with a five-day precipitation accumulation exceeding 60 mm will increase by three more events in these two periods. According to their research, accumulations during individual precipitation episodes will increase, with a maximum increase of 40% expected during the period 2071-2100. The northwestern parts of Bosnia and Herzegovina, near Trgovska gora, will be particularly exposed to these changes. One of the consequences of the increase in intense rainfall could be the occurrence of flash floods.

A very significant climatic factor influencing the river regime is the snow cover. According to (Spahić, 2013), in combination with spring rains, snowfall can increase the runoff coefficient above 100%. Therefore, monitoring snowfall is of great importance in determining the river regime. Snow and its occurrences are related to the winter half of the year. Therefore, the maximum number of days with a snow cover ≥10 cm in the area of the Una River basin occurs during the winter period, on average 7.2 days. Spring and autumn have an average of 1.4 such days. Heavy precipitation mainly occurs on the southern mountain slopes, and decreases towards the northern parts of the basin. The maximum height of the snow cover usually occurs in January and February, in the range of about 100 to 120 cm for inhabited areas, while at higher altitudes in the conditions of a mountain climate, it can be significantly higher, and snowdrifts can reach a height of over 200 cm.

Elimination criteria in selecting a location for radioactive waste disposal includ, among other things, natural floodplains as well as areas with increased erosion caused by the lithological composition or dynamic relief, areas with landslides and terrains prone to landslides (Conclusion of the Government of the Republic of Croatia, 1992), all of which may occur in the area of Trgovska gora in the event of increased intense precipitation and the formation of flash floods.

In the area of the Una basin, the pluviometric regime is characterized by two distinct maxima, in June and November, and two minima, in February and September. The months in which maximum precipitation occurs differ in individual areas of the basin, depending on a number of factors. Maximums may also occur during May or April, while another, secondary maximum occurs, besides November, also occurs in December. Rainfall minimums also vary in certain parts of the Una basin. They are mostly observed during January or March and then in October.

Looking at the Una River basin in general, it can be concluded that this area belongs to a continental, and a transitional continental pluviometric regime.

Table 4. Average, maximum, and absolute rainfall intensity per season (mm)

	summer	autumn	winter	spring
Average intensity / 1 rain day	11	> 12	< 9	> 11
Maximum intensity	28	30	20	26
Absolute intensity	> 60	60	50	> 50

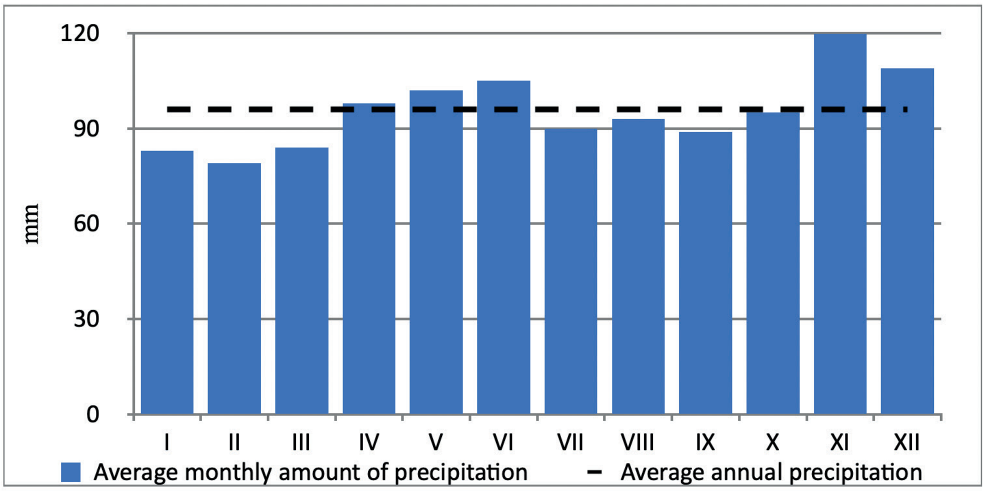

Fig. 4. Graph of the average annual flow of the rainfall regime

The southern and southeastern part of the catchment area is developed in the area dominated by karst, that is, where there is a discrepancy between the surface and underground drainage. In order to explain the impact of karst retention on water flow into the Una River, graphs of the intensity of changes in precipitation and runoff for certain gauges were created. For comparison, the water gauges in the upper and lower part of the Una River were presented and analyzed. Different values and obtained graphs, according to the data for individual gauges, result from different altitudes, geological substrate, or aquifer types represented in the catchment area up to these gauges, as well as monitoring of the annual precipitation regime characteristic for each hydrological station. When determining the relationship between precipitation, air temperature and runoff, the value specific precipitation intensity (i) was used, which indicates how many liters of precipitation are excreted, on average, per second over an area of 1 km^2 of the basin. The correlative value to the specific precipitation intensity is the specific runoff. The following graphs illustrate the dependence of average monthly runoff values on precipitation in the Una catchment area. According to the graph constructed based on the the water gauge data in Kozarska Dubica, in the lower course of the Una River, two phases of increasing and decreasing runoff are observed. The first phase of increased runoff lasts from January to April, and the second from August to December. The phases of reduced runoff last from December to January and from April to August. The positions of points 1, 2, 3 and 4 show that during these months the runoff coefficient is greater than the amount of precipitation.

Two phases of increase and decrease of runoff are clearly observed and in the upper course of the Una River. The coefficient of runoff higher than the amount of precipitation is recorded in March and April. The water meter stations record a similar annual trend, as well as an increase in runoff during the first four months. The significant increase in runoff during April indicates the occurrence of karst and snow retention, which, with a delay, brings water from melted snow and water from very rich underground karst recipients into the streams. This particularly applies to the upper and middle parts of the Una River basin, where waters often flow directly from karst without the gradual formation of a river network.

Through the mutual influence of geological structure, climate, relief, hydrological conditions, vegetation, and human activities, creates a loose surface layer of the earth - soil. The analysis of individual soil types was conducted using the ArcGIS program, based on the pedological maps of Bosnia and Herzegovina and Croatia at a scale of 1:500,000. The highest taxonomic levels of soil classification are divided, and in the area of the Una River basin, the most represented soils are from automorphic division or automorphic soils and hydromorphic division or hydromorphic soils. Different types of soils occur independently but also within a complexes or mosaics. Automorphic soils individually constitute 38.8% of the total area, hydromorphic soils 10.5%, while the largest area is covered by mosaics of different soil types, accounting for 50.6% of the total area of the Una River basin.

Vegetation and land use in the Una River basin area were analyzed using data from the digital database CLC (Corine Land Cover), for Bosnia and Herzegovina and Croatia. This database on land cover status and changes and land use was created under the CORINE program (COoRdination of INformation on the Environment). In the Una River basin area, out of a total of 22 categories identified, deciduous forest vegetation covers the largest area, approximately 3648 km^2. Mixed deciduous and coniferous vegetation accounts for 11% of the total basin area, while coniferous forests account for only 2.5%. Cultivable plots and agricultural areas have a significant share, 27% of the total area, unlike orchards and grainy fruit plantations, which cover only 2.5 km^2. The moderate continental climate, relief, as well as pedogeographic characteristics in the Una River basin area, have caused to the high production of phytogeographic resources in this area. Biogeographically, the basin belongs to the Eurosiberian region and within it to the Illyrian province. The most widespread biome in this area is the ecosystem of temperate moist deciduous forests of sedge oak and common hornbeam (Carpinion betuli illyricum), the ecosystem of beech-fir forests (Abieto-fagetion moesiacae) and the ecosystem of dark coniferous forests (Abieti - piceion illyricum). In the upper Una River area, there also exists the ecosystem of Mediterranean-montane forests of ceris (Quercion cerris), while in the area of Plješevica and the northwestern slopes of Grmeč, mountain beech forests (Fagetion moesiacae montanum) are encountered. Fragmentarly, in the valleys of the rivers Una and Sana, the floodplane forest ecosystem (Populetalia albae)

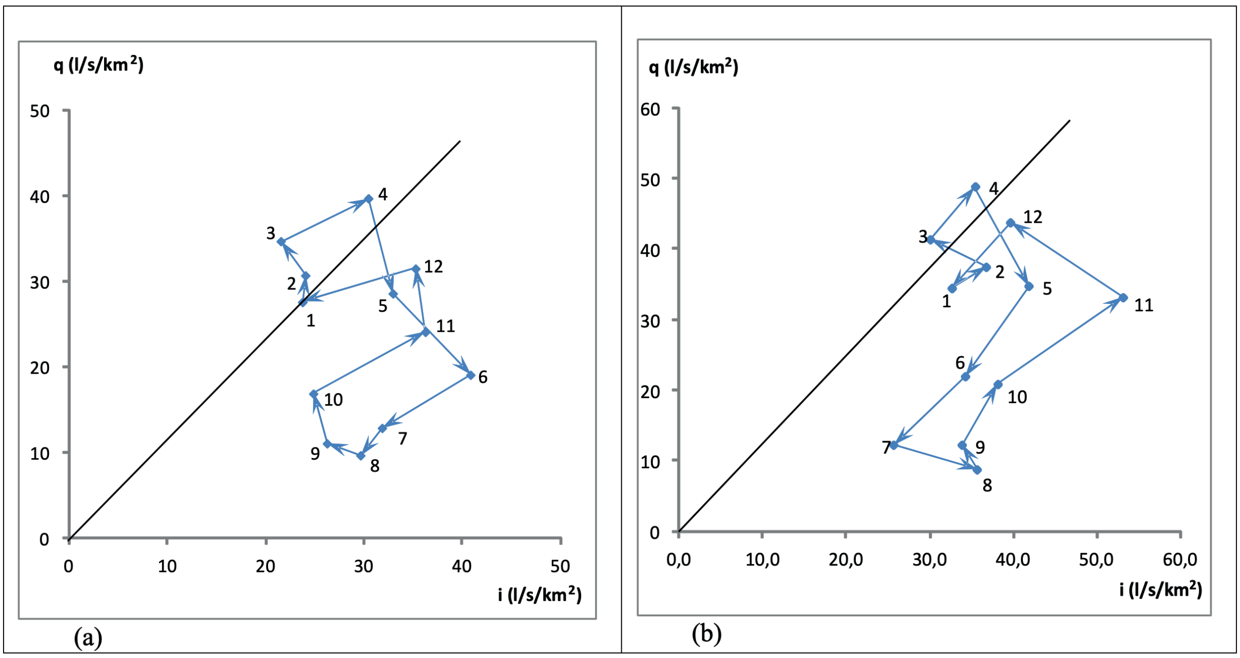

Fig. 5. Graph of precipitation change (*i* = liters per sec/km^2) and runoff (*q* = liters per sec/km^2) at the Una River in a) Bosanska Dubica, altitude *h* = 97.14 m a.s.l, b) in Kulen Vakuf, *h* = 298,8 m a.s.l

can be observed, and on Osječnica, ecosystem of conifer scrub close to the tree limit (Pinion mughi illyricum). The highest zones of the Grmeč and Osječenica belong to the ecosystem of mountainous limestone terrains (Oxytropidion dinaricae). Moderately moist forests are modified by altitude according to the highest hypsometric positions of Plješevica and Grmeč into the type of subalpine forests and pastures. Climatic conditions, primarily air temperature decreasing and the amount of precipitation that increases with the increase in altitude, the geological structure, as well as relief characteristics, slope inclination and the exposure, have largely influence on the spatial distribution of individual phytocenoses. Chestnut forests are characteristic of the basin area, especially its northwestern part. They mix with the downy oak ecosystem at the lower boundary and with beech forests at the upper boundary. The highest zones of Grmeča and Osječenica belong to the ecosystem of mountainous limestone areas (Oxytropidion dinaricae). Moderately moist forests are modified by altitude towards the highest hypsometric positions of Plješevica and Grmeč into the type of subalpine forests and pastures. Climatic conditions, primarily the air temperature which decreases and the amount of precipitation that increases with rising altitude, the geological structure, as well as relief characteristics, slope inclination and exposure, have largely influenced the spatial distribution of individual phytocenoses.

The mosaic of all physical-geographical determinants has influenced the development, shape and size of the catchment area. Through concrete and direct measurements of some basic parameters, indicators have been obtained from which more complex elements of the basin and the Una River course itself have been derived. By measuring the length of the main course as well as all unclassified courses, on the analyzed topographic maps marked as Una, the total length is obtained, which is much greater than the length of the main stream and amounts to 282.2 km.

The Una River basin is asymmetric in favor of the right basin surface, which is greatly contributed by the basin of its tributary, the Sana River. The intensity of flood waves along the entire longitudinal profile can be explained by analyzing the coefficient of basin fullness. This coefficient is always < 1, and the higher and closer to 1 it is, the greater the flood waves and floods on the river. Analyzing the slope in the river flow by sector, it is concluded that the upper course of the Una, from its spring to Bihać, is characterized by significant slopes over short distances, with an average gradient of 2.5°/$_{oo}$. The middle course of the Una, up to Novi Grad, also characterized by considerable falls (1.4°/$_{oo}$), while in the lower course down to the mouth of the Sava, a balanced profile predominates with minimal average gradients, only 0.34°/$_{oo}$. Results should be clear and concise.

CONCLUSIONS

The results of the analysis of the physical-geographical characteristics of the basin surface can be applied in solving water management problems, environmental protection, spatial planning, economic planning and other forms of economic activity. Also, these results can find their practical application in the determination of average water levels for rivers without hydrological monitoring and measurements, in the determination of water balance components and forecasting of hydrological quantities. In this case, they contribute to a better understanding of the physical-geographical conditions in the Una River basin, where the construction of a radioactive disposal site is planned. The interrelationship of the physical-geographical components within the Una River basin has created a series of natural values that formed the basis for distinguishing protected areas.

According to the spatial plan of Bosnia and Herzegovina from 1980, various sections within the valley of the Una River were included in different protection categories:

- the Una River course up to Ripač was included in the regional nature parks of Bosnia and Herzegovina of zero value, and since 2008 it has been designated as a National Park,
- the Una Valley from Ripač to Bosanski Novi (Novi Grad) was categorized as recreational and other natural areas of national importance with protection levels II-IV. Since 2019, it

Table 5. Basic morphometric characteristics

Morphometric characteristics	Value	Unit
Length of the basin	129, 4	km
Maximum width of the basin	127, 3	km
Average width	77, 1	km
Degree of asymmetry	74,7:25,3	(%)
Coefficient of basin fullness	0,63	
Maximum height (Hmax)	1961	m
Minimum height (Hmin)	92	m
Index relief of basin	1869	m
Average height of the basin	598,98	m
Length of the main stream	221,8 km	
Stream development coefficient	1,93	
Total slope of the stream	307	m
Average slope of the stream	1,4	°/$_{oo}$
Watershed incision depth	376,18	m

has been declared a protected landscape known as the "Una Nature park", which includes the lower course of the river Una and the area of the municipalities of Krupa na Uni, Novi Grad, Kostajnica and Kozarska Dubica.

The uniqueness of the Una River primarily consists of hydrological and geomorphological phenomena such as travertine barriers that create waterfalls, river islands, cascades, smaller waterfalls, as well as numerous rare and endemic species of plants. In addition to these, in the Una River basin are protected to a certain degree: Kozara Mountain as a National Park, the primeval forests area of Plješevica and Lom, sites on the Grmeč Mountain abundant with natural, untouched primordial values, primarily geomorphological and biogeographical, than the Sanica River Valley, the springs of the Sana River and the valley of the Sana River to Sanski Most and Bliha waterfall. In the Una River basin, there are registered sites within the Natura 2000 network. This ecological network consists of areas important for the conservation of endangered species and habitats of the European Union, with the aim of ensuring favorable conditions for them and their long-term survival. In the lower course of the Una River, in the territory of Bosnia and Herzegovina, among others, Acidophilic beech forests (Luzulo-Fagion), Illyrian beech forests of the Aremonio-Fagion association, Illyrian oak-hornbeam forests of the Rythronio-Carpinion association and sweet chestnut forests can be distinguished (Milanović et al. 2011). Natura 2000 also protects the area along the left bank of the Una River in the Republic of Croatia, which is located near the locality of Čerkezovac. Although the Una River basin abounds in physical-geographical (natural) values, this area is also characterized by exceptional cultural and historical value.

In this regard, there is justified concern about the potential threat to parts of the territory of Bosnia and Herzegovina and the negative consequences that the construction of this disposal site may have on the life of the population in the Una River valley and its tributaries.

Also, Delić et al. (2016) conducted an analysis of comparative criteria for a low and intermediate-level radioactive waste repository at the Trgovska Gora site. The criteria were grouped into four categories based on prevailing characteristics: technical-technological aspects, facility safety, safety and acceptability of the immediate location, and acceptability of the wider location. The valuation of comparative criteria was performed based on a Preliminary Hazard Analysis (PHA), assuming that each comparative criterion could be considered a hazard. The authors concluded that 22 criteria (79%) are expected to have high-risk levels due to the hazards arising from the selected criteria, and that the Trgovska Gora is an unacceptable location according to most comparative criteria due to the high level of risk.Lalić et al. (2023), state that the construction of a radioactive waste disposal site could cause significant pressure on the public and the population living in that area, leading to a potential emigration. Eliminating criteria according to the Conclusion of the Government of the Republic of Croatia (1992), include, among others, areas in the zone of nominal active faults, areas with intensified erosion caused by the lithological composition or dynamic relief, areas designated for the protection of drinking water sources, special purpose areas and their protective zones, areas of national parks, nominal nature parks and other significant nature reserves.

By analyzing the physical-geographical characteristics in the Una River basin and in part of Trgovska gora, it is clear that this area has a series of eliminating criteria when choosing a location for radioactive waste disposal, which need to be taken into account, leading to planning the construction of disposal sites in another location.

Additionally, a surface disposal facility is planned, which, unlike an underground one, has a lower level of safety and protection. In underground disposal facilities, any contact of people, plants and animals with waste is prevented for a much longer period.

Examples of underground disposal facilities can be found in Switzerland, where the project plans a tunnel disposal facility with a capacity of 80,000 m^3 for low and medium radioactive waste. The disposal tunnel units are lined with concrete, and after being placed in the tank, they are filled with special cement. The closure of the landfill includes the complete filling and sealing of all access tunnels and utility rooms (Levant, 2000).

The Olkiluoto underground disposal facility for low and medium-level radioactive waste in Finland is located at the location of the nuclear power plant, i.e. in the immediate vicinity of the generation of radioactive waste, and was put into operation in 1992. The disposal facility consists of two silos at a depth of 60 to 95 m in tonalites. Depending on the type of waste, the silos differ from each other in that the walls of the silo intended for the disposal of LRW are built of shotcrete, while the silo for bitumenized MRW has thick concrete walls, while both silos are surrounded by solid impermeable rock (Veinović, 2013).

Germany started the process of licensing RAW disposal facility with negligible heat emissions back in 1982. According to its characteristics, this RAW corresponds to the waste classified as low and medium radioactive waste in the Republic of Croatia. According to German legislation, all RAW must be disposed of in underground disposal facility (Commission of the European Communities, 1984).

In Croatia, due to the incomparably lower financial cost, the construction of a surface disposal site for low and medium-level radioactive waste was planned instead of an underground one, without sufficiently taking into account the interests of the local community as well as the long-term and better protection of people and the environment. ■

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